MODELING OF A GYRO-STABILIZED HELICOPTER CAMERA SYSTEM USING NEURAL NETWORKS

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by

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ABSTRACT

Modeling of a Gyro-stabilized Helicopter Camera System using Neural Networks

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On-board gimbal systems for camera stabilization in helicopters are typically based on linear models. Such models, however, are inaccurate due to system nonlinearities and complexities. As an alternative approach, artificial neural networks can provide a more accurate model of the gimbal system based on their non-linear mapping and generalization capabilities.

This thesis investigates the applications of artificial neural networks to model the inertial characteristics (on the azimuth axis) of the inner gimbal in a gyro-stabilized multi-gimbal system. The neural network is trained with time-domain data obtained from gyro rate sensors of an actual camera system. The network performance is evaluated and compared with measured data and a traditional linear model. Computer simulation results show the neural network model fits well with the measured data and significantly outperforms a traditional model.

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Chapter 1: Introduction

Video camera systems have become an integral part of a growing global information market. Frequently, camera systems are placed on helicopters and other vehicles that are utilized by the military, law enforcement and for various consumer applications such as television news programs. One of the most desirable characteristics for these applications is to view objects at great distances through the camera without any vibration or “shaking” of the image or picture. As image stability increases, so does the distance at which objects can be viewed.

The camera systems consist of a gimbal unit that houses a camera. This gimbal is typically mounted to some type of aircraft, but is often placed on boats or land vehicles. The photograph of a camera system primarily used on helicopters and built by Axsys Technologies is depicted in Figure 1.1 below.

Figure 1.1: Gyro-stabilized Camera System

Currently, these camera systems are stabilized along their line of site (LOS) using a linear closed-loop control strategy. This stabilizes against unwanted angular movements.

The camera is often mounted in a roll tube that is contained within a two-axis gimbal. This “inner” unit is, in turn, often mounted inside another two-axis “outer” gimbal. A representation of a two-axis gimbal is shown in Figure 1.2 below.

Figure 1.2: Two-Axis Gimbal

The outer two-axis gimbal allows the camera to be panned 360 degrees in azimuth and over 180 degrees in elevation. The inner two-axis gimbal has a limited range of movement (a few degrees of travel), but has a much larger bandwidth than the outer gimbal. This higher bandwidth gives the inner gimbal the ability to counteract the smaller amplitude, higher frequency vibrations of the mounting surface (such as a helicopter). Two general categories of performance requirements usually dominate the control system design trade-offs. These trade-offs are: (1) the LOS (line of sight) stability or “jitter” must be held within bounds, usually specified in microradians (or fractions of a microradian) and (2) the LOS must faithfully follow input commands [10].

An accurate model of the system must be created in order to control the system. .
In this thesis a model for the inner gimbal azimuth axis is created using a neural network.

Currently, these systems are often modeled as linear. The block diagram in Figure 1.3 below shows a traditional model of one axis of the inner gimbal [9].

Figure 1.3: Model: Inner Gimbal Azimuth Axis

The input to the system is a voltage V_{IN} and the output is relative (between inner and outer gimbal) measured angular rate ω_m in radians/s. The outer gimbal is assumed to be stationary in inertial space

The input voltage V_{IN} drives the input of an amplifier and the output of the amplifier in turn drives a “torquer” motor consisting of a coil and magnet. The coil is attached to the outer gimbal, the magnet is attached to the inner gimbal.

This topology limits the inner gimbal capability to a few degrees of angular movement. The torque T (as shown in the figure above) acts on the inner gimbal azimuth axis structure. The torque T consists of the addition of motor torque T_M and torque disturbances T_d .

The structure acceleration due to this torque is a function of the dynamics of the structure and the reciprocal of the structures moment of inertia (inertia tensor) J [10]. The

inertial angular rate ω is measured using a gyro rate sensor attached to the structure. This rate ω , and thus the measured rate ω_m , are relative between the inner and outer gimbal. This assumes that the outer gimbal is stationary in inertial space. Thus, ω_m is equal to the system output (measured relative angular rate).

A block diagram of the amplifier and motor combination is shown in Figure 1.4 below.

Figure 1.4: Motor and Amplifier Block Diagram

The above figure consists of a constant current amplifier with a nominal gain of one and the torquer motor described previously. The amplifier closes a loop around the motor current. This amplifier consists of open loop gain, G , the measurement of motor current, I , the conversion of this current to voltage, V_a (set by $K_c \left(\frac{\text{volts}}{\text{amp}} \right)$) and the calculation of the error between the desired and actual current ($V_{IN} - V_a$).

The model for the motor consists of the motor impedance $Ls + R$ (L is the inductance of the motor and R is the resistance), the Back EMF constant of the motor K_e (units of $\frac{\text{volts}}{\frac{\text{rad}}{\text{sec}}}$ or $\frac{\text{volt-sec}}{\text{rad}}$), and the motor torque constant K (units of $\frac{\text{lbs-in}}{\text{amp}}$).

By referencing the above figure the motor torque T_m can be written as $T_m = \left(\frac{G}{L_s + R + K_c G} \right) K V_{IN} - \left(\frac{K K_e}{L_s + R + K_c G} \right) \omega$. Note that if $K_c = 1$ and G is very large then the motor torque T_m approximatly equals the system input voltage V_{IN} multiplied by the motor torque constant K ($T_m \approx K \times V_{IN} (lbs - in)$).

Referencing **Figure 1.3** again: the motor torque T_m is combined with the disturbance torque T_d to create the total torque T . This torque is applied to the structure. The acceleration of the structure is a function of the total torque T , the dynamics of the structure, and the structure moment of inertia J . The acceleration of the structure is derived by dividing torque T_s (a result of the structure dynamics) by the moment of inertia J . This calculation can be explained using Newton's Law: $T = M_a A_a = J \frac{d\dot{\theta}}{dt} = J \ddot{\theta}$ where M_a is the mass of the inner gimbal structure, A_a is the angular acceleration of the inner gimbal relative to the outer gimbal, and θ is the angle of the inner gimbal relative to the outer. The rate can be calculated from this torque as $\omega = \dot{\theta} = \int \ddot{\theta} = \int \frac{T}{J} dt$. This calculation assumes the gimbal is a rigid body, a homogeneous mass (unless the full inertia tensor is used), and single axis rotation (unless rates and accelerations are vectorized) [9].

The torque disturbance T_d (shown in Figure 1.3) for an inner gimbal can include friction, unbalance of the camera/payload, static and dynamic unbalance, gyroscopic torques (such as from the gyro rate sensor), on-board shaking forces, actuator and gear reactions, cable torques, spring torques, structural bending, actuator cogging, and ripple torques [9]. These torques may or may not be present depending upon the specific design

of the gimbal system. Each of these torque disturbances are described in more detail below.

The torque disturbance caused by friction in a gimbal system usually consists of sliding or rubbing friction from the seals and bearing friction.

Figure 1.5: Bearing (rolling) Friction

The torque T (shown in Figure 1.5) due to bearing (rolling) “static” friction can be modeled using the following formula: $T = \mu_a F_a + \mu_r F_r$. In this equation, r = mean bearing radius (in.), F_a = axial load including preload (lbf), F_r = radial load (lbf), μ_a = coefficient of rolling friction, and μ_r = coefficient of rolling friction.

One of the characteristics of the friction present in inertial stabilization is a nonlinear phenomena called Coulomb friction [11]. The Coulomb model describes friction force $F_c = \mu_c F_N \text{sgn}(v)$ where μ_c is the Coulomb friction coefficient, F_N is the normal force between the two objects, and v is the velocity between the two objects.

One friction model used for ball bearings is the Dahl model [17]. In 1968, P.R. Dahl proposed an alternative to the Coulomb friction model. While observing the behavior of ball bearings, he noted that input forces with very small amplitude were reacted against by small elastic restoring forces [20]. Dahl compares the transision from static to kinetic friction to that of elastic to plastic deformation in ductile materials. His initial observation of non-linear friction effects occurred while observing ball bearings

acted on by low amplitude input forces. The elasticity observed results in hysteresis; at loads below F_c (sliding Coulomb friction). This force can be likened to torque T_s in the figure below for bearings [9]. **Figure 1.6** demonstrates the Dahl observation between bearing torque and angle.

Figure 1.6: Dahl Friction Model Example (Torque vs angle) (from [9])

The Dahl model for a bearing defines the torque rate as $\frac{dT_B}{d\theta} = \gamma [T_s - T_B \times \text{sgn}(\dot{\theta})]^\beta$

where $\gamma = \frac{s}{T_s + |T_p|}$, T_B is the torque on the bearing (y-axis in Figure 1.6 above), θ is the bearing angle (x-axis in above figure), s = slope at reversal (reversal of torque T_B direction), T_s is the maximum Dahl friction torque, T_p is the value of torque at turnaround or reversal and β (values range ≥ 0) is the parameter that determines the shape of the stress-strain curve (Torque vs angle curve) [17]. Some gimbals incorporate seals for EMI and environmental reasons. The disturbance torque resulting from these seals can be modeled as a sliding or rubbing friction.

Figure 1.7: Seal Friction

This torque (reference Figure 1.7 above) is defined as $T_r = \mu F d$ where d is the perpendicular distance between the line-of-action of F and the rotating axis (in), F is the force holding the two surfaces together (lbF), and μ is the coefficient of friction between the two surfaces. Seals between the inner gimbal and outer gimbal can sometimes contain fluid. Thus, viscous friction might have to be modeled. The torque due to this type of friction can be defined as $T = k_v \omega$ where k_v is the coefficient of viscous friction $\left(\frac{\text{in}\cdot\text{lb}\cdot\text{sec}}{\text{rad}}\right)$ and ω is the relative angular velocity $\left(\frac{\text{rad}}{\text{s}}\right)$.

The torque disturbance caused by the balance of the payload within the inner gimbal has an effect on the system dynamics. Static unbalance can cause a disturbance torque which can be modeled as $T_u = \epsilon W g$ where ϵ equals the center of gravity offset, W is the weight of the rotating assembly, and g is the gravity plus acceleration vector perpendicular to the rotating axis.

Figure 1.8: Dynamic Torque Axes

Dynamic unbalances are caused by a non-symmetrical distribution of mass. This torque can be modeled using the formula: $T_Z = I_{XY}\omega_X^2$. In this equation, I_{XY} is the product of inertia for the x and y axes shown in Figure 1.8 above (in-lbf-s²) and ω_X is the angular velocity about the x-axis ($\frac{rad}{s}$).

Aniso-elastic unbalance is caused by un-symmetrical elasticity, and requires vibration in 2 dimensions simultaneously. It is difficult to predict, and may require FEA analysis [9]. This torque can be defined using the equation $T_{ae} = Kw g_x g_y$ where K is the aniso-elastic constant for a particular mechanism ($\frac{in}{g^2}$), W is the weight of the rotating assembly (lbf), and g is the gravity plus acceleration vector perpendicular to the rotating axis (gs).

Gyroscopic “gyro” torque (precession & nutation) is a torque disturbance caused by the fact that in many cases the rate is measured using a sensor utilizing a spinning mass. This causes a torque on the object being measured. A gyro torque can be defined as $T_X = I_Z \omega_Z \omega_Y$ where I_Z is the inertia about the z axis (in-lbf-s²), ω_Z is the angular velocity about the z axis, and ω_Y is the angular velocity about the y-axis.

Disturbance torques can also be caused by shaking forces on the payload (camera). For example, a shaking force could be caused by a cryogenic cooler used with an infrared camera. The torque caused by a shaking force is defined as $T_{sf} = F_s d$ where d is the perpendicular distance from the shaking force to center of rotation and F_s is the force.

Spring torques are another form of disturbance torque and can be caused by cable wraps or Flexural Pivot bearings (a type of spring). Cables are modeled as a spring; however, they are actually quasi-linear and have a dampening effect [9]. Flexural Pivot bearings have a limited range of angular movement but are sometimes used instead of ball bearings to get rid of the non-linear effects of this type of bearing. A picture of a Flexural Pivot bearing is shown in the figure below.

Figure 1.9: Flexural Pivot Bearing

A spring torque is defined as $T_{sp} = K_s \Delta\theta$ where K_s is the spring coefficient for a particular mechanism $\left(\frac{\text{in-lbf}}{\text{rad}}\right)$ and $\Delta\theta$ is the relative rotation measured from point of zero torque (rad).

Structural bending disturbance torques result from base vibrations that may or may not be sensed by the gyro [10]. Structural flexure can also cause torque disturbances and can be modeled using Finite Element Analysis [9]. For example, a structural flexure includes bending, optical component displacements and Aniso-elastic effects [9].

The total torque T (as seen in Figure 1.3) is a combination of one or more of the torque disturbances listed previously and the motor torque. This total torque is applied to the inner azimuth gimbal structure. To model the relationship between this torque and the acceleration of the structure both the structure dynamics and inertia must be taken into account. Although practical systems are multiple degree of freedom (MDOF) and have some degree of nonlinearity, their structure dynamics can generally be represented as a superposition of single degree of freedom (SDOF) linear models [19].

The system of interest in this paper is the inner gimbal azimuth axis. system The dynamics for this system include the torsional interaction between the total torque T and the gyro rate sensor. The transfer function for this relationship is typically derived from FEA (finite element analysis) or modal analysis using the first four to five modes [9]. The response at one point in the structure to a force or torque excitation at another point in the structure can be defined as:

$$U_j = \sum_{i=1}^n \underbrace{\frac{\varphi_{ij} \times \varphi_{ik} / M_i}{s^2 + 2\delta_i \omega_i s + \omega_i^2}}_{\text{Transfer Function (ith mode component)}} \times \underbrace{f_k}_{\text{Force or Torque input at node k}}$$

Response at node j *Force or Torque input at node k*

The following parameters from the above equation are available from FEA analysis: $\varphi_{ij} = j$ is the eigenvector term of the response degree of freedom in the i th mode, $\varphi_{ik} = k$ is the eigenvector term of the input degree of freedom in the i th mode, M_i = Generalized mass in the i th mode, ω_i = Natural frequency (eigenvalue) of the i th

mode, δ_i = Damping ratio of the i th mode (typically .025 to .05 for metallic structure).

The inputs to and outputs from the above equation are: f_k = Excitation force (or torque) at the k th degree of freedom, U_j = Response displacement (either translational or rotational) at the j th degree of freedom [9]. An example of a typical frequency response plot and the individual contribution from each mode is shown in the figure below.

Figure 1.10: Example Structure Frequency Response (from [20])

The torsional structural dynamics combined with the rigid body inertia J (see Figure 1.3) will give a response typical of the example shown below [9].

Figure 1.11: Structural Dynamic Response including Structure Inertia (from [9])

It is important to note from the above figure that at DC and low frequencies the frequency response of the structure is equal to the reciprocal of the structures moment of inertia about the axis being controlled. Also note that each of the second order equations in the figures block diagram represents a structural mode.

The gyro rate sensor as shown in Figure 1.3 above can be modeled as a second order low pass filter with random noise added to input [9]. This model with input ω (angular rate) and output ω_m (measured angular rate) is shown in Figure 1.12 below.

Figure 1.12: Gyro Rate Sensor Model

In some systems, modeling of certain system dynamics is not accomplished and notch filters are added after testing to get rid of undesirable frequencies [12]. Such undesirable frequencies are common in many aerospace flexible dynamic systems where the desired center frequency shifts due to the nonlinearities and coupling of the system. An approach to eliminate these frequencies is to place notch filters after taking systems measurements. This requires significant verification and validation activity as well as a large storage for the filter coefficients.

A modeling strategy using neural networks is worth investigating due to the limitations of traditional approaches. A neural network can compute nonlinear relationships, which allows it to be trained to model an unknown system. It can generalize (map similar inputs to similar outputs) and is robust in the presence of noise. A neural network has the ability to be made adaptive by training online. Due to these characteristics, a neural network has inherent advantages over traditional approaches for modeling.

As mentioned earlier, gyro-stabilized gimbal systems include nonlinearities and are very complex due to complex structural dynamics and the many torque disturbances present. In multi-gimballed systems there are un-modeled dynamics, kinematics of the gimbal plant which result from non-symmetry in the mechanical design including products-of-inertia, gyroscopic effects, and kinematic coupling [10].

The system identified in this paper is the inner azimuth gimbal of a multi-gimballed system and is thus exposed to the characteristics and problems listed above. Specifically, the neural network model includes torque disturbances and nonlinearities from bearing friction Coulomb model effects, kinematic coupling effects, and cable nonlinearities. Aniso-elastic or dynamic unbalance. Dynamic unbalance is difficult to predict and may require FEA analysis.

Another advantage to modeling an inner gimbal system (as represented in Figure 1.3) using neural networks is to utilize this model in an adaptive control strategy. Strategies such as model reference control, predictive control, and feedback linearization control use plant models. These strategies could be made adaptive by using a neural network model and controller. Few stabilized gimbal system (such as the system being identified in this paper) parameters are stationary. The dynamic operating environment, for example, is usually undergoing constant change and only a few typical or worst case scenarios can be investigated during the design state (assuming the environment and the plant can be accurately characterized) [10]. In addition to the above, generalization and robustness to noise are also problems because of the complexity of these systems. It is possible that a neural network model could solve some of these problems.

In this thesis, an artificial neural network model is created for system identification. The system to be identified is defined by the inertial response of the azimuth axis of the inner gimbal.

The model is created by training the network to map the relationship between system input (voltage V_{IN} in Figure 1.3) to system output (measured relative angular rate ω_m in Figure 1.3). The network is trained using experimentally measured data from the gyro-stabilized camera system to be identified. (The camera system is built by Axsys Technologies in Grass Valley, California).

The model is created using several different types of time domain data input/output sets gathered from the real system. Several network structures are compared and the neural networks ability to generalize well over the full input range of the system is tested. This is accomplished by training the network on one data set and then simulating the networks response to several other inputs. The network response from these inputs is then compared to the actual system output. In addition, a traditional model is created and compared to the neural network model. This was accomplished by comparing the errors between the two model outputs with the real system output.

This thesis is organized into six chapters. An overview and theory of neural networks is presented in Chapter 2. The process of acquiring the data from the system to be modeled is described in Chapter 3. The simulation results for modeling the system using an artificial network is presented in Chapter 4. Chapter 5 includes a comparison between a traditional model and the neural network model. Finally, the summary and conclusion of this study are presented in Chapter 6, along with future works involving neural networks.

Chapter 2: Overview of Artificial Neural Networks

The human biological system of neurons and synapses has inspired the development of artificial neural network methodologies in computer science. In the human brain there are billions of neurons and synaptic connections that create a complex network that modifies itself as it learns through experience. Like the human brain, an artificial neural network can learn from experience and relationships.

As implemented in a computer system an artificial neural network learns by classifying data and recognizing patterns. It can then be trained to find solutions and forecast future events.

Artificial neural networks are commonly referred to as “neural networks”. They are a method of computing input/output relationships comprised of a set of parallel processing neurons with interconnections called synapses. A network can have any number of inputs and outputs. Based on its inputs and an activation or transfer function, each neuron produces one output. A neuron is not limited to linear relationships. A value is placed on the output of a neuron which adjusts the importance, or weight, of a synapse. The result of this weighted synapse can be fed into the input of one or more other neurons or to the output of the network. These weights can be modified to adjust the outcome of the network.

2.1 - Brief History of Neural Networks

The concept of neural networks came about in 1943 when W.S. McCulloch and W.A. Pitts combined many simple units in order to design Boolean logic. Each unit

performed a certain logic function .The units combined to produce the desired network output. Their network is generally considered to be the first artificial neural network.

In 1949, Donald Hebb, a psychologist at McGill University, introduced an idea of learning when he published a biologically plausible learning rule. Reinforcement learning was introduced by Minsky around 1954.

In 1958, Frank Rosenblatt coined the term “perceptron”, defined as a single layer network in which the neuron activation functions have a hard-limiting threshold.

In 1960, Bernard Widrow and Marcian Hoff at Stanford University created an algorithm called the least mean square (LMS) algorithm, also known as the Widrow-Hoff rule. This rule was applied to a simple adaptive linear neuron (ADALINE). The LMS algorithm was successfully used to classify linearly separable patterns.

Waltz and Fu independently introduced and applied reinforcement learning in control theory in 1965 and Michie and Chambers reinforced this in 1968.

In the 1970’s, a large amount of attention was focused on artificial intelligence (AI). During this time several pioneering works were created, one of which did forecasting analysis using the concept of backpropagation (BP) proposed by Werbos in 1974.

Neural networks became more popular in the 1980’s due to faster and cheaper computers and independent researchers advancing the field with new training algorithms. The backpropagation algorithm became popular in the mid 1980’s and has led the field forward ever since.

2.2 - Neural Network Architecture

A neural network consists of neurons, which are connected together to form a network. These neurons are generally grouped into layers. Each layer's outputs are fed into the next layer's inputs. The inputs to the network are fed into the first layer of neurons and the last layer of neurons provide the outputs of the network.

The neuron is an information-processing unit. Each neuron can have any number of inputs and one output. The unit consists of two basic components, the summer and the activation function (also called transfer function). A model of the neuron and its symbol are shown in Figure 2.1 and Figure 2.2 below.

Figure 2.1: Neuron Model

Figure 2.2: Neuron Symbol

As expected, the summer sums the inputs to the neuron. The result is passed through the activation function, which supplies the output of the neuron. Some common

activation functions include the linear activation function, the sigmoid function, and the hyperbolic tangent function. Figure 2.3 below shows a graphical representation of the three activation functions.

(a)

(b)

(c)

Figure 2.3: a) Linear Function b) Sigmoid Function c) Hyperbolic Tangent Function

The linear function has a slope of 1 and merely passes the input through the neuron. The sigmoid and hyperbolic tangent functions are limiting functions and are sometimes referred to as squashing functions for this reason. They accept an input of any range and produce an output in a strictly limited range, hence a squashing effect. The sigmoid

functions output is limited between 0 and 1. The sigmoid function is defined in Equation 1 below.

$$f(v) = \frac{1}{1 + e^{-v}} \quad (1)$$

The hyperbolic tangent functions output is limited in range between -1 and 1 and is defined in Equation 2.

$$f(v) = \frac{e^v - e^{-v}}{e^v + e^{-v}} \quad (2)$$

As mentioned above, the neurons are generally grouped into layers. There can be any number of layers and any number of neurons in each layer. The nomenclatures for neuron layers include the output layer, which calculates the output of the network and the hidden layer, where inputs to the neural network are presented. It is important to note that any neuron that does not provide a network output is not referred to as an output neuron, even if it is in the output layer. This will become clearer when feedback networks are described later.

These neuron layers are connected to each other through a series of synapses. The inputs to the network are also connected to the first layer through these synapses. Each synapse has a numerical weight (multiplier) associated with it. The input to the synapse is multiplied by this weight and the output is fed into a neuron.

A form of shorthand is used to describe a network, consisting of the number of neurons in the layer with layers being connected by a dash. For example, a network with three neurons in the first layer, two in the second, and one output neuron would be

written as 3-2-1. A diagram of a typical 3-2-1 neural network with four inputs (x_1 through x_4) is shown in Figure 2.4.

Figure 2.4: Neural Network of Architecture 3-2-1

The above neural network is a feedforward network that is fully connected; it is feedforward because the outputs of one layer feed forward to the inputs of the next layer. It is fully connected because each neuron's output in one layer is connected to every neuron's input in the proceeding layer. When this is not true, the network is considered partially connected.

A Feedback network, also called a Recurrent network, is different from a Feedforward neural network in that it has at least one feedback loop. A feedback loop occurs when a neuron's output feeds back to its own input or inputs of other neurons within the same layer or previous layers. The feedback loops involve unit-delay elements. A Recurrent network with one output neuron and one input neuron is shown in Figure 2.5.

Figure 2.5: Recurrent Neural Network

If the task at hand has a temporal dimension, a network with some type of time history is required. There are two main ways of incorporating time information in a neural network (NN): Time lagged feedforward networks, and Recurrent (Feedback) Networks.

In a Focused time lagged Feedforward neural network, time delays are added at the input to the network in the form of Tapped-Delay-Lines (TDL). This creates a short-term memory at the beginning of the network. It is important to note that focused time lagged feedforward networks (focused TLFN) are only suitable for use in stationary (i.e. time-invariant) systems [1]. Training of this type of network can be implemented using the standard back-propagation algorithm. Figure 2.6 below shows an example of a focused TLFN.

Figure 2.6: Focused Time Lagged Feedforward Neural Network

In a Distributed Time Lagged Feedforward neural network there are time delays at the beginning of the network and throughout the network. Unlike Focused TLFNs a Distributed TLFN is suitable for a dynamic system (i.e. time-variant) system [1]. This type of network relies on use of the spatio-temporal model of the neuron (multiple-input neuronal filter). This model uses finite impulse response filters (FIR) as synaptic filters. To train this type of network an elaborate learning algorithm exemplified by a temporal back-propagation algorithm is required. Due to the complexity required to train this type of network, it will not be used.

An optional but important addition to the networks described so far is the bias. The bias is an extra input applied to all or some of the neurons of a network, and is a constant. The value is usually 1.

The syntax for a weight is as follows: a weight W_{kj} is associated with a synapse with input x_j and this synapse goes into neuron k . Thus, the input signal x_j is multiplied by weight W_{kj} and the resulting value is fed into the neuron.

$$u_k = \sum_{j=1}^m W_{kj} x_j \quad (3)$$

$$y_k = f(u_k + b_k) \quad (4)$$

where u_k in Equation 3 is the output of the adder, y_k in Equation 4 is the output of the neuron, $x_1, x_2, \dots, x_m$ are the input signals, $W_{k1}, W_{k2}, \dots, W_{km}$ are the synaptic weights of neuron k , f is the activation function, and b_k is the bias.

2.3 - Neural Network Training

Many learning algorithms have been developed to train neural networks. The relationship between a neural network's inputs and its outputs can be changed to meet a desired response by adjusting the weights of the network. Currently there are three main ways a network's weights are adjusted: reinforcement learning, unsupervised learning, or supervised learning.

In reinforcement learning (reward-penalty learning) an input vector is provided to the neural network and the output of the network is calculated. If the output is considered "good" the weights receive a "reward" and their value is increased. If the output is considered "bad", the weights are "punished" and their value will be decreased.

In unsupervised learning the neural network is provided with the input vector but not the output vector. In this type of training the network “learns” the internal features of the input vector.

Lastly, with supervised learning the neural network is provided with a training set which includes an input vector, x , and the corresponding desired output vector, y . The neural network “learns” to associate each input vector, x_i , to output vector, y_i , by changing the weights of the network.

In most control system applications the network is trained using supervised learning because there is some desired response of the system (target vector y_i) for a given input vector, x_i . Supervised learning only, will be considered for this reason.

To reduce error between the network’s output and the desired output, the weights are adjusted. This process can continue indefinitely or until a limit is reached. This limit is usually either a user-defined minimum output error or is a maximum number of user-defined training iterations. A simple block diagram showing the process is shown in Figure 2.7.

Figure 2.7: Block Diagram of Neural Network Training

Within Supervised learning there are two main categories of training methods, in addition to some other training algorithms. The two main categories are first order gradient methods and second order gradient methods.

2.3.1 - Backpropagation Algorithm (BP)

The backpropagation algorithm is one of the most well known and widely used training methods. It is based on the steepest descent techniques and is extended to each layer of the network, starting at the output layer, using the chain rule. The algorithm calculates the gradient of a performance measure using the error between the desired and actual output with respect to the weights of the network. In other words, the relationship between a change in the weights and a change in error is calculated. The backpropagation process is divided into a forward pass and a backward pass. In the forward pass the networks outputs are calculated given a set of inputs. In the backward pass the weights are adjusted in order to reduce the error at the output of the network.

In order to adjust the weights of the network, a performance measure is created. This is commonly done by calculating the total error energy at the output of the network. This is accomplished by summing the error energies at each output of the neural network. The error at each output is defined as:

$$e_j(n) = d_j(n) - y_j(n) \quad (5)$$

Where, at output, j , $d_j(n)$ is the desired output, $y_j(n)$ is the actual output, and n is the time sample. The error energy for each output of the network is defined as $\frac{1}{2}e_j(n)^2$. Thus, the total energy (performance measure) at the network output is as follows:

$$\mathcal{E}(n) = \frac{1}{2} \sum_{j=1}^J e_j(n)^2 \quad (6)$$

Here, J is the number of network outputs, also the number of neurons in the output layer.

In order to define how well the neural network responds to all inputs or the whole data set the mean-squared-error (MSE) criterion is commonly used and is defined as:

$$MSE = \frac{1}{N} \sum_{n=1}^N \mathcal{E}(n) \quad (7)$$

In the above equation, N is the number of input/target pairs (input vector/target vector pairs). The MSE is an average of the total error energy at the output of the network. As the MSE is minimized the neural network will give a response closer to the desired output. To have a better idea of how this works, consider a neural network with two weights. If the total error energy at the output of the neural network is graphed in

relation to the weights it might look like the following graph.

Figure 2.8: Performance vs. Weights of Neural Networks

In the above graph the lowest total error energy is obtained when both weights are zero. If a neural network contains q weights, the goal is to find the smallest total error energy in the $(q+1)$ dimensional space at a given time sample, or the smallest MSE when considering more than one time sample.

The backpropagation algorithm uses the idea of gradient descent to find the best weight values. When the neural network is first trained, the location in weight space of the MSE is random. The weights are adjusted in the direction at which the error surface decreases the most. To accomplish this, the gradient is calculated. Since the gradient is in the direction at which the error is increasing, the weights are adjusted in the opposite direction to the gradient. To help explain this, the performance measure of the 2-weight network is plotted vs. weight 1 and weight 2 in a 2 dimensional view. Each line in the plot below represents a different value for weight 1.

Figure 2.9: Performance vs. Weight 2

If a single point is focused on in weight space, the plot might look like that shown in Figure 2.10 below.

Figure 2.10: Performance vs. Weight 2 Given Weight 1

The gradient for any one weight at a point in weight space is the derivative (slope) of the performance measure relative to that weight. Thus, as shown in the above figure, if the slope is positive the weight is decreased, and if the slope is negative the weight is increased. Note that the relationship between the weight change and the slope of performance vs. weight (gradient) is opposite in sign.

There are several steps to the backpropagation algorithm: 1) calculate the performance measure for each output, 2) calculate the derivative (slope/gradient) of the performance measure with respect to weights at the output layer of the network, 3) calculate the derivative of the performance measure in respect to all other weights in the network, 4) apply the gradients to update the weights.

1) Finding the Output Performance Measure

The output performance measure is calculated using Equation 8:

$$\varepsilon(n) = \frac{1}{2} \sum_{j=1}^J e_j(n)^2 \text{ where, } e_j(n) = d_j(n) - y_j(n). \quad (8)$$

2) Calculate the performance measure derivatives (gradients) for output weights

The following figure is a signal flow graph of output neuron j.

Figure 2.11: Output Neuron Signal Flow Graph

In the above figure, $x_i(n)$ is the output of neuron, i , in the previous layer, $W_{ji}(n)$ is the weight from neuron i to neuron j . Local field $v_j(n)$ is the summation of inputs to neuron j . $f(\cdot)$ is the transfer function (activation function) of the neuron. $y_j(n)$ is the output of neuron j . $d_j(n)$ is the desired output of the neuron. And $e_j(n)$ is the error at the output. Thus, $v_j(n)$ and $y_j(n)$ can be calculated as follows:

$$v_j(n) = \sum_{i=0}^m w_{ji}(n)x_i(n) \quad (9)$$

$$y_j(n) = f(v_j(n)) \quad (10)$$

Using the chain rule and the above figure the gradient of the performance measure (total error energy) in respect to the weights between the output layer of neurons and the previous layer is calculated as:

$$\frac{\partial \mathcal{E}(n)}{\partial w_{ji}(n)} = \frac{\partial \mathcal{E}(n)}{\partial e_j(n)} \frac{\partial e_j(n)}{\partial y_j(n)} \frac{\partial y_j(n)}{\partial v_j(n)} \frac{\partial v_j(n)}{\partial w_{ji}(n)} \quad (11)$$

Each term on the right side of the above equation can be simplified. Taking the derivative of both sides of Equation 6, the first term can be calculated as:

$$\frac{\partial \mathcal{E}(n)}{\partial e_j(n)} = e_j(n) \quad (12)$$

Differentiating both sides of Equation 5 with respect to $y_j(n)$ results in:

$$\frac{\partial e_j(n)}{\partial y_j(n)} = -1 \quad (13)$$

Differentiating both sides of Equation 12 results in:

$$\frac{\partial y_j(n)}{\partial v_j(n)} = f'_j(v_j(n)) \quad (14)$$

Differentiating both sides of Equation 9 results in:

$$\frac{\partial v_j(n)}{\partial w_{ji}(n)} = x_i(n) \quad (15)$$

Now, rewrite Equation 11 using Equations 12 through 15 as:

$$\frac{\partial \mathcal{E}(n)}{\partial w_{ji}(n)} = -e_j(n) f'_j(v_j(n)) x_i(n) \quad (\text{output gradient}) \quad (16)$$

The derivative of transfer functions (activation functions) $f'_j(v_j(n))$ can be put in terms of the neurons output. The derivatives for two of the most common are shown below:

$$\text{Sigmoid Function: } f_j(v_j(n)) = \frac{1}{1 + e^{-av_j(n)}} \quad a > 0 \text{ and } -\infty < v_j(n) < \infty$$

$$f'_j(v_j(n)) = \frac{ae^{-av_j(n)}}{(1 + e^{-av_j(n)})^2}$$

$$f'_j(v_j(n)) = af_j(v_j(n)) \frac{e^{-av_j(n)}}{1 + e^{-av_j(n)}} = af_j(v_j(n)) \frac{1 + e^{-av_j(n)} - 1}{1 + e^{-av_j(n)}}$$

$$f'_j(v_j(n)) = af_j(v_j(n)) \left[\frac{1 + e^{-av_j(n)}}{1 + e^{-av_j(n)}} - \frac{1}{1 + e^{-av_j(n)}} \right] = af_j(v_j(n)) [1 - f_j(v_j(n))]$$

the output of neuron $j = y_j(n) = f_j(v_j(n))$ so:

$$f'_j(v_j(n)) = ay_j(n) [1 - y_j(n)] \quad (\text{sigmoid function}) \quad (17)$$

$$\text{Hyperbolic Tangent Function: } f_j(v_j(n)) = a \tanh(bv_j(n)) \quad (a, b) > 0$$

$$f'_j(v_j(n)) = ab \operatorname{sech}^2(bv_j(n)) = ab(1 - \tanh^2(bv_j(n)))$$

$$f'_j(v_j(n)) = \frac{b}{a} [a - y_j(n)] [a + y_j(n)] \quad (\text{hyperbolic tangent}) \quad (18)$$

3) Calculate the performance measure gradients for hidden weights

The above equation represents the gradient for weights between the output layer and the previous layer (a hidden layer). From now on, k will be used to indicate a hidden neuron and j will be used to indicate a neuron in the next layer. The gradient for a hidden neuron is then written:

$$\frac{\partial \mathcal{E}(n)}{\partial w_{ki}(n)} = -e_k(n) f'_k(v_k(n)) x_i(n) \quad (19)$$

Since there is no way to measure $e_k(n)$ (the error at the output at hidden neuron k) it must be determined recursively in terms of the error signals of all neurons in the next layer to which that hidden neurons output is directly connected. The local gradient is defined as the derivative of the performance measure $\mathcal{E}(n)$ in respect to the output of the local field $v(n)$:

$$\delta(n) = -\frac{\partial \mathcal{E}(n)}{\partial v(n)} \quad (20)$$

For neuron k the local gradient can be written as:

$$\delta_k(n) = \frac{\partial \mathcal{E}(n)}{\partial v_k(n)} = e_k(n) f'_k(v_k(n)) \quad (21)$$

Equation 12 and 13 show that $-e_k(n) = \frac{\partial \mathcal{E}(n)}{\partial e_k(n)} \frac{\partial e_k(n)}{\partial y_k(n)} = \frac{\partial \mathcal{E}(n)}{\partial y_k(n)}$

Therefore, the local gradient can be written as:

$$\delta_k(n) = -\frac{\partial \mathcal{E}(n)}{\partial y_k(n)} f'_k(v_k(n)) \quad (22)$$

Note that $y_k(n)$ is the output of hidden neuron, k. To obtain $\frac{\partial \mathcal{E}(n)}{\partial y_k(n)}$ in Equation 19, take the partial derivative of both sides of Equation 6 (performance measure/total output error energy) with respect to the error and then divide both sides by $\partial y_k(n)$.

$$\frac{\partial \mathcal{E}(n)}{\partial y_k(n)} = \sum_{j=1}^J e_j \frac{\partial e_j(n)}{\partial y_k(n)} \quad (23)$$

Here, k is the neuron in the hidden layer and j is a neuron in the output layer. This equation can be rewritten as:

$$\frac{\partial \mathcal{E}(n)}{\partial y_k(n)} = \sum_{j=1}^J e_j(n) \frac{\partial e_j(n)}{\partial v_j(n)} \frac{\partial v_j(n)}{\partial y_k(n)} \quad (24)$$

In order to solve for $\frac{\partial e_j(n)}{\partial v_j(n)}$ the error (Equation 5) is rewritten:

$$e_j(n) = d_j(n) - y_j(n) = d_j(n) - f(v_j(n)) \quad (25)$$

The partial derivative is taken of both sides in respect to $v_j(n)$:

$$\frac{\partial e_j(n)}{\partial v_j(n)} = -f'_j(v_j(n)) \quad (26)$$

In order to obtain $\frac{\partial v_j(n)}{\partial y_k(n)}$ take the partial derivative of Equation 9

$$v_j(n) = \sum_{k=0}^m w_{jk}(n) y_k(n) \text{ in terms of } y_k(n) \text{ where } m \text{ is the total number of inputs to}$$

neuron j excluding the bias (because the bias does not have an output of the previous layer):

$$\frac{\partial v_j(n)}{\partial y_k(n)} = w_{jk}(n) \quad (27)$$

Equation 23 can now be rewritten using Equations 25 and 26:

$$\frac{\partial \mathcal{E}(n)}{\partial y_k(n)} = \sum_{j=1}^J -e_j(n) f'_j(v_j(n)) w_{jk}(n) \quad (28)$$

By comparing Equation 28 with Equation 21 (the local gradient) $\frac{\partial \mathcal{E}(n)}{\partial y_k(n)}$ can be rewritten

as:

$$\frac{\partial \mathcal{E}(n)}{\partial y_k(n)} = \sum_{j=1}^J -\delta_j(n) w_{jk}(n) \quad (29)$$

Plugging Equation 28 into Equation 21, the local gradient for hidden neuron k can be written in terms of the local gradients of all the neurons in the next layer:

$$\delta_k(n) = f'_k(v_k(n)) \sum_{j=1}^J \delta_j(n) w_{jk}(n) \quad (30)$$

The gradient for hidden neuron k can be written in terms of the neurons local gradient:

$$\frac{\partial \mathcal{E}(n)}{\partial w_{ki}(n)} = \delta_k(n) y_i(n) \text{ (hidden neuron gradient)} \quad (31)$$

4) Updating the weights

Once the gradients have been calculated the weights can be updated using the following change in weight:

$$\Delta w = -\eta \frac{\partial \mathcal{E}(n)}{\partial w_{jk}(n)} \quad (32)$$

Thus, the new weight can be calculated by:

$$w_{new} = w_{old} - \eta \frac{\partial \mathcal{E}(n)}{\partial w_{jk}(n)} \quad (33)$$

where η is the learning rate and controls the algorithm's convergence speed. Usually η is a small value between 0.001 and 0.5, and is set by the user in a guess-and-check manner or through an adaptive learning rate algorithm.

Once the weights have been adjusted a new input/output pair (Sequential training) or a new set of input/output pairs (batch training/epoch training) are presented to the network and the procedure is repeated.

When batch training is used the average gradient at the output layer instead of the gradient for one time step is used. This means that the gradients must be stored into memory until the weights are updated. The algorithm stops when either a maximum number of iterations are reached, or the mean-squared-error reaches an acceptable value.

In summary, the weights are updated using Equation 34 below:

$$w(n) = w(n-1) - \eta \delta(n) x_i(n) \quad (34)$$

The local gradient $\delta(n)$ is:

$$\delta(n) = e_j(n) f'_j(v_j(n)) \quad \text{for neuron } j \text{ in output layer} \quad (35)$$

$$\delta(n) = f'_k(v_k(n)) \sum_{j=1}^J \delta_j(n) w_{jk}(n) \quad \text{for neuron } k \text{ in hidden layer} \quad (36)$$

In Equation 36, neuron j is in the following layer in respect to hidden neuron k .

2.3.2 - Sequential vs. Batch Training

In sequential training (training by sample) the network weights are updated after each time sample or input/output pair. In batch training (training by epoch) the weights are updated after a set of input/output pairs (one epoch) are presented. When using the backpropagation algorithm with this type of training the gradients for the output layer of the network are averaged over the training set and this average is used to update the weights. Thus, the output neuron gradients must be stored in memory until the weights are updated.

There are advantages and disadvantages to using either of the training methods. Since the weights are updated in Sequential training after every input/output pair (time sample) the weights begin to update immediately and thus the error decreases immediately. In batch training, the network is not updated until a set number of input/output pairs are presented and error reduction takes longer to occur as a result. When batch training, the weights are updated using a function proportional to the average error at the neural network output. Therefore the weight trajectory is more likely to move in a direction that will generalize the network for all input/output pairs. In other words, batch training can make the network respond better to inputs on average.

2.3.3 - Online vs. Offline Training

Online training occurs when the neural network is trained in real-time. That is, the number of inputs is continuous. Offline training occurs when the neural network is

trained using a finite number of input/output pairs. Both sequential and batch training can occur during online or offline training. While offline training, the neural network can be updated after every input/output pair has been presented (sequential training) or after the whole or part of the entire data set has been presented (batch training). Batch training can be used by updating the weights after every user defined number of time samples (input/target pairs). However, with online training the neural network is usually trained sequentially.

2.3.4 - Pre and Post Processing

The transfer function (activation function) for each neuron is typically chosen so that it accepts an input of any range and produces an output in a strictly limited range (has a squashing effect). Although the input can be in any range, there is a saturation effect so that the neuron is only sensitive to inputs within a fairly limited range. An example of such transfer functions would be the hyperbolic tangent or the sigmoid, as shown in Figure 2.3. For this reason, pre and post processing is done in order to scale the input and output into a range such as -1 to 1 when using a hyperbolic tangent function. If the maximum and minimum values are known for the input to the network, then these values can be set to 1 and -1 respectively, and every other input is set relative to those values. When the output neuron of a network is a squashing function the output is limited in range and thus scaling is required to obtain the desired response. In order to do this, the output is usually scaled to the maximum and minimum of the target. When the range of the target is unknown (as with online training), the output neurons are usually given a linear activation function that is not limited in range.

2.3.5 - Weight Initialization

Initialization of the weights of a neural network before they are optimized is imperative. When training a neural network, the goal is to find the global minimum from all possible local minimums on the error surface. Thus, it is advantageous to initialize the weights with a set of values as close to the global minimum as possible. Doing so will minimize the number of training cycles. Some methods used for initializing weights include distributing them randomly.

There is also a special method for initializing network weights. This algorithm is based upon a paper by Derrick Nguyen and Bernard Widrow presented at the proceedings of the International Joint Conference on Neural Network in 1990. The Nguyen-Widrow algorithm chooses values in order to distribute the active region of each neuron in a layer evenly across the layer's input space [5]. The advantages of this algorithm over purely random weights are fewer wasted neurons (since all are in the input space), and faster training. The algorithm works as follows: small random values are picked for the weights of the network. The weights are then modified so that the region of interest is divided into small intervals. By setting the initial weights of the first layer so that each neuron is assigned its own interval the training process can be sped up.

2.4 - Alternative Training Method

The backpropagation algorithm, which is based on a steepest-descent technique is easy to implement and computationally less complex than other algorithms. However, it

has disadvantages such as: slow convergence speed, sensitivity to local minima, and instability if the learning rate is too large [2]. An alternative (the Levenberg-Marquardt algorithm) to backpropagation is used in this study.

2.4.1 - Levenberg-Marquardt (LM)

The Levenberg-Marquardt (LM) is a high-performance algorithm which can converge on a solution much faster than the backpropagation algorithm. It is an optimization algorithm that is based on a second derivative of the error, a characteristic of the Gauss Newton Method. The LM algorithm is regarded as an intermediate method between the steepest descent and the Gauss Newton method. The basic idea of the Gauss Newton Method is to minimize the quadratic approximation of the performance measure $\mathcal{E}(w)$ around the current point $w(n)$. This is done by using a Taylor series expansion of the error as a function of w , calculating an approximated $\mathcal{E}(w)$ using this error, and finding the minimum by taking the derivative and setting it equal to zero. In essence, the curvature of the error surface is looked at; where it is assumed that the curvature seen is due to a parabolic bowl. The weights are then found for the bottom of this fictitious bowl and then re-evaluated again. The weights using this algorithm are updated using the following equation:

$$\mathbf{w}(n + 1) = \mathbf{w}(n) - (H(n))^{-1} \frac{\partial \mathcal{E}(n)}{\partial \mathbf{w}(n)} \quad (37)$$

In the above equation, $\mathbf{w}(n) = [w_1(n), w_2(n), \dots, w_m(n)]^T$ where $\mathbf{w}$ is a network weight vector containing all network weights, n is the current time sample or training pair (input/target pair) and m is the total number of weights in the neural network. $H(n)$ is an

approximation to the Hessian matrix, where the Hessian matrix is the second derivative of the performance measure (cost function) with respect to the network weights. An approximation of the Hessian matrix is made because the Hessian matrix computation is very extensive, and may not be positive definite on every point of the error surface. With the Levenberg-Marquardt algorithm, the Hessian matrix is approximated using the following equation:

$$H(n) = J^T(n)J(n) + \mu I \quad (38)$$

In the above equation, I is the identity matrix with size n and μ is a small constant that will be explained in further detail later. $J(n)$ is the Jacobian matrix and contains the first derivative of the output neuron errors with respect to the network weights. For sequential training this matrix is defined as:

$$J(n) = \begin{bmatrix} \frac{\partial e}{\partial w_1} & \frac{\partial e}{\partial w_2} & \cdots & \frac{\partial e}{\partial w_m} \end{bmatrix} \quad (39)$$

Again, m is the total number of weights in the network. The terms in $J(n)$ can be found by calculating the network gradients using the standard backpropagation algorithm with one modification at the output layer: the output layer local gradient is defined as $\delta_j^{LM} = -f'_j(v_j(n))$, where f is the activation function for output neuron j . Using this modified local gradient δ_j^{LM} the terms in the Jacobian matrix for the output layer are defined as

$\frac{\partial e}{\partial w_{ji}} = \delta_j^{LM} x_i(n)$ where $x_i(n)$ is the input to weight w_{ji} between output neuron j and neuron i in the previous layer. For neuron bias's the expression is defined as $\frac{\partial e}{\partial b_j} = \delta_j^{LM}$.

The terms for hidden layer weights can be calculated in a similar fashion by backpropagating the local gradient through the network using Equation 36. The last term

in Equation 37, $\left(\frac{\partial \varepsilon(n)}{\partial \mathbf{w}(n)}\right)$, is the gradient vector consisting of the gradients for each weight

in the network. This vector is defined as $\frac{\partial \varepsilon(n)}{\partial \mathbf{w}(n)} = \left[\frac{\partial \varepsilon(n)}{\partial w_1}, \frac{\partial \varepsilon(n)}{\partial w_1}, \dots, \frac{\partial \varepsilon(n)}{\partial w_m}\right]^T$ where the

performance/cost function $\varepsilon(n) = \frac{1}{2} \sum_{j=1}^J e_j(n)^2$ where $e_j(n)$ is the error at the output of

the j th neuron in the output layer. Note that the gradient vector is equal to the Jacobian matrix multiplied by the error $e(n)$. This relationship can be shown with the following calculation:

$$J^T(n)e(n) = \begin{bmatrix} \frac{\partial e(n)e(n)}{\partial w_1} \\ \vdots \\ \frac{\partial e(n)e(n)}{\partial w_m} \end{bmatrix} = \begin{bmatrix} \frac{\partial \left(\frac{1}{2}e(n)^2\right)}{\partial w_1} \\ \vdots \\ \frac{\partial \left(\frac{1}{2}e(n)^2\right)}{\partial w_m} \end{bmatrix} = \begin{bmatrix} \frac{\partial \varepsilon(n)}{\partial w_1} \\ \vdots \\ \frac{\partial \varepsilon(n)}{\partial w_m} \end{bmatrix} = \frac{\partial \varepsilon(n)}{\partial \mathbf{w}(n)} \quad (40)$$

Using the equalities defined in Equations 38 and 40, Equation 35 can be re-written as:

$$\mathbf{w}(n+1) = \mathbf{w}(n) - (J^T(n)J(n) + \mu I)^{-1} J^T(n)e(n) \quad (41)$$

Introduced earlier, the value μ is a small positive value and I is the identity matrix. Note

that the Gauss-Newton method does not include the μI term. This term keeps the

approximated Hessian from becoming singular. Note that when μ is zero, Equation 39

becomes the Gauss-Newton method. Also note that when μ is large, the algorithm

becomes the backpropagation algorithm (a steepest gradient descent method) with

learning rate $\frac{1}{\mu}$ which has a small step size. The Gauss-Newton method is faster and

more accurate near an error minimum (small gradient or slope), so the goal is to shift

toward the Gauss-Newton method as quickly as possible. To accomplish this the value μ

can be made adaptive using the following expression:

$$\mu(n+1) = \begin{cases} \mu(n)\beta & , \varepsilon(n) > \varepsilon(n-1) \\ \mu(n)\alpha & , \varepsilon(n) < \varepsilon(n-1) \end{cases} \quad (42)$$

Here, β and α are values set by the user.

The Levenberg-Marquardt algorithm can also be used for batch training. In this form of training the weights can be updated using the following formula:

$$\mathbf{w}(n+1) = \mathbf{w}(n) - (J^T(\mathbf{w})J(\mathbf{w}) + \mu I)^{-1}J^T(\mathbf{w})\mathbf{e}(\mathbf{w}) \quad (43)$$

All variables and constants in the above equation are defined as they were in Equation 41 (sequential training) except for the Jacobian matrix and the error. In the above equation $\mathbf{e}(\mathbf{w})$ is a vector of the network output errors over the entire training set (instead of the error $e(n)$ for one training pair). For batch training the Jacobian matrix is defined as:

$$J(\mathbf{w}) = \begin{bmatrix} \frac{\partial e(1)}{\partial w_1} & \frac{\partial e(1)}{\partial w_2} & \dots & \frac{\partial e(1)}{\partial w_m} \\ \frac{\partial e(2)}{\partial w_1} & \frac{\partial e(2)}{\partial w_2} & \dots & \frac{\partial e(2)}{\partial w_m} \\ \vdots & \vdots & \dots & \vdots \\ \frac{\partial e(N)}{\partial w_1} & \frac{\partial e(N)}{\partial w_2} & \dots & \frac{\partial e(N)}{\partial w_m} \end{bmatrix} \quad (44)$$

In the above equation, $N = Q \times J$ where Q is the total number of training pairs in the training set and J is the number of network outputs [21]. It is important to note that unlike that for sequential training the performance function for the above algorithm is defined as $\varepsilon(\mathbf{w}) = \sum_{i=1}^N e_i^2(\mathbf{w})$. It should also be noted that the gradient of this performance function is equal to $J^T(n)\mathbf{e}(n)$ (as seen in Equation 43) [21].

Chapter 3: Camera System Inertial Data

3.1 – Data Acquisition Procedure

The model was created using data gathered from a camera system owned by Axsys Technologies (a division of General Dynamics Advanced Information Systems). Details about this system are kept confidential for proprietary reasons and because the product is controlled under the International Trade and Arms Regulation. The data was gathered in the time domain as a time history dataset and consisted of input/output pairs. The input was a voltage command (in volts) to the motor/amplifier that controls the inner azimuth gimbal. The output was the azimuth inertial rate (radians/second) measured from a gyro rate sensor located on the payload (i.e. camera).

To collect the data, a program was written and two others were modified. First, a MATLAB program was written to create the input data and to store it in an Excel file. Second, the software residing inside the gimbal electronics was modified in C language. These electronics included a processor and a digital to analog converter for creating the system input voltage VIN. The gimbal electronics also included the motor amplifier circuit described in Chapter 1. Third, a computer program that communicates between a personal computer and the gimbal had to be modified using C++. The computer program was modified to read the motor command (input) data via a .csv file and to send this data down to the turret. The software was also modified to read the inertial rate (output) data from the turret and save this data to a .csv file. The code in the turret was modified to receive this data and output it to the motors.

The procedure for obtaining real system input/output data is as follows: First, the input signal VIN is generated and saved to an Excel file using the MATLAB program mentioned above. Second, this file is re-saved in a .csv format. Third, the modified Axsys Technologies computer program is used to load this .csv file and send the data to the gimbal electronics where it is stored in memory. Fourth, the computer program is used to send a “start” command to the gimbal electronics which indicates that the stored VIN signal is to be generated at the input of the system (inner gimbal azimuth axis). This command also indicates to the gimbal that the inertial rate is to be recorded and sent back to the computer. Finally, the computer program is used to save this data to a .csv file.

3.2 – Software Tool Development

To automate the creation of the input signals needed to create the training data, a program in MATLAB was created. The program contains a graphical user interface (GUI) that can be used to create several different types of time domain signals, save these signals to an Excel file, and plot the signal. The GUI is shown in Figure 3.1 below.

Figure 3.1: GUI for Time Domain Signal Creation Program

The GUI contains a pull down menu in the top left portion of the window that is used to select what type of signal the user wants to create. Just below the pull down menu is an input for the sampling frequency. Under the input for sampling frequency different signal parameters are visible depending upon the signal type selected. At the bottom left of the window there is a button for viewing the signal. If this button is pushed a separate figure window appears displaying the signal. The user can then zoom, scale, print, or save the figure for viewing at a later time. Also, on the bottom of the window there is a button for saving the signal to an Excel file. The signal is saved to the first column in the file.

3.3 - Input Signals

There are six different types of signals that can be created using the program shown in Figure 3.1. Since the signals are generated and used in a digital system the user has the ability to set the sampling frequency f_s for all the signals mentioned below.

The first signal consists of multiple sine waves appended where each sine wave is a different frequency. This type of signal was chosen so that the neural networks ability to model the system at specific system critical frequencies could be tested. The sine waves are appended to make testing more efficient. This also adds a non-linearity between sine waves.

The next signal is a multiple frequency signal. This signal was chosen so that the neural network model could be tested for a more “normal” situation where more than one frequency is present in the signal.

The third signal is a combination of the previous two. This signal consists of multiple sine waves appended with a multiple frequency wave appended at the end. This signal was chosen to test the networks ability to model changes between single and multiple frequency waves and to possibly better generalize the network model.

The fourth signal is a linear swept-frequency cosine (Chirp) signal. This signal was chosen to test the neural networks ability to model the system when frequencies are continuously changing and to test for frequencies up to the Nyquist frequency.

The fifth signal is random in amplitude and time. This signal is used to test the network models ability to identify the system when random sharp changes in amplitude

are present as is needed in situations where the helicopter suddenly changes direction or a torque disturbance such as coulomb friction is present. It is also chosen for the purpose of training the network model so that it better generalizes the system.

The sixth and last signal is a step function. A step function is used to test the dampening effect of the model compared to the real system.

3.3.1 - Multiple Sine Waves Appended

The first signal consists of up to six sine waves of different frequencies adjacent to each other. The signal is defined as:

$$x(t) = \begin{cases} A \sin(2\pi f_1 t), & 0 \leq t < t_1 \\ A \sin(2\pi f_2 t), & t_1 \leq t < 2t_1 \\ \vdots & \\ A \sin(2\pi f_p t), & (p-1)t_1 \leq t \leq pt_1 \end{cases} \quad (43)$$

In the above equation: f_1 through f_p are the frequencies (Hz) for each sine wave where p is the number of frequencies from one to six, A is the amplitude of the signal, and t_1 is the length of time at each frequency. The user can set the value for A , the number of frequencies, the value for each frequency, and the time duration t_1 for each frequency.

3.3.2 - Multiple Frequency Wave

The second signal consists of a multiple frequency sine wave consisting of up to six frequencies. The signal is defined as:

$$x(t) = \sum_{n=1}^{n=N} A \sin(2\pi f_n t), \quad 1 \leq t \leq t_1 \quad (44)$$

In the above equation t_1 is the total time duration of the signal, A is the amplitude, f_n is a frequency (Hz) and N is the number of frequencies in the signal. The user sets the value for t_1 , N , A , and f_n .

3.3.3 - Multiple Sine Waves Appended and Multiple Frequency Wave Appended

The third signal consists of up to six sine waves of different frequencies and a multiple frequency wave appended on the end. The multiple frequency wave can consist of up to six frequencies. This signal is defined as:

$$x(t) = \begin{cases} A \sin(2\pi f_1 t), & 0 \leq t < t_1 \\ \vdots & \\ A \sin(2\pi f_p t), & (p-1)t_1 \leq t < pt_1 \\ \sum_{n=1}^N B \sin(2\pi f_n t), & pt_1 \leq t \leq t_2 \end{cases} \quad (45)$$

Here, f_1 through f_p are frequencies (Hz) for each sine wave where p is the number of frequencies from one to six, A is the amplitude of the sine waves, t_1 is the length of time at each frequency, f_n is a frequency used in the multiple frequency wave, N is the number of frequencies in the multiple frequency wave (one to six), B is the amplitude of the multiple frequency wave, and f_2 is the duration of the multiple frequency wave. The user sets the value of p , N , A , B , f_1 through f_p for the single frequency sines waves, f_1 through f_N for the multiple frequency wave, the number of time samples m for each single frequency ($t_1 = \frac{m}{f_s}$), and the time duration for the multiple frequency wave ($t_2 - pt_1$).

3.3.4 - Chirp Signal

The fourth signal is a linear swept-frequency cosine (Chirp) signal. The amplitude and time duration of the signal is adjustable along with the frequency range. The equation for this signal is shown below.

$$x(t) = A \cos \left(\pi \left(f_0 + \left(\frac{f_1 - f_0}{\frac{t_1}{2}} \right) t \right) t \right), \quad 0 \leq t \leq t_1 \quad (46)$$

In the above equation, A is the amplitude, $f_0 = 0 \text{ Hz}$ (frequency at time 0), $f_1 = \frac{f_s}{2}$ (frequency at time $\frac{t_1}{2}$) and t_1 is the total time duration of the signal. Note that f_s is the sampling frequency set by the user and that the total frequency range is between f_0 and f_1 . Also note that frequency of the cosine signal is $\frac{1}{2} \left(f_0 + \left(\frac{f_1 - f_0}{\frac{t_1}{2}} \right) t \right)$ at time t. The user sets the values for A, f_s , and t_1 .

3.3.5 - Appended Multiple Random Amplitude & Random Interval (ARARI)

The fifth signal is random in amplitude and changes amplitude at random times. The minimum and maximum time duration at a given amplitude and the amplitude limits are defined by the user. In addition, the amplitude limits can be set differently for up to four different settable time segments. The signal is defined as:

$$x(t) = \begin{cases} a_1 + (b_1 - a_1) \cdot rand(1), & 0 \leq t < t_1 \\ \vdots & \\ a_m + (b_m - a_m) \cdot rand(1), & t_{m-1} \leq t < t_m \\ \vdots & \\ a_p + (b_p - a_p) \cdot rand(1), & t_{p-1} \leq t \leq t_p \end{cases} \quad (47)$$

where

$$t_m = t_{m-1} + i_1 + (i_2 - i_1) \cdot rand(1) \quad (48)$$

and

$$a_m = \begin{cases} \alpha_1, & 0 \leq t < t_1 \\ \vdots & \\ \alpha_n, & t_{s_{n-1}} \leq t \leq t_{s_n} \end{cases} \quad (49)$$

and

$$b_m = \begin{cases} \beta_1, & 0 \leq t < t_1 \\ \vdots & \\ \beta_n, & t_{s_{n-1}} \leq t \leq t_{s_n} \end{cases} \quad (50)$$

Here, $rand()$ is a Matlab function and $rand(1)$ is a uniformly distributed pseudorandom value from 0 to 1, a_m is the minimum random amplitude and b_m is the maximum random amplitude during the time interval $t_m - t_{m-1}$. Time $t_m = t_{m-1} + i_1 + (i_2 - i_1) \cdot rand(1)$ where value i_1 is the minimum random time duration at a given amplitude and i_2 is the maximum random time duration at a given amplitude. The time index m ranges between 1 and the maximum number of time intervals p . Note that the value p is not determined until the signal is generated as it depends on the duration of all time intervals $(t_m - t_{m-1})$, which are set randomly during signal generation. The amplitude limits a_m and b_m are determined by the user-defined constants α_1 to α_n and β_1 to β_n respectively, where n ranges between 1 and 4. Note that the total signal duration $t_p = t_{s_n}$. The user

sets the values for i_1, i_2, n (1 to 4), α_1 to α_n, β_1 to β_n , and the time segment duration for the different amplitude limits by setting t_{s_1} through t_{s_n} .

3.3.6 - Step Function

The last signal is a step function. The equation for the function is shown below.

$$x(t) = \begin{cases} 0, & 0 \leq t < t_1 \\ A, & t_1 \leq t \leq t_2 \end{cases} \quad (52)$$

In the above equation: A is the amplitude of the step, t_1 is the time before the step and t_2 is the total signal time. The user sets the values for A, t_1 and t_2 .

3.4 – Experimental Data Description

Several types of input/output data sets are gathered from the system. All input signals are created using a 2500 Hz sampling rate because this is the actual closed loop rate during normal system operation.

The type of data used to simulate the model include a 5 Hz sine wave (Section 3.3.1), a 35 Hz sine wave (Section 3.3.1), a multiple frequency wave (Section 3.3.2), appended sine waves with appended multiple frequency wave (Section 3.3.3), a chirp signal (Section 3.3.4), random signal (Section 3.3.5), and a step function (Section 3.3.6). Multiple types of signals were chosen for the purpose of testing and comparing how well the network can generalize to different types of signals.

3.5 - Experimental Data Measurement Results

For this study, a MATLAB program was created to automate training of the neural network and to plot the results as well as the experimentally measured data. The program is introduced in more detail in Chapter 4. The results of the experimentally measured data are shown in the following figures.

Figure 3.2: Plant Response: 5 Hz Sine Wave (Section 3.3.1)

Figure 3.2 shows the inner azimuth gimbal inertial response to a 5 Hz sine wave.

The signal was described in Section 3.3.1. The equation is defined as: $x(t) =$

$0.5 \sin(2\pi \cdot 5 \cdot t)$, $0 \leq t < 1.4$. The sampling frequency $f_s = 2500$ Hz, and total number of samples = 3500.

Figure 3.3: Plant Input: 35 Hz Sine Wave (first .5 seconds out of 12)

Figure 3.4: Plant Output: 35 Hz Sine Wave Input

Figure 3.5: Plant Output: 35 Hz Sine Wave Input (first 0.5 seconds out of 12)

Figure 3.3 **Error! Reference source not found.** shows the first 0.5 seconds (12 second signal) of the 35 Hz sine wave input to the inner azimuth gimbal. Figure 3.3 through Figure 3.5 shows the gimbal response for the full 12 seconds and Figure 3.5 shows the response for the first 0.5 seconds. The input signal is also described in Section 3.3.1. The equation for the 35 Hz sine wave is defined as: $x(t) = 0.5 \sin(2\pi \cdot 35 \cdot t)$, $0 \leq t < 12$. The sampling frequency $f_s = 2500$ Hz, and total number of samples = 3000.

Figure 3.6: Plant Response: Multiple Frequency Wave (Section 3.3.2)

Figure 3.6 shows the inner azimuth gimbal inertial rate response to the multiple frequency input signal described in Section 3.3.2. The signal is defined as:

$x(t) = \sum_{n=1}^{n=6} 0.5 \sin(2\pi f_n t)$, $1 \leq t \leq 1$, where f_n : $f_1 = 5 \text{ Hz}$, $f_2 = 15 \text{ Hz}$, $f_3 = 20 \text{ Hz}$, $f_4 = 30 \text{ Hz}$, $f_5 = 40 \text{ Hz}$, $f_6 = 50 \text{ Hz}$. The total number of samples equals 2500 and the sampling rate $f_s = 2500 \text{ Hz}$.

Figure 3.7: Plant Response: Single Freq with Multiple Appended (Section 3.3.3)

Figure 3.8: Plant Output: Single Freq with Multiple Appended Input (Section 3.3.3)

Figure 3.9: Single Freq with Multiple Appended Zoomed (10 Hz)

Figure 3.10: Single Freq with Multiple Appended Zoomed (20 Hz)

Figure 3.11: Single Freq with Multiple Appended Zoomed (30 Hz)

Figure 3.12: Single Freq with Multiple Appended Zoomed (50 Hz & Multiple Freq)

Figure 3.7 shows the inner azimuth gimbal inertial response to a signal consisting of 5 appended sine waves of different frequencies and a multiple frequency wave appended at the end. Figure 3.8 shows the plant output for this input signal and more detailed views can be seen in Figure 3.9 through Figure 3.12. The signal was described in Section 3.3.3. The equation is defined as:

$$x(t) = \begin{cases} 0.5 \sin(2\pi \cdot 10 t), & 0 \leq t < 2 \\ 0.5 \sin(2\pi \cdot 20 t), & 2 \leq t < 4 \\ 0.5 \sin(2\pi \cdot 30 t), & 4 \leq t < 6 \\ 0.5 \sin(2\pi \cdot 40 t), & 6 \leq t < 8 \\ 0.5 \sin(2\pi \cdot 50 t), & 8 \leq t < 10 \\ \sum_{n=1}^{n=6} .5 \sin(2\pi f_n), & 10 \leq t \leq 12 \end{cases}$$

with sampling frequency $f_s = 2500$ Hz. The total number of samples in this 12 second signal is 30,000. The frequencies included in the multiple frequency wave were set as follows: f_n : $f_1 = 5$ Hz, $f_2 = 15$ Hz, $f_3 = 25$ Hz, $f_4 = 35$ Hz, $f_5 = 45$ Hz, $f_6 = 55$ Hz.

Figure 3.13: Plant Response: Chirp Signal (Section 3.3.4)

Figure 3.14: Chirp Zoomed: Low Freq

Figure 3.15: Chirp Zoomed: High Frequency

Figure 3.16: Chirp Response: Output at Low Freq

Figure 3.17: Chirp Response: Output Zoomed

Figure 3.13 shows the inertial rate output (radians/second) of the inner azimuth gimbal due to a voltage command in the form of a chirp signal. More detailed views can be seen in Figure 3.14 through Figure 3.17. The expression for the input voltage (chirp signal) is defined as follows: $x(t) = .5 \cos \left(\pi \left(0 + \left(\frac{1250-0}{\frac{1}{2}} \right) t \right) t \right)$, $0 \leq t \leq 1$. Note again that the sampling frequency $f_s = 2500 \text{ Hz}$.

Figure 3.18: Plant Response: Random Signal (ARARI) (Section 3.3.5)

Figure 3.18 shows the response of the inner azimuth gimbal to the random signal described in Section 3.3.5. The sampling frequency for the signal was $f_s = 2500$ Hz and the total time duration was $t_p = 8$ seconds. The expression for the signal is defined as follows:

$$x(t) = \begin{cases} a_1 + (b_1 - a_1) \cdot rand(1), & 0 \leq t < t_1 \\ \vdots & \\ a_m + (b_m - a_m) \cdot rand(1), & t_{m-1} \leq t < t_m \\ \vdots & \\ a_p + (b_p - a_p) \cdot rand(1), & t_{p-1} \leq t \leq t_p \end{cases}$$

Where

$$t_m = t_{m-1} + .01 + (.1 - .01) \cdot rand(1)$$

And

$$a_m = \begin{cases} -0.5, & 0 \leq t < 2 \\ -0.33, & 2 \leq t < 4 \\ -0.4, & 4 \leq t < 6 \\ -0.5, & 6 \leq t \leq 8 \end{cases}$$

And

$$b_m = \begin{cases} 0.5, & 0 \leq t < 2 \\ 0.33, & 2 \leq t < 4 \\ 0.4, & 4 \leq t < 6 \\ .167, & 6 \leq t \leq 8 \end{cases}$$

Figure 3.19: Plant Response: Step Function (Section 3.3.6)

Figure 3.19 shows the response of the plant (inner azimuth gimbal) due to a step function with amplitude of 0.5 volts. An amplitude of 0.5 was chosen based on experimental trial and error. At larger amplitudes the inner gimbal was reaching its limits in travel and distorted the data. The step function is described in section 3.3.6. The expression for the input voltage is defined as follows: $x(t) = \begin{cases} 0, & 0 \leq t < 1 \\ 0.5, & 1 \leq t \leq 12 \end{cases}$. The sampling frequency $f_s = 2500$ Hz.

Chapter 4: Simulation Results

This chapter presents the results obtained for a study of neural network modeling of the plant (inner azimuth gimbal) based on the data presented in Chapter 3. Included in this chapter is a study of the capabilities for the neural network to generalize, or the ability of the neural network to emulate the plant over a general operating range. The Levenberg-Marquardt (LM) algorithm is used to train the neural network because it has a high speed of divergence. The network is trained in batch mode (epoch mode) because networks tend to generalize better when trained in this fashion. The network weights are initialized using the Nguyen-Widrow method in order to expedite training time and increase the probability of finding a global minimum.

This chapter consists of four sections. The first section describes a software tool created in MATLAB in order to automate the training and simulation process. The second section focuses on finding the best network structure using one of the data sets given in Chapter 3. The third section presents the results when using this network structure to model each of the data sets given in Chapter 3. The last section presents the results for network generalization over all data sets.

4.1 – Software Tool Development

To speed the process of training and simulation of neural networks, a program was created in MATLAB. This program automates the training and simulation process. The program contains a graphical user interface (GUI) that can be utilized to import the

data used for training, creates neural networks of several different structures, and initializes, trains, and simulates the neural networks using the imported data. In addition, the program can plot the imported data and the simulation results. The program's graphical user interface is shown in the figure below.

Figure 4.1: Program for Training & Simulating Neural Networks

Figure 4.2: Training Setup for MATLAB Program

The GUI shown in Figure 4.1 contains two buttons at the top used for saving or loading neural networks. One of these buttons allows a trained or untrained neural network and all the current settings to be saved to a file for later use. The other button can be used to load a previously saved neural network and settings.

Below these two buttons are inputs to setup the neural network structure. Four network structures can be created: (1) static feedforward; (2) the focused time-delay neural network (a standard feedforward network with a tapped-delay line on the input signal); (3) the nonlinear autoregressive network with exogenous inputs (NARX) (includes the tapped-delay line on the input signal, but adds feedback from the output of the network, which can also have a tapped-delay line) and; (4) the series parallel version of the nonlinear autoregressive network with exogenous inputs (NARXSP) (does not feedback the network output to the input but instead uses the network output target as a second input to the network). The latter three structures are dynamic.

Any number of delays, layers and neurons can be chosen for the network. In addition, a different neuron transfer function (activation function) can be chosen for each layer. Three transfer functions can be chosen: linear, sigmoid, and hyperbolic tangent.

The row of buttons below the network structure inputs are used for importing the input/target data sets used to train the network. They also plot this data in both the time and frequency domain. The time-domain data can be plotted in two ways: target vs. input or target and input plotted vs. time.

Step 3 in Figure 4.2 displays a button that is used to bring up a window for setting the Levenberg-Marquardt (LM) algorithm training parameters. These parameters include: μ , μ decrease, μ increase, maximum μ , number of total epochs to train, and the interval between plot updates (in epochs). Note that the Levenberg-Marquardt algorithm is explained in Section 2.4.1. In this implementation of the algorithm, μ is decreased after each successful step and is increased only when a tentative step would increase the performance function. Step 4 in Figure 4.2 displays a button that is used to actually create the network and initialize the weights using the Nguyen-Widrow method as described in Section 2.3.5. Last, the two buttons at the bottom of the window under Step 5 in Figure 4.2 are used to start training and simulate the network using the last data set imported.

Using of the program to create and train a neural network can be summarized by following the steps: Step 1) – the network structure and inputs are set up; Step 2) – the data used for training is imported; Step 3) – the training parameters are set up; Step 4) – the network is created; and Step 5) – the network is trained. As long as a network has been created, the weights can be re-initialized or network can be simulated at any time. Also, a data set can be plotted as long as a data set has been imported. The current

trained or un-trained network can be simulated using a new data set by importing the data and pushing the “Simulate” button.

4.2 – Network Structure Comparison, Training and Simulation Results

Various neural network structures are compared by training to the 5 Hz sine wave data set described in Section 3.3.1 and Figure 3.2. Each structure is trained three times while re-initializing the weights each time. The networks are trained using the Levenberg-Marquardt algorithm which uses a batch method for training the network. As a reminder, with batch training (training by epoch) the network weights are not updated until after a complete set of input/target pairs have been presented to the network, where the complete set is considered one epoch. Note that there are 3500 training pairs in the training set for the 5 Hz sine wave mentioned above. This equates to a 1.4 second signal when the sampling rate is 2500 Hz. After training each network structure through 200 iterations (200 epochs or weight updates) or 5 minutes, whichever comes first, the mean squared error (MSE) of the different structures is compared. The 5 minute time period refers to the time during which the computer trains the neural network. This value was chosen based on experimental data as it was discovered that the MSE for all network structures reached a relatively constant value within a 5 minute time period or before 200 epochs. The MSE is calculated by comparing the actual system output with the neural network output. The MSE is defined as: $MSE = \frac{\sum_{i=0}^n e(i)^2}{n}$ where i is the training pair index, n is the total number of training pairs (3500 for the 5 Hz sine wave) in the training set, and e is the error between the neural network output and the actual system output. In addition to comparing the MSE of different structures, an R-squared value (Coefficient of

Determination) was calculated. The R-squared value is defined as the square of the Person Correlation coefficient R. This value is obtained by dividing the covariance of the network output and real system output by the standard deviations of these two outputs multiplied. Thus, $R^2 = \left(\frac{cov(\hat{Y}, Y)}{\sigma_{\hat{Y}} \sigma_Y} \right)^2 = \left(\frac{E[(\hat{Y} - \bar{\hat{Y}})(Y - \bar{Y})]}{\sigma_{\hat{Y}} \sigma_Y} \right)^2$ where $\hat{Y}$ is the neural network output vector and Y is the real system output vector. The R-squared value is used for comparison because it is a good measure of how well the model output fits the real system output or predicts future real system outputs. In other words, the value measures the agreement between the real output and the network output. The R-squared value can range between 0 and 1. If the value is equal to 1, it indicates that the model identifies the real system perfectly for the given training set. If the value equals 0 the two outputs are completely independent. The R-squared value is a commonly used measurement. For example, Microsoft Excel uses the value.

4.2.1 Network Structure Description and Weight Initialization

The networks are confined to having two layers; an input and output layer. Two-layer feed forward neural networks have been proven capable of approximating any arbitrary function [22]. The advantages of a two-layer network (one input and one output layer) include (1) rapid convergence, (2) computationally less expensive than a multilayer network, (3) no local minima, (4) network convergence is guaranteed, and (5) linear adaptive algorithms can be applied [2]. The disadvantages of a two layer network include (1) it is only applicable to small dimensional input space, (2) it is poor at generalizing the output training set, and (3) the training output layer may be ill-conditioned if the training set does not span whole input space [2].

All networks in this study use the Hyperbolic Tangent Transfer function for neurons in the first layer and use the linear transfer function for neurons in the output layer. The Hyperbolic Tangent function is defined as $y(v(n)) = \frac{e^{v(n)} - e^{-v(n)}}{e^{v(n)} + e^{-v(n)}}$ where n is training pair index (or signal time sample). This function is used because it is fairly linear in the active region and has a finite active input range. This allows weight initialization using the Nguyen-Widrow method (described in more detail below). This function is also used because it allows the network to learn non-linear relationships. The linear function is defined as $y(v(n)) = v(n)$ and is used for the output layer of the network. This function is used because it allows the network to scale to any magnitude target by changing the weights between input and output layer.

Four different network input arrangements or structure types are used in this study. The first of these is the standard Feedforward, as mentioned in chapter 2 and shown in Figure 2.4. The second network structure used is called the Focus Time-Delay Line Neural Network (FTDNN) or Focused Time Lagged Feedforward as described in chapter 2 and shown in Figure 2.6. This structure includes a Tapped Delay Line (TDL) on the input to the network. The third network structure is called a NonLinear Autogressive Network with Exogenous Inputs (NARX) and is a Recurrent network. In this type of structure, the network output is fed back as a second input. As with the FTDNN network, a TDL occurs at the input and in this case two TDL occur (one for each input). Recurrent networks are described in chapter 2 and an example is shown in Figure 2.5. The fourth and last network structure is a Series-Parallel Nonlinear Autogressive network (NARXSP). This structure is similar to the NARX, except that instead of the network output being fed back as a second input, the network target is used as the second

input. Again, both inputs consist of TDLs. In order to generate the above networks the Matlab NN Toolbox (Version 6) is utilized. To create the Static FeedForward and FTDNN networks the `newfftd()` Matlab function is used. The NARX network is created using the `newnarx()` function and the NARXSP network is created using the `newnarxsp()` function.

The weights and biases (bias weights) of layer 1 for all network structures throughout this study are initialized using the Nguyen-Widrow method (introduced in section 2.3.5). The weights and bias weights for the output layer of the network are initialized using the Matlab function `rands()`. The `rands()` function initializes the weights to a uniformly distributed pseudorandom value between -1 and 1. The Nguyen-Widrow method is used for the purpose of decreasing training time.

The basis for the Nguyen-Widrow method rely on how well a two-layer neural network can approximate any nonlinear function by forming a union of piece-wise linear segments [22]. Each of these segments is attributed by a neuron in the first layer of the network. In this method the weights of the first layer (of the 2-layer network) are chosen in order to distribute the active region of each neuron in the layer evenly across the layer's input space [7]. Note that the input space is defined as the range of input values for that layer. The active region referred to above equals -1 to 1 for a neuron using the Hyperbolic Tangent function. The Nguyen-Widrow method is used in this study because this method has been shown to achieve major improvements in training time over a large number of different training problems [22].

In order to implement the algorithm the Matlab Neural Network Toolbox (Version 6) function is used and is called by default when generating the network

structures mentioned above. The steps to implement the weight initialization are as follows: First, the weights in layer one are uniformly distributed randomly between -1 and 1 using the `randnr()` Matlab function. Next, the magnitude of the weight vector W_i for each neuron i is scaled using the following formula: $|W_i| = 0.7H^{\frac{1}{N}}$, where H is the number of neurons in layer 1, and N is the number of elements in vector X or vector W_i . Lastly, the bias weights of the layer are set equal to a uniform random number between $-|W_i|$ and $|W_i|$. It is important to note that for the above equation to work the range of the input vector X must be -1 to 1. Therefore, when the network is simulated and trained the input vector X is scaled between these two values.

4.2.2 Training Method

All training in this study is accomplished by batch training using the Levenberg-Marquardt algorithm (explained in Section 2.4.1). To implement the training the Matlab Neural Network Toolbox function `trainlm()` was used. The method and algorithm used for this training is described below and in [21]. In the Levenberg-Marquardt algorithm (as defined for batch training), the weights are updated using the expression $\Delta \mathbf{w} = -(J^T(\mathbf{w})J(\mathbf{w}) + \mu I)^{-1}J^T(\mathbf{w})\mathbf{e}(\mathbf{w})$ where $\mathbf{w}$ is a weight vector containing all the weights in the network and is defined as $\mathbf{w}(i) = [w_1(i), w_2(i), \dots, w_m(i)]^T$. In this equation m is the total number of weights in the network, J symbolizes the Jacobian matrix, μ is a small positive value, and I is the identity matrix. In addition, $\mathbf{e}(\mathbf{w}) = [e(1), e(2), \dots, e(N)]^T$ is a vector of network output errors where $N = Q \times J$. The value Q is the total number of training pairs in the training set and J is the number of network outputs. For batch training the Jacobian matrix is defined as:

$$J(\mathbf{w}) = \begin{bmatrix} \frac{\partial e(1)}{\partial w_1} & \frac{\partial e(1)}{\partial w_2} & \dots & \frac{\partial e(1)}{\partial w_m} \\ \frac{\partial e(2)}{\partial w_1} & \frac{\partial e(2)}{\partial w_2} & \dots & \frac{\partial e(2)}{\partial w_m} \\ \vdots & \vdots & & \vdots \\ \frac{\partial e(N)}{\partial w_1} & \frac{\partial e(N)}{\partial w_2} & \dots & \frac{\partial e(N)}{\partial w_m} \end{bmatrix} \quad (44)$$

As mentioned in Chapter 2, the terms in $J(n)$ can be found by calculating the network gradients using the standard backpropagation algorithm with one modification at the output layer: the output layer local gradient is defined as $\delta_j^{LM} = -f'_j(v_j(n))$, where f is the activation function for output neuron j . Using this modified local gradient δ_j^{LM} the terms in the Jacobian matrix for the output layer are defined as $\frac{\partial e}{\partial w_{ji}} = \delta_j^{LM} x_i(n)$ where $x_i(n)$ is the input to weight w_{ji} between output neuron j and neuron i in the previous layer. The terms for hidden layer weights can be calculated in a similar fashion by backpropagating the local gradient through the network using Equation 36.

Again, note that the performance function for this algorithm is $\varepsilon(\mathbf{w}) = \sum_{i=1}^N e_i^2(\mathbf{w})$ where N is the total number of training pairs for a network with one output and the gradient for this performance function is equal to $J^T(n)\mathbf{e}(n)$ (as seen in the above expression).

The constant μ in the expression for $\Delta\mathbf{w}$ above is made to be adaptive using the following equation:

$$\mu(n+1) = \begin{cases} \mu(n)\beta, & \varepsilon(n) > \varepsilon(n-1) \\ \mu(n)\alpha, & \varepsilon(n) < \varepsilon(n-1) \\ \mu(n), & \mu(n+1) > \mu_{max} \end{cases} \quad (54)$$

The training parameters are set as follows: the initial value for $\mu = 0.001$, $\alpha = 0.1$, $\beta = 10$, $\mu_{max} = 1E10$, and the number of epochs to train is 200. The above expression allows the network to be trained in a Gauss-Newton type fashion as the performance

measure reaches a minimum. The value for μ decreases whenever this performance measure $\varepsilon(n)$ decreases and is increased whenever a step would increase the performance function. If μ becomes larger than μ_{max} the algorithm is stopped. In addition to the above parameters the MSE is set to be plotted every epoch.

In summary, the Marquardt algorithm proceeds as follows: 1) All inputs are presented to the network and the corresponding outputs and errors are calculated. The sum of squares of errors is computed over all inputs. 2) The Jacobian matrix is calculated using $\frac{\partial e}{\partial w_{ji}} = \delta_j^{LM}(n)x_i(n)$ where $\delta_j^{LM}(n) = -f'_j(v_j(n))$ for the output layer and $\delta_k^{LM}(n) = f'_k(v_k(n)) \sum_{j=1}^J \delta_j^{LM}(n)w_{jk}(n)$ (reference Equation 36) for a hidden neuron layer. 3) The value for $\Delta \mathbf{w}$ is calculated as $\Delta \mathbf{w} = -(J^T(\mathbf{w})J(\mathbf{w}) + \mu I)^{-1}J^T(\mathbf{w})\mathbf{e}(\mathbf{w})$. 4) The sum of squares of errors is re-computed using new weights $\mathbf{w} + \Delta \mathbf{w}$. If the new sum of squares is smaller than what was computed in step one, then μ is multiplied by α , $\mathbf{w}$ is set equal to $\mathbf{w} + \Delta \mathbf{w}$ and step 1 through 3 is repeated. If the sum of squares is not reduced then μ is multiplied by β and steps 3 through 4 are repeated.

All of the training and simulations in this study were accomplished using the same personal computer. The computer had an AMD Athlon 64 X2 Dual Core Processor 3800+ 2.01 GHz and 1 GB of ram.

4.2.3 Training and Simulation Results

The first neural network structure studied was a standard Feedforward with 5 neurons in the hidden layer, and one neuron in the output layer. The network was created using the Matlab function `newfftd()` with the number of delays on the input set to zero.

As a reminder, the Nguyen-Widrow method is used for weight initialization, the Hyperbolic Tangent function is used for the hidden layer and the Linear activation function is used for the output layer. The Levenberg-Marquardt algorithm is used with batch training. A block diagram of the network is shown in Figure 4.3 below. The network was trained through three trials (200 epochs each). Before each trial the network weights were re-initialized. All three trials produced the same mean squared error: 0.014151. The R-squared value was also the same for all three trials was equal to 0.0028621. This R-squared value is relatively close to zero thus indicating this neural network structure does not model the system very well. A Plot of the mean squared error vs. epoch for the last trial and the simulation results are shown in Figure 4.4 through Figure 4.6 below.

Figure 4.3: Network Structure (Standard Feedforward)

Figure 4.4: Performance Plot (Standard Feedforward NN)

Figure 4.5: Performance Zoomed (Standard Feedforward NN)

Figure 4.6: Simulation (Standard FF Structure)

The next network structure was a focus time-delay line neural network (FTDNN). The network also had 5 neurons in the hidden layer, but had a tapped delay line on the input consisting of 5 delays. The network was also created using the Matlab function `newfftd()`, but with five input delays. Again, the Nguyen-Widrow method is used for weight initialization, the hyperbolic Tangent function is used for the hidden layer and the Linear activation function for the output layer. The Levenberg-Marquardt algorithm is used for training. The network structure is shown in Figure 4.7 below. Note that the value n is the training pair index or time sample and ranges between 1 and 3500 for the 5 Hz sine wave training set. After 200 epochs the MSE for the three trials (weights re-initialized before each trial) equaled 0.0059231, .005923, 0.0059257. The R-squared values were 0.58264, .58265, 0.58245. A plot of the mean squared error vs. epoch and the simulation results for the last trial are shown in Figure 4.8 through Figure 4.10. The network that produced the lowest MSE was simulated and the results are shown below.

Figure 4.7: Network Structure (FTDNN)

Figure 4.8: Performance (FTDNN Structure)

Figure 4.9: Performance Zoomed (FTDNN Structure)

Figure 4.10: Simulation (FTDNN Structure)

The next network structure was a Nonlinear Autoregressive Network with Exogenous Inputs (NARX). The network again had 5 neurons in the first layer and 1 output neuron. The networks output was fed back as a second input and both inputs included a 5 delay tapped delay line. The neural network was created using the Matlab function `newnarx()`. The network structure is shown in the Figure 4.11 below. The training was stopped after five minutes for all three trials. The mean squared error for trials one through three was 0.0057619, .0086563, .0058255, respectively, and the number of epochs reached after the 5 minutes was 14, 12, and 13 respectively. The R-squared values for the three trails were .59419, .40543, .58954. A plot of the mean squared error vs. epoch and the simulation results for the first trial is shown in Figure 4.12 and Figure 4.13 below.

Figure 4.11: Network Structure (NARX)

Figure 4.12: Performance (NARX Structure)

Figure 4.13: Simulation (NARX Structure)

The next network structure was the Serial-Parallel Nonlinear Autoregressive Network with Exogenous Inputs (NARXSP). The network had 2 layers; a 5 neuron hidden layer and a 1 neuron output layer. Again, a tapped delay line with five delays was placed on the input. However, instead of the network output being fed back to the input the networks target d is fed as a second input with a 5 delay tapped delay line. The basic block diagram of the network is shown in Figure 4.14 below. After 200 epochs the three trials produced mean squared errors of $1.3702\text{E-}7$, $1.4432\text{E-}7$, $1.4169\text{E-}7$ respectively. The R-squared values for all three trails was .99999. A plot of the mean squared error vs. epoch and the simulation results for the last trial are shown in Figure 4.15 and Figure 4.17 below.

Figure 4.14: NARXSP Network Structure

Figure 4.15: Performance (NARXSP w/ 5 neurons)

Figure 4.16: Performance (NARXSP w/ 5 neurons) Zoomed

Figure 4.17: Simulation (NARXSP Structure w/ 5 neurons)

Three more NARXSP network structures were tested. The transfer functions, number of layers, and output layer size was kept constant but the size of the first layer and number of input delays were changed. As with the networks tested previously, the Hyperbolic Tangent transfer function was used in the first layer and the Linear function for the output layer. The three structures are represented in Figure 4.18 below. Each network structure was trained three times for 200 epochs.

Figure 4.18: NARXSP Networks (3,2 layers with different delays)

The network structures and training results for all NARXSP networks tested thus far are shown in Table 4.1 and Table 4.2 below.

Table 4.1: NARXSP Structure MSE Comparison

Layer 1 Size	Input (VIN) Delays	Target Delays	Trial 1 MSE	Trial 2 MSE	Trial 3 MSE	Average MSE
5	5	5	1.3702E-7	1.4432E-7	1.4169E-7	1.4101E-7
3	5	5	1.4255E-7	1.4543E-7	1.4353E-7	1.4384E-7
2	5	5	1.4443E-7	1.3912E-7	1.4309E-7	1.4221E-7
2	2	2	9.1823E-7	9.1316E-7	8.7917E-7	9.0352E-7

Table 4.2: NARXSP Structure R^2 Comparison

Layer 1 Size	Input (VIN) Delays	Target Delays	Trial 1 R^2	Trial 2 R^2	Trial 3 R^2	Average R^2
5	5	5	0.99999	0.99999	0.99999	0.99999
3	5	5	0.99999	0.99999	0.99999	0.99999
2	5	5	0.99999	0.99999	0.99999	0.99999
2	2	2	0.99994	0.99994	0.99994	0.99994

It can be seen from the above tables that the NARXSP network decreases in performance (MSE) only slightly with a decrease in layer size and number of delays. However, reducing the number of delays seems to affect (worsen) the results more so than decreasing the number of neurons. Table 4.3: Network Structure Comparison below summarizes the performances of the seven networks tested.

Table 4.3: Network Structure Comparison

Network	Average MSE	Average R^2
FF	0.014151	0.0028621
FTDNN	0.005924	0.58258
NARX	0.0067479	0.52972
NARXSP (5 hidden neurons, 5 delay TDL on input x, 4 delay TDL on input d(n-1))	1.4101E-7	0.99999
NARXSP (3 hidden neurons, 5 delay TDL on input x, 4 delay TDL on input d(n-1))	1.4384E-7	0.99999
NARXSP (2 hidden neurons, 5 delay TDL on input x, 4 delay TDL on input d(n-1))	1.4221E-7	0.99999
NARXSP (2 hidden neurons, 2 delay TDL on input x, 1 delay TDL on input d(n-1))	9.0352E-7	0.99994

The results in the table above indicate that the NARXSP network structure yielded the lowest MSE, and the best R-Squared value (closest to one) from the structures tested. Given the 5 Hz sine wave training set this network structure was able to model the system very accurately with an average R-Squared value of 0.99999. The standard Feedforward network gave the worst results with an R-squared value of 0.0028621. The fact that the NARXSP network was able to model the data more accurately coincides with the observation that the data is time-variant. This can be seen from looking at the plot of the input/target training set (Figure 3.2). It was also shown that reducing the number of neurons and delays for the NARXSP type structure did not have a significant impact on the mean squared error.

4.3 – Training and Simulation Results for Each Data Set

The modeling of the neural network was next studied for every input/target data set experimentally measured. The network however was not trained to the 5 Hz sine wave training set since the same network structure (mentioned below) was already trained to this signal. The Serial-Parallel Nonlinear Autoregressive Network with Exogenous Inputs (NARXSP) was chosen as the network structure. This structure was chosen because it performed well when training to the 5 Hz sine wave in section 5.2. Also, the smallest NARXSP structure size was chosen (2 neurons in hidden layer with 2 delays) because there was little difference in MSE or R-squared values between the smallest and largest network for this type of structure, and because a smaller network will train faster. The

network is shown in Figure 4.19 below. The network was trained three times for each input/target data set and the results are shown in the figures below.

Figure 4.19: 2 Neuron NARXSP Network

The network was first trained to the Chirp signal (Figure 3.13). After 200 epochs the MSE values for the three trials were 1.0182E-6, 1.0194E-6, and 1.0177E-6. The R-squared values were as follows: 0.99576, 0.99576, 0.99577. The plot of MSE vs. training epoch and simulation results of the last trial are shown in Figure 4.20 through Figure 4.23 below.

Figure 4.20: Performance (Chirp Signal)

Figure 4.21: Performance (Chirp Signal)
Zoomed

Figure 4.22: Simulation: Chirp Signal

Figure 4.23: Simulation: Chirp Signal Zoomed (1st 0.1 seconds)

The network was next trained to the step function training set (Figure 3.19). After 200 epochs the MSE values for the three trials were 1.1698E-6, 1.1235E-6, and 1.1238E-6. The R-squared values for all three trials were 0.99991. The plot of MSE vs. training epoch and the simulation results for the third trial are shown in Figure 4.24 through Figure 4.26 below.

Figure 4.24: Performance (Step Function)

Figure 4.25: performance (Step Function) Zoomed

Figure 4.26: Simulation: Step Input (Section 4.3.9)

The network was trained to the random signal data set (Figure 3.18). After 200 epochs the MSE values for the three trials were each 2.0339-6, 1.9789E-6, 2.0172E-6.

The R-squared values for all three trials as 0.99997. The training and simulation results for the third and last trial are shown in Figure 4.27 through Figure 4.29 below.

Figure 4.27: Performance (Random Signal)

Figure 4.28: Performance (Random Signal) Zoomed

Figure 4.29: Simulation: Random Signal (Section 4.3.8)

The network was next trained and simulated using the multiple frequency signal data set (Figure 3.6). After 200 epochs the MSE values for the three trials were 1.8523E-6, 1.859E-6, and 1.8167E-6. The R-squared values for all three trials were 0.99994. The training and simulation results for the last trial are shown in Figure 4.30 through Figure 4.32 below.

Figure 4.30: Performance (Mult Freq)

Figure 4.31: Performance (Mult Freq) Zoomed

Figure 4.32: Simulation: Multiple Frequency Wave (Section 4.3.4)

The network was then trained to the multiple sine wave and multiple frequency wave appended (Figure 3.7). After 200 epochs the MSE values for the three trials were each 1.4655E-6, 1.4535E-6, 1.4565E-6, The R-squared value for all three trials was 0.99972. The results of trial 3 of the training and simulation are shown in Figure 4.33 through Figure 4.36 below.

Figure 4.33: Performance (Mult Single Freq w/ Mult)

Figure 4.34: Performance (Mult Single Freq w/ Mult) Zoomed

Figure 4.35: Simulation: Single & Multiple Frequency Waves

Figure 4.36: Simulation: Single & Multiple Frequency Waves Zoomed

The last set of input/target pairs was the 35 Hz sine wave input (Figure 3.4). After 200 epochs the MSE values for the three trials were 7.916E-7, 7.8916E-7, and 7.9052E-7. The R-squared values were 0.99571, 0.99573, and, 0.99572. The simulation results are show in Figure 4.37 through Figure 4.40 below.

Figure 4.37: Performance (35 Hz Sine Wave)

Figure 4.38: Performance (35 Hz Sine Wave)
Zoomed

Figure 4.39: Simulation: 35 Hz Sine Wave

Figure 4.40: Simulation: 35 Hz Sine Wave Zoomed (1st 0.35 seconds)

The neural network was able to model the inner azimuth gimbal accurately for the 7 input/target data sets measured. A summary of the average mean squared error and R-squared values is shown in Table 4.4 below. Note that the results for the 5 Hz sine wave input were obtained in the previous section 4.3. The simulation result figures and the table below show that the neural network was able to accurately model the system for all input types tested. This is indicated by the similarities between plots and the low mean squared error values. In addition, the R-squared values are very close to 1, indicating that the network model output accurately models the real system output. It is interesting to note that the random signal has the second worst average MSE value but had the best R-squared value. The network had the most difficulty training to the 35 Hz sine wave with

an average MSE of 7.9007E-6 (the largest MSE of training sets). The 5 Hz sine wave had the lowest MSE value (9.0352E-7).

Table 4.4: Plant Modeling for Several Data Sets

Input/Target Data Type	Average MSE	Average R-Squared
Chirp Signal	1.0184E-6	0.99576
Step Signal	1.1390E-6	0.99991
Random Signal	2.0100E-6	0.99997
Multiple Frequency Signal	1.8427E-6	0.99994
Multiple & Single Frequency	1.4585E-6	0.99972
5 Hz Sine Wave	9.0352E-7	0.99994
35 Hz Sine Wave	7.9007E-6	0.99572

4.4 – Network Generalization Study

It has been shown that the neural network is able to model the plant (inner azimuth gimbal) accurately for all the experimentally measured input/target data sets. However, it is important to also study how well the neural network can generalize over the full operating range of the system.

In order to test for generalization the network is trained to one training set. The weights are then held constant while the network output is simulated for each input signal mentioned in Chapter 3. The MSE and R-squared values are then calculated by comparing the neural network output with the real system output for each training set. If the network generalizes well, the MSE values should be small, and the R-squared value should be close to 1 for all training sets.

The input/target set chosen to train the network was the random signal data set (Figure 3.18). Again, the equation for this signal is:

$$x(t) = \begin{cases} a_1 + (b_1 - a_1) \cdot rand(1), & 0 \leq t < t_1 \\ \vdots & \\ a_m + (b_m - a_m) \cdot rand(1), & t_{m-1} \leq t < t_m \\ \vdots & \\ a_p + (b_p - a_p) \cdot rand(1), & t_{p-1} \leq t \leq t_p \end{cases}$$

Where

$$t_m = t_{m-1} + .01 + (.1 - .01) \cdot rand(1)$$

And

$$a_m = \begin{cases} -0.5, & 0 \leq t < 2 \\ -0.33, & 2 \leq t < 4 \\ -0.4, & 4 \leq t < 6 \\ -0.5, & 6 \leq t \leq 8 \end{cases}$$

And

$$b_m = \begin{cases} 0.5, & 0 \leq t < 2 \\ 0.33, & 2 \leq t < 4 \\ 0.4, & 4 \leq t < 6 \\ .167, & 6 \leq t \leq 8 \end{cases}$$

The sampling frequency was $f_s = 2500$ Hz and the total time duration was $t_p = 8$ seconds. This signal is chosen because it contains frequencies up to the Nyquist frequency, is pseudorandom, and contains a large amount of energy in the frequency range spanning the servo bandwidth of the system (below 45 Hz). The frequency spectrum for this signal is shown in Figure 4.41 below. Note that the spectrum is not flat because the signal is not completely random.

Figure 4.41: Frequency Spectrum for the Random Input Signal

The NARXSP neural network structure used in Section 4.3 in Figure 4.19 is again used for this study and was trained one time for 200 epochs. To help define the weights of the network, the structure is shown in Figure 4.42 below with the weights labeled.

Figure 4.42: Generalization Study: NARXSP Network

In reference to the above figure: the input weights are of the form $w_{k,j}^m$ where m defines the input vector with $m = 1$ for system input vector X and $m = 2$ for target vector D . The value k is the neuron in the first layer and j is the element of vector m . The weight vector for layer 1 neuron 1 is $W_1^1 = [w_{1,1}^1 w_{1,2}^1 w_{1,3}^1 w_{1,1}^2 w_{1,2}^2] = [0.0000 \ 0.0001 \ - .0003 \ - .3276 \ .1039]$ and the weight vector for layer 1 neuron 2 is $W_2^1 = [w_{2,1}^1 w_{2,2}^1 w_{2,3}^1 w_{2,1}^2 w_{2,2}^2] = [-0.0003 \ 0.0014 \ - .0010 \ 0.8781 \ - .4762]$. Note that the input weight vector can be defined as $W^1 = [W_1^1 \ W_2^1]$. The weight vector between the hidden layer and the output layer is $W^2 = [w_{1,1}^1, w_{1,2}^1] = [-4.0736 \ 1.2295]$. Lastly, the bias's are $b_1^1 = 0.4443$, $b_2^1 = 0.8810$, and $b_1^2 = 0.8302$.

After training the network the mean squared error MSE and R-squared values were $1.9801\text{E-}6$, and 0.99997 respectively. The training and simulation results for the Random signal are shown in Figure 4.43 through Figure 4.45 below.

Figure 4.43: Generalization Study - Performance (Random Signal)

Figure 4.44: Generalization Study - Performance (Random Signal) Zoomed

Figure 4.45: Generalization Study Simulation Results (Random Signal)

Without changing weight values the network response is simulated for each of the remaining six input/target data sets mentioned in Chapter 3. The mean squared error, and R-Squared values are calculated for each data set. The simulation results are shown in the figures below. A summary of the results of this study is given at the end of this section.

Figure 4.46: Simulation: Chirp Signal (Generalized Network)

Figure 4.47: Simulation: Chirp Signal (Generalized Network) Zoomed

The first input/target data set used the Chirp signal (Figure 3.13) as input for simulation. The simulation results are shown in Figure 4.46 and Figure 4.47 above. The mean squared error was 1.9082E-6 and the R-squared value was 0.9921.

Figure 4.48: Simulation: Multiple Frequency Wave (Generalized Network)

The next input/target data set included the multiple frequency wave as input (Figure 3.6). The simulations results are shown in Figure 4.48 above. The mean squared error was 2.2514E-6 and the R-squared value was 0.99993.

Figure 4.49: Simulation: 5 Hz Sine Wave (Generalized Network)

The next input/target pair included the 5 Hz sine wave as input and is shown in Figure 3.2. The simulations results are shown in Figure 4.49 above. The mean squared error was 1.7119E-6 and the R-squared value was 0.99988.

Figure 4.50: Simulation: 35 Hz Sine (Generalized Network)

Figure 4.51: Simulation: 35 Hz Sine (Generalized Network) Zoomed

The 35 Hz sine wave input was used for the next simulation. The data measured from the real system is shown in Figure 3.4 through Figure 3.5 and the simulation results are shown in Figure 4.50 and Figure 4.51 above. The mean squared error was 1.848E-6 and the R-squared value was 0.99003.

Figure 4.52: Simulation: Single & Multiple Freq Waves (Generalized Network)

Figure 4.53: Simulation: Single & Mult Freq Waves (Generalized Network) Zoomed

The next data set includes the input defined by multiple sine waves appended and a multiple frequency wave appended. The data measured from the actual system is shown in

Figure 3.7 and the simulation results are shown in Figure 4.52 and Figure 4.53 above. The mean squared error was 1.9481E-6 and the R-squared value was 0.99963.

Figure 4.54: Simulation: Step Function (Generalized Network)

The data set using a step function as input is used for the last simulation. The measured system response is shown in Figure 3.19. The simulation results are shown in Figure 4.54 above. The mean squared error was 1.8854E-6 and the R-squared value was 0.99986.

The neural network was able to generalize well over the experimentally measured data. The input/output data pair which included a multiple frequency wave as input had the worst mean squared error with a value of 2.2514E-6. However the worst R-squared value (0.99003) occurred when simulating with the 35 Hz sine wave as input.

Visually, the plotted simulation results looked very accurate. Only small aberrations could be seen when looking at the simulation results given a Chirp signal or 35Hz sine wave as input.

To recap, the neural network used for the simulations was trained to the random signal (Figure 3.18) and reached MSE and R-squared values of $1.9801\text{E-}6$, and 0.99997 respectively. A summary of the results is shown in Table 4.5 below.

Table 4.5: Network Generalization Simulation Results

Input/Target Data Type	MSE	R-Squared
Chirp Signal	$1.9082\text{E-}6$	0.9921
Multiple Frequency Signal	$2.2514\text{E-}6$	0.99993
5 Hz Sine Wave	$1.7119\text{E-}6$	0.99988
35 Hz Sine Wave	$1.848\text{E-}6$	0.99003
Single & Multiple Frequency Sine Waves	$1.948\text{E-}6$	0.99963
Step Function	$1.8854\text{E-}6$	0.99986

Chapter 5: Traditional vs. Neural Network Model Comparison

System identification with neural network models is compared to a traditional method of modeling a gyro-stabilized camera system. First, using the traditional method, a model is created. Second, the model's output is simulated using the same input data sets used to simulate the neural network model output in section 4.4. Third, the traditional model output was compared to the real system output for each data set by calculating the mean squared error (MSE) and R-squared value. Lastly, the traditional model was compared to the neural network model by comparing the MSE and R-squared values.

5.1 – Traditional Model

A traditional method for system identification is to model the plant assuming a linear system. The model is created and simulated in Matlab Simulink. The block diagram for a traditional inner azimuth gimbal model is again shown in Figure 5.1 below.

Figure 5.1: Traditional Model

The Structural Dynamics (as referenced in the above figure) are generally represented as a superposition of single degree of freedom (SDOF) linear models. The transfer function

of each of these models is typically derived from FEA (finite element analysis) or modal analysis. FEA is accomplished through extensive computer simulation and modal analysis is typically executed using accelerometers and special computer software and equipment. Both of these options were not fully available at the time this paper was written. The finite element analysis was available in limited form for a small portion of the structure. When implemented the analysis indicated small oscillations at frequencies in the thousands of Hz. Since the rate of sensor measurement in the system under study is 2500 Hz (Nyquist frequency of 1250 Hz) it can be argued that the system can be modeled to within an acceptable level by assuming the structure is rigid. Using this assumption the system can now be modeled as shown in the figure below.

Figure 5.2: Inner Azimuth Gimbal (Rigid Structure)

The input V_{IN} is a voltage and the output ω_m is measured relative (between inner and outer gimbal) angular rate in radians/s (outer gimbal assumed stationary in inertial space).

The torque disturbance T_d in the above figure consists mostly of a spring torque created by a flexural pivot bearing or flex pivot (see Figure 1.9). It is important to note that the flex pivot is used in place of a standard roller bearing in order to remove non-linearities associated with this type of bearing. Thus, friction torques in this particular gimbal can be assumed sufficiently small and thus can be ignored. The flex pivot accounts for a large majority of the disturbance torque; applies a torque in the opposite direction the motor torque, and is related proportionally to the position of the inner gimbal (relative to outer). Other torques such as gyroscopic torque (created by the gyro rate sensor), on-board shaking forces, and cable torques are very hard to model. A portion of these torques can be taken into account by assuming they sum to equal a “dampening” torque. Assuming the only torque disturbance is due to the spring torque and a dampening torque then $T_D = T_s + T_d = -K_s\Delta\theta - c\dot{\theta}$ where T_s is the spring torque, T_d is a “dampening” torque, K_s is the spring constant, $\Delta\theta$ is the relative angular displacement between inner and outer azimuth gimbal, c is the system damping, and $\dot{\theta}$ is angular velocity. The damping can be defined as $c = \zeta C_{cr} = \zeta(2\sqrt{K_s \cdot J})$ where C_{cr} is called the critical damping, ζ is the damping coefficient, K_s is the spring constant, and J is the inertial Tensor (moment of inertia). The damping coefficient is defined as $\zeta = \frac{\ln(\frac{u_1}{u_2})}{2\pi}$, where u_1 is the amplitude of a spring mass oscillation in period one, u_2 is the amplitude in period two. Included in the equation for damping results is

$$c = \zeta C_{cr} = \frac{\ln(\frac{u_1}{u_2})}{2\pi} (2\sqrt{K_s \cdot J}).$$

Note that the negative signs in the equation for T_D are

present because the spring applies a torque in the opposite direction (as mentioned above)

the motor torque at all times. Given the above equation for T_D the model can be again redrawn as shown in the figure below.

Figure 5.3: Gimbal (Rigid Structure w/ Spring & Dampening Torque Disturbances)

To obtain the spring constant $K_s = \frac{T_d}{\Delta\theta}$, a known torque $-T_d$ was applied to the inner azimuth axis while the angular displacement $\Delta\theta$ at steady state was measured. This was accomplished by pointing the gimbal toward the ground and hanging weights on the edge of the inner azimuth gimbal. The torque was calculated based on the weight and its distance from the flex pivots (gimbal pivot points). The corresponding angles for a given weight were measured using the Axsys "PC Scope" (also called "Gimbal Tool") program. Several data points were taken. A plot of torque vs. angular displacement is shown in Figure 5.4 below.

Figure 5.4: Spring Torque vs. Angle

It can be seen from the above plot that $K_s \approx -203 \frac{\text{in-lbs}}{\text{rad}}$. This number coincides with the spring constant of the flex pivots ($\approx -86 \frac{\text{in-lbs}}{\text{rad}} \times 2 \text{ flex pivots} \approx -172 \frac{\text{in-lbs}}{\text{rad}}$). It is important to note the bias of -0.53 in-lbs in the above figure. This could be caused by a static imbalance of the inner gimbal, angle offset of the flex pivots, or another spring torque acting on the gimbal.

The inertia Tensor, J , and dampening, c , can be calculated by measuring the oscillation frequency and rate of dampening after applying a step function to the system. A plot of angular displacement vs. time is shown in Figure 5.5 below given a step input of $V_{IN} = .5V$.

Figure 5.5: Angular displacement vs. Time for a .5 Volt Step Input

The inertia tensor J (moment of Inertia) in Figure 5.3 can be calculated using the equation for the period of a mass-spring system $T = 2\pi \sqrt{\frac{m}{k}}$. For rotational motion of a torsion oscillator, the moment of inertia J replaces the mass m , and the torsion constant K_s replaces the spring constant k from Hooke's law. Therefore, $T = 2\pi \sqrt{\frac{J}{K_s}}$. Calculating for J , results in $J = K_s \left(\frac{T}{2\pi}\right)^2$, where T is the oscillation period (seconds), and K_s is the torsion constant $\left(\frac{\text{in-lbs}}{\text{radian}}\right)$. The period T is measured from Figure 5.5 above as $T = .56$ seconds. Using this period and the torsion constant, K_s calculated previously, the inertia tensor can be calculated as: $J = K_s \left(\frac{T}{2\pi}\right)^2 = 203 \frac{\text{in-lbs}}{\text{rad}} \left(\frac{.56 \text{ sec}}{2\pi}\right)^2 = 1.6125 \frac{\text{in-lbs-sec}^2}{\text{rad}}$.

Using the measurement in Figure 5.5 the dampening can now be calculated.

Again, the dampening is defined as $c = \zeta C_{cr} = \frac{\ln\left(\frac{u_1}{u_2}\right)}{2\pi} (2\sqrt{K_s \cdot J})$. The values for u_1 and

u_2 are found by measuring the amplitude of the first two oscillations in Figure 5.5 above:

$u_1 = .06463$ and $u_2 = .06256$. The dampening value is thus

$$c = \frac{\ln\left(\frac{.06463}{.06256}\right)}{2\pi} \left(2 \sqrt{203 \frac{\text{in-lbs}}{\text{rad}} \cdot 1.6125 \frac{\text{in-lbs-s}^2}{\text{rad}}} \right) = 0.18747 \frac{\text{in-lbs-sec}}{\text{rad}}.$$

The motor/amplifier block shown in Figure 5.3 consists of a current amplifier (implemented as an analog circuit) which drives a “torquer” motor consisting of a coil and magnet. The coil is attached to the outer gimbal where as the magnet is attached to the inner gimbal. The motor/amplifier block can be modeled as shown in the figure below.

Figure 5.6: Amplifier/Motor Model

The amplifier open loop gain in the above figure is defined as $G = \frac{6(.754E-3s+1)}{0.0158E-6s^2+.168E-3s}$.

The gain G was calculated based on the analog circuit. The current scale factor $K_c = 1$, motor inductance $L = 4.23mH$, and motor resistance $R = 10.1 \text{ ohms}$. The motor torque constant can be calculated as $K = \frac{T_m}{I}$ where T_m is the motor output torque and I is the input current to the motor. Since the flex pivot applies a torque in the opposite direction the motor torque the two torques are equal in magnitude at a steady state position. To obtain T_m the steady state angular displacement $\Delta\theta$ is measured using the data obtained in Figure 5.5. T_m is then calculated as: $T_m = -T_d = -K_s\Delta\theta - c\dot{\theta}$. Since at steady state

$\dot{\theta} = 0 \frac{rad}{s}$ then $T_m = -K_s \Delta\theta$. Given the data shown in the above plot the steady state angular displacement was measured as .034 radians. The torque can now be calculated as

$$T_m = -K_s \Delta\theta = -\left(-203 \frac{in-lbs}{rad}\right)(.0352 radians) = 7.146 in-lbs. \text{ The motor}$$

$$\text{torque constant can now be calculated as } K_t = \frac{T_m}{I} = \frac{7.146 in-lbs}{.5 amps} = 14.29 \frac{in-lbs}{amp}.$$

The back EMF constant of the motor K_e with units of $\frac{volt}{\left(\frac{rad}{sec}\right)}$ is equal to the motor torque

constant K_t with units of $\frac{N-m}{amp}$. Using the value of the torque constant calculated above:

$$K_t = \left(\frac{14.29 in-lbs}{amp}\right) \left(\frac{1 N-m}{8.850732 in-lbs}\right) = 1.615 \frac{N-m}{amp}. \text{ Thus, } K_e = 1.615 \frac{volt}{\left(\frac{rad}{sec}\right)} \text{ or } \frac{volt-sec}{rad}.$$

The gyro rate sensor can be modeled as shown in the figure below.

Figure 5.7: Gyro Rate Sensor

In the above figure the corner frequency of the gyro $\omega_n \cong 628 \frac{rad}{s}$ and the quality factor $Q \cong 10$. The random noise shown in the figure above is typically modeled as a Gaussian white noise. To increase accuracy this noise was instead generated by measuring the gyro rate sensor while it remains motionless. This measured gyro signal is displayed in the Figure 5.8 and Figure 5.9 below.

Figure 5.8: Measured Gyro Rate Sensor Noise

Figure 5.9: Measured Gyro Rate Sensor Noise (Zoomed)

The traditional model was generated and simulated in Matlab Simulink. The model is shown below with all constants included.

Figure 5.10: Simulink Traditional Model

It is important to note that the inertial tensor constant J was adjusted from the calculated value of 1.6125 to $2 \frac{\text{in-lbs-sec}^2}{\text{rad}}$, the flex pivot spring torque constant K_s was adjusted from the calculated value of 203 to $230 \frac{\text{in-lbs}}{\text{rad}}$ and the damping value c from 0.18747 to 0.85. This was done to increase the accuracy of the model and was accomplished through a basic understanding of how the constants affect the response and through trial and error. The values were adjusted based on the following assumptions: an increase in spring constant K_s magnitude causes a decrease in rate output magnitude; an increase in inertia Tensor J causes a decrease in oscillation frequency, and an increase in damping c causes a more rapid decrease in magnitude over time (more damping). The Step function data set (Figure 3.19) was used to test the response while adjusting the above values.

The motor constants are entered into Simulink by double clicking on the Amp + Motor block in Figure 5.10 above. The window that appears and the parameters entered is shown in the figure below.

Figure 5.11: Simulink Motor Constants

The Simulink model for the amplifier and motor block in Figure 5.10 is presented in Figure 5.12 below.

Figure 5.12: Simulink Amplifier and Motor Model

5.2 – Traditional Model Simulation

The traditional model was simulated using the same real system data used when simulating the neural network model in section 4.4. Using the simulation results a mean squared error and R-squared value is calculated by comparing the traditional model output with the actual measured output. Seven data sets are used: Random signal, Chirp Signal, Multiple Frequency signal, 5 Hz sine wave, 35 Hz sine wave, single and multiple frequency, and a Step function. The simulation results are shown below.

Figure 5.13: LTI Model Simulation Results (Random Signal)

Figure 5.14: LTI Model Simulation Results (Chirp Signal)

Figure 5.15: LTI Model Simulation Results (Multiple Frequency)

Figure 5.16: LTI Model Simulation Results (5 Hz Sine Wave)

Figure 5.17: LTI Model Simulation Results (35 Hz Sine Wave)

Figure 5.18: LTI Model Simulation Results (35 Hz Sine Wave) - Zoomed

Figure 5.19: LTI Model Simulation Results (Single & Multiple Frequency)

Figure 5.20: LTI Model Simulation Results (Single & Multiple Frequency) - Zoomed

Figure 5.21: LTI Model Simulation Results (Step Function)

5.4 – Traditional vs. Neural Network Model Results

In summary, a traditional model was first created using the standard linear method for identification. The model's output was then simulated using the same input data sets used to simulate the neural network output in Section 4.4. After that, the traditional model output was compared to the real system output for each data set by calculating the mean squared error (MSE) and R-squared value. The neural network model output, traditional model output, and real system (target) output are plotted together for each training set and are shown below. In addition, Table 5.1 below shows the simulation

results of both the traditional model and the neural network model (simulated in section 5.4).

Figure 5.22: Traditional vs. NN Model Outputs: Random Input Signal

Figure 5.23: Traditional vs. NN Model Outputs: Chirp Input Signal

Figure 5.24: Traditional vs. NN Model Outputs: Chirp Input (Zoomed)

Figure 5.25: Traditional vs. NN Model Outputs: Multiple Freq Input Signal

Figure 5.26: Traditional vs. NN Model Outputs: 5 Hz Sine Input Signal

Figure 5.27: Traditional vs. NN Model Outputs: 5 Hz Sine Input (Zoomed)

Figure 5.28: Traditional vs. NN Model Outputs: 35 Hz Sine Input Signal

Figure 5.29: Traditional vs. NN Model Outputs: 35 Hz Sine (Zoomed 1)

Figure 5.30: Traditional vs. NN Model Outputs: 35 Hz Sine (Zoomed 2)

Figure 5.31: Traditional vs. NN Model Outputs: Single & Multiple Freq Input Signal

Figure 5.32: Traditional vs. NN Model Outputs: Single & Mult. Freq (Zoomed)

Figure 5.33: Traditional vs. NN Model Outputs: Step Function Input Signal

Figure 5.34: Traditional vs. NN Model Outputs: Step Function Input (Zoomed)

Table 5.1: Traditional vs. Neural Network Model Results

Signal	Traditional Model MSE	Neural Network MSE	Traditional Model R-squared	Neural Network R-squared
Random Signal	0.026229	1.9801E-6	0.74866	0.99997
Chirp Signal	6.1893E-5	1.9082E-6	0.85409	0.9921
Multiple Frequency Signal	0.0039535	2.2514E-6	0.89522	0.99993
5 Hz Sine Wave	0.001343	1.7119E-6	0.92557	0.99988
35 Hz Sine Wave	0.00020419	1.848E-6	0.40264	0.99003
Single & Multiple Frequency	0.0015455	1.948E-6	0.75175	0.99963
Step Function	0.0042323	1.8851E-6	0.67779	0.99986
Average	0.0053671	1.93329E-6	0.75082	0.99734

In conclusion, the neural network modeled the actual system more accurately than the traditional model. This can be seen by comparing the mean squared error and R-

squared values between the two models. On average, the R-squared value of the neural network model was 32.8% better than the traditional model.

Chapter 6: Conclusion and Future Works

Gyro-stabilized cameras use gimbal systems for stabilizing cameras on different types of vehicles such as helicopters, boats or land vehicles. Typically, gimbal systems use traditional linear models to develop control stabilization strategies. However, linear models can lead to inaccuracies due to system complexities and non-linear relationships.

Artificial neural networks, also referred to as “neural networks (NN)”, are computer methodologies inspired by the biological systems of the human brain. Neural networks are non-linear information processing models that “learn” by classifying data and recognizing patterns. They can lead to a more accurate model of the gimbal system by mapping the input/output relationships of a system that includes characteristics left out of a traditional model.

Data gathered from experiments measuring the inertial characteristics of a gyro-stabilized camera system were analyzed using the off-line batch training method to perform non-linear input/output mapping. A proprietary camera system was used for this study.

Computer simulation results demonstrate that neural networks can successfully model the inertial response of gyro-stabilized camera systems. Modeling of several types of time-domain data sets network structures, and sizes were analyzed. The network was tested on other data sets to find how well the network was able to generalize over all

data sets. Larger network structures showed no apparent advantage over smaller structures and the network was able to generalize well over all measured data sets.

A MATLAB tool was developed and two other proprietary systems were modified to gather data from the gyro-stabilized camera system. Another MATLAB program was developed as a tool for training a neural network offline. The network was trained to perform input/output mapping of time history data, where the data represents the inertial response of the system. The Levenberg-Marquardt algorithm was used to train the network and the Nguyen-Widrow method was used to initialize the network weights. Motor voltage commands were used as inputs to the system and the inertial rate was used as the measured output.

Several different network structure types and sizes were compared. The networks were trained to map the input/output relationship of the same data set and were compared using the mean squared error, R-squared value and by observing plots of network output vs. target.

The network types included: (1) standard feedforward (FF), (2) focus time-delay (FTDNN), (3) nonlinear auto regressive network with exogenous inputs (NARX), and (4) a series parallel version of the nonlinear autoregressive network with exogenous inputs (NARXSP).

Only the NARXSP network structure was able to successfully map the input/target data set. The structure's performance was based on the mean squared error, R-squared value and visual observations. When comparing the different structure's abilities to map input/target data sets the structures from best to worst were: FF, FTDNN, NARX and NARXSP.

Several NARXSP structure sizes were compared using the mean squared error and R-squared values. The different sizes included a 2 layer network with 5, 3 or 2 neurons with either a 5 or 2 tapped delay line on each input. No significant difference was found between the mean squared error and R-squared value for each of these network sizes.

The structure, NARXSP, was trained to map several input/target data sets with different input signals. The input signals included: (1) chirp signal, (2) step function, (3) random, (4) multiple frequency wave, (5) single frequencies with multiple frequency appended and (6) single frequency sine waves. The neural network was able to generalize well with the largest mean squared error of $2.25\text{E-}6$.

A traditional model was generated to compare with the neural network model. The model was tested utilizing the same data that tested the neural network in the generalization study. The neural network was a significant improvement over the traditional approach and generalized well with a best mean squared error (MSE) of $2.25\text{E-}6$ and a minimum (worst) R-squared value of 0.99003. By comparison, the traditional model's best MSE was $6.1893\text{E-}5$ and best R-squared value was 0.92557.

The results of this work are indicative of the potential benefits for the future use of artificial neural network models in the study of online adaptive control of gyro-stabilized camera systems. Certain neural network online control strategies, such as predictive control and model reference control, use neural network models and a gyro-stabilized camera system can use these online control strategies if it uses a neural network model. The Levenberg-Marquardt algorithm could be used in an online adaptive control scheme.

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Appendix A: MATLAB Code

Signal Creation GUI:

File: GUI_Create_i.m

Description: Brings up a GUI interface which allows for creation of eight different types of signals. The user can also plot the signals and save the signals to an excel file. This file uses the create_i.m file for signal calculations.

```
function varargout = GUI_Create_i(varargin)
% GUI_CREATE_I M-file for GUI_Create_i.fig
% GUI_CREATE_I, by itself, creates a new GUI_CREATE_I or raises the existing
% singleton*.
%
% H = GUI_CREATE_I returns the handle to a new GUI_CREATE_I or the handle to
% the existing singleton*.
%
% GUI_CREATE_I('CALLBACK',hObject,eventData,handles,...) calls the local
% function named CALLBACK in GUI_CREATE_I.M with the given input arguments.
%
% GUI_CREATE_I('Property','Value',...) creates a new GUI_CREATE_I or raises the
% existing singleton*. Starting from the left, property value pairs are
% applied to the GUI before GUI_Create_i_OpeningFunction gets called. An
% unrecognized property name or invalid value makes property application
% stop. All inputs are passed to GUI_Create_i_OpeningFcn via varargin.
%
% *See GUI Options on GUIDE's Tools menu. Choose "GUI allows only one
% instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Copyright 2002-2003 The MathWorks, Inc.

% Edit the above text to modify the response to help GUI_Create_i

% Last Modified by GUIDE v2.5 30-Aug-2010 01:09:56

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
    'gui_Singleton',  gui_Singleton, ...
    'gui_OpeningFcn', @GUI_Create_i_OpeningFcn, ...
    'gui_OutputFcn',  @GUI_Create_i_OutputFcn, ...
    'gui_LayoutFcn',  [] , ...
    'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
```



```

[varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

% --- Executes just before GUI_Create_i is made visible.
function GUI_Create_i_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles     structure with handles and user data (see GUIDATA)
% varargin   command line arguments to GUI_Create_i (see VARARGIN)

load input_setup;
update_GUI_Create_i;
handles.input_setup = input_setup;
set(handles.signal_type,'Value',1);

% Choose default command line output for GUI_Create_i
%handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% Determine the position of the dialog - centered on the callback figure
% if available, else, centered on the screen
FigPos=get(0,'DefaultFigurePosition');
OldUnits = get(hObject, 'Units');
set(hObject, 'Units', 'pixels');
OldPos = get(hObject,'Position');
FigWidth = OldPos(3);
FigHeight = OldPos(4);
if isempty(gcbf)
    ScreenUnits=get(0,'Units');
    set(0,'Units','pixels');
    ScreenSize=get(0,'ScreenSize');
    set(0,'Units',ScreenUnits);

    FigPos(1)=1/2*(ScreenSize(3)-FigWidth);
    FigPos(2)=2/3*(ScreenSize(4)-FigHeight);
else
    GCBFOldUnits = get(gcbf,'Units');
    set(gcbf,'Units','pixels');
    GCBFPos = get(gcbf,'Position');
    set(gcbf,'Units',GCBFOldUnits);
    FigPos(1:2) = [(GCBFPos(1) + GCBFPos(3) / 2) - FigWidth / 2, ...
        (GCBFPos(2) + GCBFPos(4) / 2) - FigHeight / 2];
end
FigPos(3:4)=[FigWidth FigHeight];
set(hObject, 'Position', FigPos);
set(hObject, 'Units', OldUnits);

% Make the GUI have normal window style
set(handles.figure1,'WindowStyle','normal')

```

```

% UIWAIT makes GUI_Create_i wait for user response (see UIRESUME)
uiwait(handles.figure1);

% --- Outputs from this function are returned to the command line.
function varargout = GUI_Create_i_OutputFcn(hObject, eventdata, handles)
% varargout cell array for returning output args (see VARARGOUT);
% hObject handle to figure
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
% varargout{1} = handles.output;

input_setup = handles.input_setup;
create_i;
handles.input_setup.signal = signal;
input_setup = handles.input_setup;
save input_setup input_setup;

% Hint: delete(hObject) closes the figure
delete(handles.figure1);

% --- Executes on selection change in signal_type.
function signal_type_Callback(hObject, eventdata, handles)
% hObject handle to signal_type (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns signal_type contents as cell array
% contents{get(hObject,'Value')} returns selected item from signal_type

val = get(hObject,'Value');
contents = get(hObject,'String');
handles.input_setup.type = get(hObject,'Value');

% Set panel visibility
switch(val)
case 1
    set(handles.panel_single_mult,'Visible','on');
    set(handles.uipanel4,'Visible','off');
    set(handles.uipanel8,'Visible','off');
    set(handles.uipanel5,'Visible','off');
    set(handles.uipanel6,'Visible','off');
    set(handles.uipanel7,'Visible','off');
    set(handles.uipanel9,'Visible','off');
    set(handles.uipanelStepFunction,'Visible','off');
case 2
    set(handles.panel_single_mult,'Visible','off');
    set(handles.uipanel4,'Visible','on');
    set(handles.uipanel8,'Visible','off');
    set(handles.uipanel5,'Visible','off');

```

```

set(handles.uipanel6,'Visible','off');
set(handles.uipanel7,'Visible','off');
set(handles.uipanel9,'Visible','off');
set(handles.uipanelStepFunction,'Visible','off');
case 3
    set(handles.panel_single_mult,'Visible','off');
    set(handles.uipanel4,'Visible','off');
    set(handles.uipanel8,'Visible','off');
    set(handles.uipanel5,'Visible','on');
    set(handles.uipanel6,'Visible','off');
    set(handles.uipanel7,'Visible','off');
    set(handles.uipanel9,'Visible','off');
    set(handles.uipanelStepFunction,'Visible','off');
case 4
    set(handles.panel_single_mult,'Visible','off');
    set(handles.uipanel4,'Visible','off');
    set(handles.uipanel8,'Visible','off');
    set(handles.uipanel5,'Visible','off');
    set(handles.uipanel6,'Visible','on');
    set(handles.uipanel7,'Visible','off');
    set(handles.uipanel9,'Visible','off');
    set(handles.uipanelStepFunction,'Visible','off');
case 5
    set(handles.panel_single_mult,'Visible','off');
    set(handles.uipanel4,'Visible','off');
    set(handles.uipanel8,'Visible','off');
    set(handles.uipanel5,'Visible','off');
    set(handles.uipanel6,'Visible','off');
    set(handles.uipanel7,'Visible','on');
    set(handles.uipanel9,'Visible','off');
    set(handles.uipanelStepFunction,'Visible','off');
case 6
    set(handles.panel_single_mult,'Visible','off');
    set(handles.uipanel4,'Visible','off');
    set(handles.uipanel8,'Visible','on');
    set(handles.uipanel5,'Visible','off');
    set(handles.uipanel6,'Visible','off');
    set(handles.uipanel7,'Visible','off');
    set(handles.uipanel9,'Visible','off');
    set(handles.uipanelStepFunction,'Visible','off');
case 7
    set(handles.panel_single_mult,'Visible','off');
    set(handles.uipanel4,'Visible','off');
    set(handles.uipanel8,'Visible','off');
    set(handles.uipanel5,'Visible','off');
    set(handles.uipanel6,'Visible','off');
    set(handles.uipanel7,'Visible','off');
    set(handles.uipanel9,'Visible','on');
    set(handles.uipanelStepFunction,'Visible','off');
case 8
    set(handles.panel_single_mult,'Visible','off');
    set(handles.uipanel4,'Visible','off');
    set(handles.uipanel8,'Visible','off');
    set(handles.uipanel5,'Visible','off');
    set(handles.uipanel6,'Visible','off');
    set(handles.uipanel7,'Visible','off');

```

```

        set(handles.uipanel9,'Visible','off');
        set(handles.uipanelStepFunction,'Visible','on');
    end

    handles.output = hObject;
    guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function signal_type_CreateFcn(hObject, eventdata, handles)
% hObject    handle to signal_type (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function sampling_frequency_Callback(hObject, eventdata, handles)
% hObject    handle to sampling_frequency (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of sampling_frequency as text
%        str2double(get(hObject,'String')) returns contents of sampling_frequency as a double

handles.input_setup.samp_freq = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function sampling_frequency_CreateFcn(hObject, eventdata, handles)
% hObject    handle to sampling_frequency (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function num_samp_per_freq_type_1_Callback(hObject, eventdata, handles)
% hObject    handle to num_samp_per_freq_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of num_samp_per_freq_type_1 as text
%        str2double(get(hObject,'String')) returns contents of num_samp_per_freq_type_1 as a double

```

```

handles.input_setup.SMSF.num_samples = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function num_samp_per_freq_type_1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to num_samp_per_freq_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function amplitude_type_1_Callback(hObject, eventdata, handles)
% hObject    handle to amplitude_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of amplitude_type_1 as text
%       str2double(get(hObject,'String')) returns contents of amplitude_type_1 as a double

handles.input_setup.SMSF.amplitude = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function amplitude_type_1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to amplitude_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_1_type_1_Callback(hObject, eventdata, handles)
% hObject    handle to freq_1_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_1_type_1 as text
%       str2double(get(hObject,'String')) returns contents of freq_1_type_1 as a double

```

```

handles.input_setup.SMSF.freq(1) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_1_type_1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_1_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_2_type_1_Callback(hObject, eventdata, handles)
% hObject    handle to freq_2_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_2_type_1 as text
%       str2double(get(hObject,'String')) returns contents of freq_2_type_1 as a double

handles.input_setup.SMSF.freq(2) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_2_type_1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_2_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on selection change in num_freq_type_1.
function num_freq_type_1_Callback(hObject, eventdata, handles)
% hObject    handle to num_freq_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns num_freq_type_1 contents as cell array
%       contents{get(hObject,'Value')} returns selected item from num_freq_type_1

handles.input_setup.SMSF.num_freq = get(hObject,'Value');

```

```

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function num_freq_type_1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to num_freq_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

% Hint: popupmenu controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_3_type_1_Callback(hObject, eventdata, handles)
% hObject    handle to freq_3_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_3_type_1 as text
%        str2double(get(hObject,'String')) returns contents of freq_3_type_1 as a double

handles.input_setup.SMSF.freq(3) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_3_type_1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_3_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_4_type_1_Callback(hObject, eventdata, handles)
% hObject    handle to freq_4_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_4_type_1 as text
%        str2double(get(hObject,'String')) returns contents of freq_4_type_1 as a double

handles.input_setup.SMSF.freq(4) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function freq_4_type_1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_4_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function freq_5_type_1_Callback(hObject, eventdata, handles)
% hObject    handle to freq_5_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_5_type_1 as text
%        str2double(get(hObject,'String')) returns contents of freq_5_type_1 as a double

handles.input_setup.SMSF.freq(5) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function freq_5_type_1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_5_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function freq_6_type_1_Callback(hObject, eventdata, handles)
% hObject    handle to freq_6_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_6_type_1 as text
%        str2double(get(hObject,'String')) returns contents of freq_6_type_1 as a double

handles.input_setup.SMSF.freq(6) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.

```



```

function freq_6_type_1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_6_type_1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function samp_per_freq_type_2a_Callback(hObject, eventdata, handles)
% hObject    handle to samp_per_freq_type_2a (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of samp_per_freq_type_2a as text
%       str2double(get(hObject,'String')) returns contents of samp_per_freq_type_2a as a double

handles.input_setup.SMSF_w_MFE.single_freq.num_samples = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function samp_per_freq_type_2a_CreateFcn(hObject, eventdata, handles)
% hObject    handle to samp_per_freq_type_2a (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function amplitude_type_2a_Callback(hObject, eventdata, handles)
% hObject    handle to amplitude_type_2a (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of amplitude_type_2a as text
%       str2double(get(hObject,'String')) returns contents of amplitude_type_2a as a double

handles.input_setup.SMSF_w_MFE.single_freq.amplitude = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function amplitude_type_2a_CreateFcn(hObject, eventdata, handles)
% hObject    handle to amplitude_type_2a (see GCBO)

```

```

% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function freq_1_type_2a_Callback(hObject, eventdata, handles)
% hObject handle to freq_1_type_2a (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_1_type_2a as text
% str2double(get(hObject,'String')) returns contents of freq_1_type_2a as a double

handles.input_setup.SMSF_w_MFE.single_freq.freq(1) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function freq_1_type_2a_CreateFcn(hObject, eventdata, handles)
% hObject handle to freq_1_type_2a (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function freq_2_type_2a_Callback(hObject, eventdata, handles)
% hObject handle to freq_2_type_2a (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_2_type_2a as text
% str2double(get(hObject,'String')) returns contents of freq_2_type_2a as a double

handles.input_setup.SMSF_w_MFE.single_freq.freq(2) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function freq_2_type_2a_CreateFcn(hObject, eventdata, handles)
% hObject handle to freq_2_type_2a (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

```

```

% Hint: edit controls usually have a white background on Windows.
%   See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on selection change in num_freq_type_2a.
function num_freq_type_2a_Callback(hObject, eventdata, handles)
% hObject   handle to num_freq_type_2a (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns num_freq_type_2a contents as cell array
%        contents{get(hObject,'Value')} returns selected item from num_freq_type_2a

handles.input_setup.SMSF_w_MFE.single_freq.num_freq = get(hObject,'Value');

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function num_freq_type_2a_CreateFcn(hObject, eventdata, handles)
% hObject   handle to num_freq_type_2a (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
%   See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_3_type_2a_Callback(hObject, eventdata, handles)
% hObject   handle to freq_3_type_2a (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_3_type_2a as text
%        str2double(get(hObject,'String')) returns contents of freq_3_type_2a as a double

handles.input_setup.SMSF_w_MFE.single_freq.freq(3) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_3_type_2a_CreateFcn(hObject, eventdata, handles)
% hObject   handle to freq_3_type_2a (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.

```

```
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function freq_4_type_2a_Callback(hObject, eventdata, handles)
% hObject handle to freq_4_type_2a (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_4_type_2a as text
% str2double(get(hObject,'String')) returns contents of freq_4_type_2a as a double

handles.input_setup.SMSF_w_MFE.single_freq.freq(4) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);
```

```
% --- Executes during object creation, after setting all properties.
function freq_4_type_2a_CreateFcn(hObject, eventdata, handles)
% hObject handle to freq_4_type_2a (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function freq_5_type_2a_Callback(hObject, eventdata, handles)
% hObject handle to freq_5_type_2a (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_5_type_2a as text
% str2double(get(hObject,'String')) returns contents of freq_5_type_2a as a double

handles.input_setup.SMSF_w_MFE.single_freq.freq(5) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);
```

```
% --- Executes during object creation, after setting all properties.
function freq_5_type_2a_CreateFcn(hObject, eventdata, handles)
% hObject handle to freq_5_type_2a (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
```

```

    set(hObject,'BackgroundColor','white');
end

function freq_6_type_2a_Callback(hObject, eventdata, handles)
% hObject    handle to freq_6_type_2a (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_6_type_2a as text
%        str2double(get(hObject,'String')) returns contents of freq_6_type_2a as a double

handles.input_setup.SMSF_w_MFE.single_freq.freq(6) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_6_type_2a_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_6_type_2a (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function num_samples_type_2b_Callback(hObject, eventdata, handles)
% hObject    handle to num_samples_type_2b (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of num_samples_type_2b as text
%        str2double(get(hObject,'String')) returns contents of num_samples_type_2b as a double

handles.input_setup.SMSF_w_MFE.mult_freq.num_samples = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function num_samples_type_2b_CreateFcn(hObject, eventdata, handles)
% hObject    handle to num_samples_type_2b (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function amplitude_type_2b_Callback(hObject, eventdata, handles)
% hObject   handle to amplitude_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of amplitude_type_2b as text
%        str2double(get(hObject,'String')) returns contents of amplitude_type_2b as a double

handles.input_setup.SMSF_w_MFE.mult_freq.amplitude = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function amplitude_type_2b_CreateFcn(hObject, eventdata, handles)
% hObject   handle to amplitude_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_1_type_2b_Callback(hObject, eventdata, handles)
% hObject   handle to freq_1_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_1_type_2b as text
%        str2double(get(hObject,'String')) returns contents of freq_1_type_2b as a double

handles.input_setup.SMSF_w_MFE.mult_freq.freq(1) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_1_type_2b_CreateFcn(hObject, eventdata, handles)
% hObject   handle to freq_1_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function freq_2_type_2b_Callback(hObject, eventdata, handles)
% hObject   handle to freq_2_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_2_type_2b as text
%        str2double(get(hObject,'String')) returns contents of freq_2_type_2b as a double

handles.input_setup.SMSF_w_MFE.mult_freq.freq(2) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_2_type_2b_CreateFcn(hObject, eventdata, handles)
% hObject   handle to freq_2_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on selection change in num_freq_type_2b.
function num_freq_type_2b_Callback(hObject, eventdata, handles)
% hObject   handle to num_freq_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns num_freq_type_2b contents as cell array
%        contents{get(hObject,'Value')} returns selected item from num_freq_type_2b

handles.input_setup.SMSF_w_MFE.mult_freq.num_freq = get(hObject,'Value');

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function num_freq_type_2b_CreateFcn(hObject, eventdata, handles)
% hObject   handle to num_freq_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFns called

% Hint: popupmenu controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_3_type_2b_Callback(hObject, eventdata, handles)

```



```

% hObject   handle to freq_3_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_3_type_2b as text
%        str2double(get(hObject,'String')) returns contents of freq_3_type_2b as a double

handles.input_setup.SMSF_w_MFE.mult_freq.freq(3) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_3_type_2b_CreateFcn(hObject, eventdata, handles)
% hObject   handle to freq_3_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_4_type_2b_Callback(hObject, eventdata, handles)
% hObject   handle to freq_4_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_4_type_2b as text
%        str2double(get(hObject,'String')) returns contents of freq_4_type_2b as a double

handles.input_setup.SMSF_w_MFE.mult_freq.freq(4) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_4_type_2b_CreateFcn(hObject, eventdata, handles)
% hObject   handle to freq_4_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_5_type_2b_Callback(hObject, eventdata, handles)
% hObject   handle to freq_5_type_2b (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB

```



```

% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_5_type_2b as text
%        str2double(get(hObject,'String')) returns contents of freq_5_type_2b as a double

handles.input_setup.SMSF_w_MFE.mult_freq.freq(5) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_5_type_2b_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_5_type_2b (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%        See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_6_type_2b_Callback(hObject, eventdata, handles)
% hObject    handle to freq_6_type_2b (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_6_type_2b as text
%        str2double(get(hObject,'String')) returns contents of freq_6_type_2b as a double

handles.input_setup.SMSF_w_MFE.mult_freq.freq(6) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_6_type_2b_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_6_type_2b (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%        See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function num_samples_type_3_Callback(hObject, eventdata, handles)
% hObject    handle to num_samples_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

```

```

% Hints: get(hObject,'String') returns contents of num_samples_type_3 as text
%       str2double(get(hObject,'String')) returns contents of num_samples_type_3 as a double

handles.input_setup.MFW.num_samples = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function num_samples_type_3_CreateFcn(hObject, eventdata, handles)
% hObject   handle to num_samples_type_3 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function amplitude_type_3_Callback(hObject, eventdata, handles)
% hObject   handle to amplitude_type_3 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of amplitude_type_3 as text
%       str2double(get(hObject,'String')) returns contents of amplitude_type_3 as a double

handles.input_setup.MFW.amplitude = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function amplitude_type_3_CreateFcn(hObject, eventdata, handles)
% hObject   handle to amplitude_type_3 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_1_type_3_Callback(hObject, eventdata, handles)
% hObject   handle to freq_1_type_3 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_1_type_3 as text
%       str2double(get(hObject,'String')) returns contents of freq_1_type_3 as a double

```

```

handles.input_setup.MFW.freq(1) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_1_type_3_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_1_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_2_type_3_Callback(hObject, eventdata, handles)
% hObject    handle to freq_2_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_2_type_3 as text
%       str2double(get(hObject,'String')) returns contents of freq_2_type_3 as a double

handles.input_setup.MFW.freq(2) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_2_type_3_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_2_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on selection change in num_freq_type_3.
function num_freq_type_3_Callback(hObject, eventdata, handles)
% hObject    handle to num_freq_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns num_freq_type_3 contents as cell array
%       contents{get(hObject,'Value')} returns selected item from num_freq_type_3

handles.input_setup.MFW.num_freq = get(hObject,'Value');

```

```

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function num_freq_type_3_CreateFcn(hObject, eventdata, handles)
% hObject    handle to num_freq_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_3_type_3_Callback(hObject, eventdata, handles)
% hObject    handle to freq_3_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_3_type_3 as text
%        str2double(get(hObject,'String')) returns contents of freq_3_type_3 as a double

handles.input_setup.MFW.freq(3) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_3_type_3_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_3_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_4_type_3_Callback(hObject, eventdata, handles)
% hObject    handle to freq_4_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_4_type_3 as text
%        str2double(get(hObject,'String')) returns contents of freq_4_type_3 as a double

handles.input_setup.MFW.freq(4) = str2double(get(hObject,'String'));

handles.output = hObject;

```

```

guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_4_type_3_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_4_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_5_type_3_Callback(hObject, eventdata, handles)
% hObject    handle to freq_5_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_5_type_3 as text
%        str2double(get(hObject,'String')) returns contents of freq_5_type_3 as a double

handles.input_setup.MFW.freq(5) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function freq_5_type_3_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_5_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function freq_6_type_3_Callback(hObject, eventdata, handles)
% hObject    handle to freq_6_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq_6_type_3 as text
%        str2double(get(hObject,'String')) returns contents of freq_6_type_3 as a double

handles.input_setup.MFW.freq(6) = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function freq_6_type_3_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq_6_type_3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function amplitude_type_4_Callback(hObject, eventdata, handles)
% hObject    handle to amplitude_type_4 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

```

```

% Hints: get(hObject,'String') returns contents of amplitude_type_4 as text
%        str2double(get(hObject,'String')) returns contents of amplitude_type_4 as a double

```

```

handles.input_setup.chirp.amplitude = str2double(get(hObject,'String'));

```

```

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function amplitude_type_4_CreateFcn(hObject, eventdata, handles)
% hObject    handle to amplitude_type_4 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function time_type_4_Callback(hObject, eventdata, handles)
% hObject    handle to time_type_4 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

```

```

% Hints: get(hObject,'String') returns contents of time_type_4 as text
%        str2double(get(hObject,'String')) returns contents of time_type_4 as a double

```

```

handles.input_setup.chirp.time = str2double(get(hObject,'String'));

```

```

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function time_type_4_CreateFcn(hObject, eventdata, handles)

```

```

% hObject   handle to time_type_4 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function num_samples_type_5_Callback(hObject, eventdata, handles)
% hObject   handle to num_samples_type_5 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

```

```

% Hints: get(hObject,'String') returns contents of num_samples_type_5 as text
%       str2double(get(hObject,'String')) returns contents of num_samples_type_5 as a double

```

```

handles.input_setup.NSCRS.num_samples = str2double(get(hObject,'String'));

```

```

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function num_samples_type_5_CreateFcn(hObject, eventdata, handles)
% hObject   handle to num_samples_type_5 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

```

```

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function min_amplitude_type_5_Callback(hObject, eventdata, handles)
% hObject   handle to min_amplitude_type_5 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

```

```

% Hints: get(hObject,'String') returns contents of min_amplitude_type_5 as text
%       str2double(get(hObject,'String')) returns contents of min_amplitude_type_5 as a double

```

```

handles.input_setup.NSCRS.min_amp = str2double(get(hObject,'String'));

```

```

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function min_amplitude_type_5_CreateFcn(hObject, eventdata, handles)
% hObject   handle to min_amplitude_type_5 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB

```

```

% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function max_amplitude_type_5_Callback(hObject, eventdata, handles)
% hObject    handle to max_amplitude_type_5 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of max_amplitude_type_5 as text
%    str2double(get(hObject,'String')) returns contents of max_amplitude_type_5 as a double

handles.input_setup.NSCRS.max_amp = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function max_amplitude_type_5_CreateFcn(hObject, eventdata, handles)
% hObject    handle to max_amplitude_type_5 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function interval_type_5_Callback(hObject, eventdata, handles)
% hObject    handle to interval_type_5 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of interval_type_5 as text
%    str2double(get(hObject,'String')) returns contents of interval_type_5 as a double

handles.input_setup.NSCRS.interval = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function interval_type_5_CreateFcn(hObject, eventdata, handles)
% hObject    handle to interval_type_5 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

```



```

% Hint: edit controls usually have a white background on Windows.
%   See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function num_samples_type_6_Callback(hObject, eventdata, handles)
% hObject   handle to num_samples_type_6 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of num_samples_type_6 as text
%        str2double(get(hObject,'String')) returns contents of num_samples_type_6 as a double

handles.input_setup.RSLC.num_samples = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function num_samples_type_6_CreateFcn(hObject, eventdata, handles)
% hObject   handle to num_samples_type_6 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%   See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function min_amplitude_type_6_Callback(hObject, eventdata, handles)
% hObject   handle to min_amplitude_type_6 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of min_amplitude_type_6 as text
%        str2double(get(hObject,'String')) returns contents of min_amplitude_type_6 as a double

handles.input_setup.RSLC.min_amp = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function min_amplitude_type_6_CreateFcn(hObject, eventdata, handles)
% hObject   handle to min_amplitude_type_6 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%   See ISPC and COMPUTER.

```

```

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function max_amplitude_type_6_Callback(hObject, eventdata, handles)
% hObject    handle to max_amplitude_type_6 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

```

```

% Hints: get(hObject,'String') returns contents of max_amplitude_type_6 as text
%        str2double(get(hObject,'String')) returns contents of max_amplitude_type_6 as a double

```

```

handles.input_setup.RSLC.max_amp = str2double(get(hObject,'String'));

```

```

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.

```

```

function max_amplitude_type_6_CreateFcn(hObject, eventdata, handles)
% hObject    handle to max_amplitude_type_6 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

```

```

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.

```

```

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function min_interval_type_6_Callback(hObject, eventdata, handles)
% hObject    handle to min_interval_type_6 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

```

```

% Hints: get(hObject,'String') returns contents of min_interval_type_6 as text
%        str2double(get(hObject,'String')) returns contents of min_interval_type_6 as a double

```

```

handles.input_setup.RSLC.min_interval = str2double(get(hObject,'String'));

```

```

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.

```

```

function min_interval_type_6_CreateFcn(hObject, eventdata, handles)
% hObject    handle to min_interval_type_6 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

```

```

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.

```

```

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

end

```
function max_interval_type_6_Callback(hObject, eventdata, handles)
% hObject    handle to max_interval_type_6 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of max_interval_type_6 as text
%        str2double(get(hObject,'String')) returns contents of max_interval_type_6 as a double

handles.input_setup.RSLC.max_interval = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function max_interval_type_6_CreateFcn(hObject, eventdata, handles)
% hObject    handle to max_interval_type_6 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on selection change in Segments_type_7.
function Segments_type_7_Callback(hObject, eventdata, handles)
% hObject    handle to Segments_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns Segments_type_7 contents as cell array
%        contents{get(hObject,'Value')} returns selected item from Segments_type_7

handles.input_setup.RSLC_w_DAS.num_segments = get(hObject,'Value');

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function Segments_type_7_CreateFcn(hObject, eventdata, handles)
% hObject    handle to Segments_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```

function min_seg2_type_7_Callback(hObject, eventdata, handles)
% hObject   handle to min_seg2_type_7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of min_seg2_type_7 as text
%        str2double(get(hObject,'String')) returns contents of min_seg2_type_7 as a double

handles.input_setup.RSLC_w_DAS(seg(2).min_amp = str2double(get(hObject,'String')));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function min_seg2_type_7_CreateFcn(hObject, eventdata, handles)
% hObject   handle to min_seg2_type_7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit46_Callback(hObject, eventdata, handles)
% hObject   handle to edit46 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit46 as text
%        str2double(get(hObject,'String')) returns contents of edit46 as a double

% --- Executes during object creation, after setting all properties.
function edit46_CreateFcn(hObject, eventdata, handles)
% hObject   handle to edit46 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit47_Callback(hObject, eventdata, handles)
% hObject   handle to edit47 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

```

```

% Hints: get(hObject,'String') returns contents of edit47 as text
%      str2double(get(hObject,'String')) returns contents of edit47 as a double


% --- Executes during object creation, after setting all properties.
function edit47_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit47 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called


% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function max_seg2_type_7_Callback(hObject, eventdata, handles)
% hObject    handle to max_seg2_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)


% Hints: get(hObject,'String') returns contents of max_seg2_type_7 as text
%      str2double(get(hObject,'String')) returns contents of max_seg2_type_7 as a double

handles.input_setup.RSLC_w_DAS.seg(2).max_amp = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);


% --- Executes during object creation, after setting all properties.
function max_seg2_type_7_CreateFcn(hObject, eventdata, handles)
% hObject    handle to max_seg2_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called


% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function samples_seg_2_type_7_Callback(hObject, eventdata, handles)
% hObject    handle to samples_seg_2_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)


% Hints: get(hObject,'String') returns contents of samples_seg_2_type_7 as text
%      str2double(get(hObject,'String')) returns contents of samples_seg_2_type_7 as a double

handles.input_setup.RSLC_w_DAS.seg(2).num_samples = str2double(get(hObject,'String'));

```

```

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function samples_seg_2_type_7_CreateFcn(hObject, eventdata, handles)
% hObject    handle to samples_seg_2_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function min_interval_type_7_Callback(hObject, eventdata, handles)
% hObject    handle to min_interval_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of min_interval_type_7 as text
%        str2double(get(hObject,'String')) returns contents of min_interval_type_7 as a double

handles.input_setup.RSLC_w_DAS.min_interval = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function min_interval_type_7_CreateFcn(hObject, eventdata, handles)
% hObject    handle to min_interval_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function max_interval_type_7_Callback(hObject, eventdata, handles)
% hObject    handle to max_interval_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of max_interval_type_7 as text
%        str2double(get(hObject,'String')) returns contents of max_interval_type_7 as a double

handles.input_setup.RSLC_w_DAS.max_interval = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function max_interval_type_7_CreateFcn(hObject, eventdata, handles)
% hObject    handle to max_interval_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function min_seg1_type_7_Callback(hObject, eventdata, handles)
% hObject    handle to min_seg1_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of min_seg1_type_7 as text
%        str2double(get(hObject,'String')) returns contents of min_seg1_type_7 as a double

handles.input_setup.RSLC_w_DAS.seg(1).min_amp = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function min_seg1_type_7_CreateFcn(hObject, eventdata, handles)
% hObject    handle to min_seg1_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function max_seg1_type_7_Callback(hObject, eventdata, handles)
% hObject    handle to max_seg1_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of max_seg1_type_7 as text
%        str2double(get(hObject,'String')) returns contents of max_seg1_type_7 as a double

handles.input_setup.RSLC_w_DAS.seg(1).max_amp = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.

```

```

function max_seg1_type_7_CreateFcn(hObject, eventdata, handles)
% hObject    handle to max_seg1_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function samples_seg_1_type_7_Callback(hObject, eventdata, handles)
% hObject    handle to samples_seg_1_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

```

```

% Hints: get(hObject,'String') returns contents of samples_seg_1_type_7 as text
%       str2double(get(hObject,'String')) returns contents of samples_seg_1_type_7 as a double

```

```

handles.input_setup.RSLC_w_DAS.seg(1).num_samples = str2double(get(hObject,'String'));

```

```

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function samples_seg_1_type_7_CreateFcn(hObject, eventdata, handles)
% hObject    handle to samples_seg_1_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

```

```

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function min_seg3_type_7_Callback(hObject, eventdata, handles)
% hObject    handle to min_seg3_type_7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

```

```

% Hints: get(hObject,'String') returns contents of min_seg3_type_7 as text
%       str2double(get(hObject,'String')) returns contents of min_seg3_type_7 as a double

```

```

handles.input_setup.RSLC_w_DAS.seg(3).min_amp = str2double(get(hObject,'String'));

```

```

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function min_seg3_type_7_CreateFcn(hObject, eventdata, handles)
% hObject    handle to min_seg3_type_7 (see GCBO)

```



```

% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function max_seg3_type_7_Callback(hObject, eventdata, handles)
% hObject handle to max_seg3_type_7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of max_seg3_type_7 as text
% str2double(get(hObject,'String')) returns contents of max_seg3_type_7 as a double

handles.input_setup.RSLC_w_DAS.seg(3).max_amp = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function max_seg3_type_7_CreateFcn(hObject, eventdata, handles)
% hObject handle to max_seg3_type_7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function samples_seg_3_type_7_Callback(hObject, eventdata, handles)
% hObject handle to samples_seg_3_type_7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of samples_seg_3_type_7 as text
% str2double(get(hObject,'String')) returns contents of samples_seg_3_type_7 as a double

handles.input_setup.RSLC_w_DAS.seg(3).num_samples = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function samples_seg_3_type_7_CreateFcn(hObject, eventdata, handles)
% hObject handle to samples_seg_3_type_7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

```

```

% Hint: edit controls usually have a white background on Windows.
%   See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function min_seg4_type_7_Callback(hObject, eventdata, handles)
% hObject   handle to min_seg4_type_7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of min_seg4_type_7 as text
%        str2double(get(hObject,'String')) returns contents of min_seg4_type_7 as a double

handles.input_setup.RSLC_w_DAS.seg(4).min_amp = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function min_seg4_type_7_CreateFcn(hObject, eventdata, handles)
% hObject   handle to min_seg4_type_7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%   See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function max_seg4_type_7_Callback(hObject, eventdata, handles)
% hObject   handle to max_seg4_type_7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of max_seg4_type_7 as text
%        str2double(get(hObject,'String')) returns contents of max_seg4_type_7 as a double

handles.input_setup.RSLC_w_DAS.seg(4).max_amp = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function max_seg4_type_7_CreateFcn(hObject, eventdata, handles)
% hObject   handle to max_seg4_type_7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.

```

```

% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function samples_seg_4_type_7_Callback(hObject, eventdata, handles)
% hObject handle to samples_seg_4_type_7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of samples_seg_4_type_7 as text
% str2double(get(hObject,'String')) returns contents of samples_seg_4_type_7 as a double

handles.input_setup.RSLC_w_DAS.seg(4).num_samples = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function samples_seg_4_type_7_CreateFcn(hObject, eventdata, handles)
% hObject handle to samples_seg_4_type_7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on button press in view_button.
function view_button_Callback(hObject, eventdata, handles)
% hObject handle to view_button (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

input_setup = handles.input_setup;
create_i;
handles.input_setup.signal = signal;
fs = input_setup.samp_freq;
time = n/fs;

% Plot the Time Domain Signal
figure;
h = gca;
plot(time,signal);
TITLE('Input Time Domain Signal','FontWeight','bold','FontSize',16);
XLABEL('Time (seconds)','FontWeight','bold','FontSize',16);
YLABEL('Command Voltage (volts)','FontWeight','bold','FontSize',16);
set(h, 'FontWeight','bold','FontSize',16);

% Compute the Frequency Domain Signal
%NFFT = 2^nextpow2(fs); % Next power of 2 from length of y

```

```

%Y = fft(signal,NFFT)/fs;
%f = fs/2*linspace(0,1,NFFT/2+1);

% Plot the single-sided Frequency amplitude spectrum.
%figure;
%plot(f,2*abs(Y(1:NFFT/2+1)))
%xlabel('Frequency (Hz)')
%ylabel('|Mag|')
%title('Single-Sided Amplitude Spectrum');

% --- Executes on button press in load_input_button.
function load_input_button_Callback(hObject, eventdata, handles)
% hObject    handle to load_input_button (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

input_setup = 0;
[filename, pathname, filterindex] = uigetfile('*.mat', 'Pick your input file');
load(filename);
update_GUI_Create_i; % shows loaded settings on screen
handles.input_setup = input_setup;

handles.output = hObject;
guidata(hObject, handles);

% --- Executes on button press in save_input_button.
function save_input_button_Callback(hObject, eventdata, handles)
% hObject    handle to save_input_button (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

input_setup = handles.input_setup;
create_i;
handles.input_setup.signal = signal;

input_setup = handles.input_setup;
uisave('input_setup','input_setup');

% --- Executes when user attempts to close figure1.
function figure1_CloseRequestFcn(hObject, eventdata, handles)
% hObject    handle to figure1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% input_setup = handles.input_setup;
% create_i;
% handles.input_setup.signal = signal;
% input_setup = handles.input_setup;
% save input_setup input_setup;
%
% uiresume(handles.figure1);

```

```

%
% % Hint: delete(hObject) closes the figure
% delete(hObject);

% --- Executes on button press in ok_button.
function ok_button_Callback(hObject, eventdata, handles)
% hObject    handle to ok_button (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

uiresume(handles.figure1);

% --- Executes on button press in PlantOutput.
function PlantOutput_Callback(hObject, eventdata, handles)
% hObject    handle to PlantOutput (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

load training_values training_values;
input_setup = handles.input_setup;
create_i;
handles.input_setup.signal = signal;
training_values.online.signals{2} = signal;
for q = 1:length(signal)
    plant_output;
end
figure;
plot(n,signal,n,training_values.online.signals{3}); title('Plant input i, Plant Output yp');
legend('i','yp');

% --- Executes on button press in "Save to Excel File".
function pushbutton7_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

input_setup = handles.input_setup;
create_i; % creates "signal"
[filename, pathname, filterindex] = uiputfile('*.xlsx', 'Save signal to Excel 2007 file');
S = strcat(pathname, filename);
xlswrite(S,signal');

```

```

function TotalStepTime_Callback(hObject, eventdata, handles)
% hObject   handle to TotalStepTime (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of TotalStepTime as text
%        str2double(get(hObject,'String')) returns contents of TotalStepTime as a double

handles.input_setup.StepFunction.TotalStepTime = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function TotalStepTime_CreateFcn(hObject, eventdata, handles)
% hObject   handle to TotalStepTime (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function TimeBeforeStep_Callback(hObject, eventdata, handles)
% hObject   handle to TimeBeforeStep (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of TimeBeforeStep as text
%        str2double(get(hObject,'String')) returns contents of TimeBeforeStep as a double

handles.input_setup.StepFunction.TimeBeforeStep = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function TimeBeforeStep_CreateFcn(hObject, eventdata, handles)
% hObject   handle to TimeBeforeStep (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function StepAmplitude_Callback(hObject, eventdata, handles)
% hObject   handle to StepAmplitude (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hint: get(hObject,'String') returns contents of StepAmplitude as text
%   str2double(get(hObject,'String')) returns contents of StepAmplitude as a double

handles.input_setup.StepFunction.StepAmplitude = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function StepAmplitude_CreateFcn(hObject, eventdata, handles)
% hObject   handle to StepAmplitude (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%   See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

Update Signal Creation GUI:

File: update_GUI_Create_i.m

Description: Updates displayed values when loading previous settings.

% Set visibility

```
set(handles.panel_single_mult,'Visible','on');
set(handles.uipanel4,'Visible','off');
set(handles.uipanel8,'Visible','off');
set(handles.uipanel5,'Visible','off');
set(handles.uipanel6,'Visible','off');
set(handles.uipanel7,'Visible','off');
set(handles.uipanel9,'Visible','off');
set(handles.uipanelStepFunction,'Visible','off');
```

% General settings

```
set(handles.signal_type,'Value',input_setup.type);
set(handles.sampling_frequency,'String',num2str(input_setup.samp_freq));
set(handles.num_samp_per_freq_type_1,'String',num2str(input_setup.SMSF.num_samples));
```

% SMSF settings

```
set(handles.amplitude_type_1,'String',num2str(input_setup.SMSF.amplitude));
set(handles.num_freq_type_1,'Value',input_setup.SMSF.num_freq);
set(handles.freq_1_type_1,'String',num2str(input_setup.SMSF.freq(1)));
set(handles.freq_2_type_1,'String',num2str(input_setup.SMSF.freq(2)));
set(handles.freq_3_type_1,'String',num2str(input_setup.SMSF.freq(3)));
set(handles.freq_4_type_1,'String',num2str(input_setup.SMSF.freq(4)));
set(handles.freq_5_type_1,'String',num2str(input_setup.SMSF.freq(5)));
set(handles.freq_6_type_1,'String',num2str(input_setup.SMSF.freq(6)));
```

% SMSF_w_MFE settings

```
set(handles.num_freq_type_2a,'Value',input_setup.SMSF_w_MFE.single_freq.num_freq);
set(handles.samp_per_freq_type_2a,'String',num2str(input_setup.SMSF_w_MFE.single_freq.num_samples));
set(handles.amplitude_type_2a,'String',num2str(input_setup.SMSF_w_MFE.single_freq.amplitude));
set(handles.freq_1_type_2a,'String',num2str(input_setup.SMSF_w_MFE.single_freq.freq(1)));
set(handles.freq_2_type_2a,'String',num2str(input_setup.SMSF_w_MFE.single_freq.freq(2)));
set(handles.freq_3_type_2a,'String',num2str(input_setup.SMSF_w_MFE.single_freq.freq(3)));
set(handles.freq_4_type_2a,'String',num2str(input_setup.SMSF_w_MFE.single_freq.freq(4)));
set(handles.freq_5_type_2a,'String',num2str(input_setup.SMSF_w_MFE.single_freq.freq(5)));
set(handles.freq_6_type_2a,'String',num2str(input_setup.SMSF_w_MFE.single_freq.freq(6)));
set(handles.num_freq_type_2b,'Value',input_setup.SMSF_w_MFE.mult_freq.num_freq);
set(handles.num_samples_type_2b,'String',num2str(input_setup.SMSF_w_MFE.mult_freq.num_samples));
set(handles.amplitude_type_2b,'String',num2str(input_setup.SMSF_w_MFE.mult_freq.amplitude));
set(handles.freq_1_type_2b,'String',num2str(input_setup.SMSF_w_MFE.mult_freq.freq(1)));
set(handles.freq_2_type_2b,'String',num2str(input_setup.SMSF_w_MFE.mult_freq.freq(2)));
set(handles.freq_3_type_2b,'String',num2str(input_setup.SMSF_w_MFE.mult_freq.freq(3)));
set(handles.freq_4_type_2b,'String',num2str(input_setup.SMSF_w_MFE.mult_freq.freq(4)));
set(handles.freq_5_type_2b,'String',num2str(input_setup.SMSF_w_MFE.mult_freq.freq(5)));
set(handles.freq_6_type_2b,'String',num2str(input_setup.SMSF_w_MFE.mult_freq.freq(6)));
```

% MFW settings

```
set(handles.num_samples_type_3,'String',num2str(input_setup.MFW.num_samples));
set(handles.amplitude_type_3,'String',num2str(input_setup.MFW.amplitude));
```



```

set(handles.num_freq_type_3,'Value',input_setup.MFW.num_freq);
set(handles.freq_1_type_3,'String',num2str(input_setup.MFW.freq(1)));
set(handles.freq_2_type_3,'String',num2str(input_setup.MFW.freq(2)));
set(handles.freq_3_type_3,'String',num2str(input_setup.MFW.freq(3)));
set(handles.freq_4_type_3,'String',num2str(input_setup.MFW.freq(4)));
set(handles.freq_5_type_3,'String',num2str(input_setup.MFW.freq(5)));
set(handles.freq_6_type_3,'String',num2str(input_setup.MFW.freq(6)));

% chirp settings
set(handles.amplitude_type_4,'String',num2str(input_setup.chirp.amplitude));
set(handles.time_type_4,'String',num2str(input_setup.chirp.time));

% NSCRS settings
set(handles.num_samples_type_5,'String',num2str(input_setup.NSCRs.num_samples));
set(handles.min_amplitude_type_5,'String',num2str(input_setup.NSCRs.min_amp));
set(handles.max_amplitude_type_5,'String',num2str(input_setup.NSCRs.max_amp));
set(handles.interval_type_5,'String',num2str(input_setup.NSCRs.interval));

% RSLC settings
set(handles.num_samples_type_6,'String',num2str(input_setup.RSLC.num_samples));
set(handles.min_amplitude_type_6,'String',num2str(input_setup.RSLC.min_amp));
set(handles.max_amplitude_type_6,'String',num2str(input_setup.RSLC.max_amp));
set(handles.min_interval_type_6,'String',num2str(input_setup.RSLC.min_interval));
set(handles.max_interval_type_6,'String',num2str(input_setup.RSLC.max_interval));

%RSLC_w_DAS settings
set(handles.Segments_type_7,'Value',input_setup.RSLC_w_DAS.num_segments);
set(handles.min_interval_type_7,'String',num2str(input_setup.RSLC_w_DAS.min_interval));
set(handles.max_interval_type_7,'String',num2str(input_setup.RSLC_w_DAS.max_interval));
set(handles.min_seg1_type_7,'String',num2str(input_setup.RSLC_w_DAS.seg(1).min_amp));
set(handles.min_seg2_type_7,'String',num2str(input_setup.RSLC_w_DAS.seg(2).min_amp));
set(handles.min_seg3_type_7,'String',num2str(input_setup.RSLC_w_DAS.seg(3).min_amp));
set(handles.min_seg4_type_7,'String',num2str(input_setup.RSLC_w_DAS.seg(4).min_amp));
set(handles.max_seg1_type_7,'String',num2str(input_setup.RSLC_w_DAS.seg(1).max_amp));
set(handles.max_seg2_type_7,'String',num2str(input_setup.RSLC_w_DAS.seg(2).max_amp));
set(handles.max_seg3_type_7,'String',num2str(input_setup.RSLC_w_DAS.seg(3).max_amp));
set(handles.max_seg4_type_7,'String',num2str(input_setup.RSLC_w_DAS.seg(4).max_amp));
set(handles.samples_seg_1_type_7,'String',num2str(input_setup.RSLC_w_DAS.seg(1).num_samples));
set(handles.samples_seg_2_type_7,'String',num2str(input_setup.RSLC_w_DAS.seg(2).num_samples));
set(handles.samples_seg_3_type_7,'String',num2str(input_setup.RSLC_w_DAS.seg(3).num_samples));
set(handles.samples_seg_4_type_7,'String',num2str(input_setup.RSLC_w_DAS.seg(4).num_samples));

% StepFunction settings
set(handles.TotalStepTime,'String',num2str(input_setup.StepFunction.TotalStepTime));
set(handles.TimeBeforeStep,'Value',input_setup.StepFunction.TimeBeforeStep);
set(handles.StepAmplitude,'String',num2str(input_setup.StepFunction.StepAmplitude));

```

Signal Creation Calculations:

File: create_i.m

Description: Used in GUI_create_i.m file. This file holds the code to generate the time-domain data for the signals.

```
% Create input i

fs = input_setup.samp_freq;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Create input of System
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

switch(input_setup.type)
case 1 % Single or Multiple single frequencies (SMSF)
    q = 0;
    r = 0;
    fl = 0;
    r = input_setup.SMSF.num_freq;
    for q = 1:r
        fl(q) = input_setup.SMSF.freq(q);
    end
    r = 0;
    r = 1:input_setup.SMSF.num_samples;
    amp = 0;
    amp = input_setup.SMSF.amplitude;
    min_i = -amp;
    max_i = amp;
    % initilize values
    n = 0;
    signal = 0;
    p = 0;
    % Create input sinewaves
    for q = 1:length(fl)
        p = 0;
        p = amp*sin(2*pi*fl(q)/fs*r);
        signal = [signal p];
    end

case 2 % Single or Multiple single frequencies with Multiple frequency Wave attached at end
(SMSF_w_MFE)
    q = 0;
    r = 0;
    fl = 0;
    r = input_setup.SMSF_w_MFE.single_freq.num_freq;
    for q = 1:r
        fl(q) = input_setup.SMSF_w_MFE.single_freq.freq(q);
    end
    r = 0;
    r = 1:input_setup.SMSF_w_MFE.single_freq.num_samples; % Number of input periods
    amp = 0;
```

```

amp = input_setup.SMSF_w_MFE.single_freq.amplitude;
% initialize values
n = 0;
signal = 0;
p = 0;
% Create input single sinewaves
for q = 1:length(f1)
    p = 0;
    p = amp*sin(2*pi*f1(q)/fs*r);
    signal = [signal p];
end

% Add Multiple frequency wave at end
r = 0;
f1 = 0;
s = input_setup.SMSF_w_MFE.mult_freq.num_freq;
for q = 1:s
    f1(q) = input_setup.SMSF_w_MFE.mult_freq.freq(q);
end

q = 0;
q = 0:input_setup.SMSF_w_MFE.mult_freq.num_samples; % length of wave
p = 0;
amp = 0;
amp = input_setup.SMSF_w_MFE.mult_freq.amplitude;
for r = 1:s
    p = p + amp*sin(2*pi*f1(r)/fs*q);
end
signal = [signal p];
min_i = min(signal);
max_i = max(signal);

case 3 % Multiple Frequency wave (MFW)

r = 0;
f1 = 0;
s = input_setup.MFW.num_freq;
for q = 1:s
    f1(q) = input_setup.MFW.freq(q);
end

signal = 0;
q = 0;
q = 0:input_setup.MFW.num_samples; % length of wave
p = 0;
amp = 0;
amp = input_setup.MFW.amplitude;
for r = 1:s
    signal = signal + amp*sin(2*pi*f1(r)/fs*q);
end
min_i = min(signal);
max_i = max(signal);
case 4 % Chirp Signal
amp = 0;
amp = input_setup.chirp.amplitude;
min_i = -amp;

```

```

max_i = amp;
q = 0;
q = input_setup.chirp.time;
signal = 0;
t=0:1/fs:q;          % q secs @ fs sample rate (fs*q samples)
signal=amp*chirp(t,0,q/2,fs/2); % Start @ DC, cross fs/2 Hz at t=q/2 seconds

```

case 5 % N-samples-Constant Random Signal (NSCRS)

```

signal = 0;
q = 0;
interval = 0;
interval_sum = 1;
samples = input_setup.NSCRS.num_samples;
min_ = input_setup.NSCRS.min_amp;
max_ = input_setup.NSCRS.max_amp;
min_i = min_;
max_i = max_;
interval = input_setup.NSCRS.interval; % interval signal seconds to hold random value
interval = round(fs*interval); % interval signal samples to hold random value
for q = 1:samples
    if interval_sum <= samples
        rand_amp = 0;
        r = 0;
        rand_amp = min_ + (max_-min_)*rand(1); % random value
        for r = interval_sum: interval_sum + interval
            if r <= samples
                signal(r) = rand_amp;
            end
        end
        interval_sum = interval_sum + interval;
    end
end

```

case 6 % Random Signal with level change at random instances (RSLC)

```

signal = 0;
q = 0;
interval = 0;
interval_sum = 1;
samples = input_setup.RSLC.num_samples;
min_ = input_setup.RSLC.min_amp;
max_ = input_setup.RSLC.max_amp;
min_i = min_;
max_i = max_;
min_int = input_setup.RSLC.min_interval;
max_int = input_setup.RSLC.max_interval;
for q = 1:samples
    if interval_sum <= samples
        interval = 0;
        rand_amp = 0;
        r = 0;
        interval = min_int + (max_int - min_int)*rand(1); % interval signal seconds to hold
random value % interval signal samples to hold random value
        interval = round(fs*interval); % interval signal samples to hold random value
        rand_amp = min_ + (max_-min_)*rand(1); % random value
    end
end

```

```

        for r = interval_sum: interval_sum + interval
            if r <= samples
                signal(r) = rand_amp;
            end
        end
        interval_sum = interval_sum + interval;
    end
end

case 7 % Random Signal with level change at random instances with multiple min/max segments
(RSLC_w_DAS)
    signal = 0;
    q = 0;
    sample_limit = 0;
    num_segments = input_setup.RSLC_w_DAS.num_segments;
    for q = 1:num_segments
        min_(q) = input_setup.RSLC_w_DAS.seg(q).min_amp;
        max_(q) = input_setup.RSLC_w_DAS.seg(q).max_amp;
        segment_samples(q) = input_setup.RSLC_w_DAS.seg(q).num_samples;
    end
    min_i = min(min_);
    max_i = max(max_);
    interval = 0;
    interval_sum = 1;
    min_int = input_setup.RSLC_w_DAS.min_interval;
    max_int = input_setup.RSLC_w_DAS.max_interval;
    for v = 1:num_segments
        sample_limit = sample_limit + segment_samples(v);
        for q = 1:segment_samples(v)
            if interval_sum <= sample_limit
                interval = 0;
                rand_amp = 0;
                r = 0;
                interval = min_int + (max_int - min_int)*rand(1); % interval signal seconds to hold
random value
                interval = round(fs*interval); % interval signal samples to hold random value
                rand_amp = min_(v) + (max_(v)-min_(v))*rand(1); % random value
                for r = interval_sum: interval_sum + interval
                    if r <= sample_limit
                        signal(r) = rand_amp;
                    end
                end
                interval_sum = interval_sum + interval;
            end
        end
    end
end
case 8 % Step Function
    amp = input_setup.StepFunction.StepAmplitude;
    q = input_setup.StepFunction.TotalStepTime;
    q = round(q*fs);
    i = input_setup.StepFunction.TimeBeforeStep;
    i = round(i*fs);
    signal = zeros(1,q);
    signal(i+1:end) = amp;
end

```

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% save
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

n = 1:length(signal);
save signal signal;

```

Model Training GUI: Interface Used to Train & Simulate Neural Network

File: GUI_model.m

Description: Brings up a GUI interface which allows for creating a neural network, importing input/target data, plotting this data over time, plotting target vs. input, plotting input frequency spectrum and plotting plant frequency response. The GUI also allows for setup of Levenberg-Marquardt training parameters, training NN to input/target data, simulating network outputs, plotting simulation results, calculating mean squared error (mse) for simulation results vs target and error $\%(\text{mse}/\text{mean squared target value})$. The user can also re-initialize the NN weights at any time and can save or load neural network.

```
function varargout = GUI_model(varargin)
% GUI_MODEL M-file for GUI_model.fig
%   GUI_MODEL, by itself, creates a new GUI_MODEL or raises the existing
%   singleton*.
%
%   H = GUI_MODEL returns the handle to a new GUI_MODEL or the handle to
%   the existing singleton*.
%
%   GUI_MODEL('CALLBACK',hObject,eventData,handles,...) calls the local
%   function named CALLBACK in GUI_MODEL.M with the given input arguments.
%
%   GUI_MODEL('Property','Value',...) creates a new GUI_MODEL or raises the
%   existing singleton*. Starting from the left, property value pairs are
%   applied to the GUI before GUI_model_OpeningFunction gets called. An
%   unrecognized property name or invalid value makes property application
%   stop. All inputs are passed to GUI_model_OpeningFcn via varargin.
%
%   *See GUI Options on GUIDE's Tools menu. Choose "GUI allows only one
%   instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Copyright 2002-2003 The MathWorks, Inc.

% Edit the above text to modify the response to help GUI_model

% Last Modified by GUIDE v2.5 27-Aug-2010 21:12:54

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                  'gui_Singleton',   gui_Singleton, ...
                  'gui_OpeningFcn', @GUI_model_OpeningFcn, ...
                  'gui_OutputFcn',  @GUI_model_OutputFcn, ...
                  'gui_LayoutFcn',  [] , ...
                  'gui_Callback',    []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end
```

```

if nargin
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

% --- Executes just before GUI_model is made visible.
function GUI_model_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles     structure with handles and user data (see GUIDATA)
% varargin   command line arguments to GUI_model (see VARARGIN)

initialize_GUI_model;
if exist('model.mat') == 2 % load model file if exists
    load model;
end
update_GUI_model;
handles.model = model;
handles.holdPlot = 0;

% Disable "Save Model" button
set(handles.save_model, 'Enable', 'off')

% Choose default command line output for GUI_model
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% Make the GUI have a normal window style
set(handles.figure1, 'WindowStyle', 'normal')

% Determine the position of the dialog - centered on the callback figure
% if available, else, centered on the screen
FigPos=get(0, 'DefaultFigurePosition');
OldUnits = get(hObject, 'Units');
set(hObject, 'Units', 'pixels');
OldPos = get(hObject, 'Position');
FigWidth = OldPos(3);
FigHeight = OldPos(4);
if isempty(gcbf)
    ScreenUnits=get(0, 'Units');
    set(0, 'Units', 'pixels');
    ScreenSize=get(0, 'ScreenSize');
    set(0, 'Units', ScreenUnits);

    FigPos(1)=1/2*(ScreenSize(3)-FigWidth);
    FigPos(2)=2/3*(ScreenSize(4)-FigHeight);
else
    GCBFOldUnits = get(gcbf, 'Units');
    set(gcbf, 'Units', 'pixels');

```



```

    GCBFPos = get(gcf,'Position');
    set(gcf,'Units',GCBFOldUnits);
    FigPos(1:2) = [(GCBFPos(1) + GCBFPos(3) / 2) - FigWidth / 2, ...
        (GCBFPos(2) + GCBFPos(4) / 2) - FigHeight / 2];
end
FigPos(3:4)=[FigWidth FigHeight];
set(hObject, 'Position', FigPos);
set(hObject, 'Units', OldUnits);

% UIWAIT makes GUI_model wait for user response (see UIRESUME)
uiwait(handles.figure1);

% --- Outputs from this function are returned to the command line.
function varargout = GUI_model_OutputFcn(hObject, eventdata, handles)
% varargout cell array for returning output args (see VARARGOUT);
% hObject handle to figure
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
%varargout{1} = handles.output;

model = handles.model;
save model model;

% Hint: delete(hObject) closes the figure
delete(hObject);

% --- Executes on selection change in popupmenu6.
function popupmenu6_Callback(hObject, eventdata, handles)
% hObject handle to popupmenu6 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns popupmenu6 contents as cell array
% contents{get(hObject,'Value')} returns selected item from popupmenu6

% --- Executes during object creation, after setting all properties.
function popupmenu6_CreateFcn(hObject, eventdata, handles)
% hObject handle to popupmenu6 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on selection change in popupmenu7.
function popupmenu7_Callback(hObject, eventdata, handles)
% hObject handle to popupmenu7 (see GCBO)

```

```

% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns popupmenu7 contents as cell array
%       contents{get(hObject,'Value')} returns selected item from popupmenu7

% --- Executes during object creation, after setting all properties.
function popupmenu7_CreateFcn(hObject, eventdata, handles)
% hObject handle to popupmenu7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function model_rand_value_Callback(hObject, eventdata, handles)
% hObject handle to model_rand_value (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of model_rand_value as text
%       str2double(get(hObject,'String')) returns contents of model_rand_value as a double

handles.model.structure.weight_init.random.range_value = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function model_rand_value_CreateFcn(hObject, eventdata, handles)
% hObject handle to model_rand_value (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit21_Callback(hObject, eventdata, handles)
% hObject handle to edit21 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit21 as text
%       str2double(get(hObject,'String')) returns contents of edit21 as a double

```

```

% --- Executes during object creation, after setting all properties.
function edit21_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit21 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit22_Callback(hObject, eventdata, handles)
% hObject    handle to edit22 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit22 as text
%       str2double(get(hObject,'String')) returns contents of edit22 as a double

% --- Executes during object creation, after setting all properties.
function edit22_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit22 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function model_nw_ym_lower_Callback(hObject, eventdata, handles)
% hObject    handle to model_nw_ym_lower (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of model_nw_ym_lower as text
%       str2double(get(hObject,'String')) returns contents of model_nw_ym_lower as a double

handles.model.structure.weight_init.nw.ym_lower = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function model_nw_ym_lower_CreateFcn(hObject, eventdata, handles)
% hObject    handle to model_nw_ym_lower (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB

```

```

% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function model_nw_u_upper_Callback(hObject, eventdata, handles)
% hObject    handle to model_nw_u_upper (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of model_nw_u_upper as text
%    str2double(get(hObject,'String')) returns contents of model_nw_u_upper as a double

handles.model.structure.weight_init.nw.u_upper = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function model_nw_u_upper_CreateFcn(hObject, eventdata, handles)
% hObject    handle to model_nw_u_upper (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function model_nw_yp_upper_Callback(hObject, eventdata, handles)
% hObject    handle to model_nw_yp_upper (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of model_nw_yp_upper as text
%    str2double(get(hObject,'String')) returns contents of model_nw_yp_upper as a double

handles.model.structure.weight_init.nw.yp_upper = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function model_nw_yp_upper_CreateFcn(hObject, eventdata, handles)
% hObject    handle to model_nw_yp_upper (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

```

```

% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function model_nw_ym_upper_Callback(hObject, eventdata, handles)
% hObject handle to model_nw_ym_upper (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of model_nw_ym_upper as text
% str2double(get(hObject,'String')) returns contents of model_nw_ym_upper as a double

handles.model.structure.weight_init.nw.ym_upper = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function model_nw_ym_upper_CreateFcn(hObject, eventdata, handles)
% hObject handle to model_nw_ym_upper (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

% --- Executes on button press in checkbox5.
function checkbox5_Callback(hObject, eventdata, handles)
% hObject handle to checkbox5 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

```

```

% Hint: get(hObject,'Value') returns toggle state of checkbox5

```

```

function edit27_Callback(hObject, eventdata, handles)
% hObject handle to edit27 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit27 as text
% str2double(get(hObject,'String')) returns contents of edit27 as a double

```

```

% --- Executes during object creation, after setting all properties.
function edit27_CreateFcn(hObject, eventdata, handles)
% hObject handle to edit27 (see GCBO)

```

```

% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on selection change in popupmenu8.
function popupmenu8_Callback(hObject, eventdata, handles)
% hObject handle to popupmenu8 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns popupmenu8 contents as cell array
% contents {get(hObject,'Value')} returns selected item from popupmenu8

% --- Executes during object creation, after setting all properties.
function popupmenu8_CreateFcn(hObject, eventdata, handles)
% hObject handle to popupmenu8 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit28_Callback(hObject, eventdata, handles)
% hObject handle to edit28 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit28 as text
% str2double(get(hObject,'String')) returns contents of edit28 as a double

% --- Executes during object creation, after setting all properties.
function edit28_CreateFcn(hObject, eventdata, handles)
% hObject handle to edit28 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

% --- Executes on selection change in layer.
function layer_Callback(hObject, eventdata, handles)
% hObject    handle to layer (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns layer contents as cell array
%        contents{get(hObject,'Value')} returns selected item from layer

val = get(hObject,'Value');
handles.model.structure.layer = val;
if val == handles.model.structure.num_layers
    handles.model.structure.layersize.layer(val) = 1;
end

% update screen
set(handles.layer_size,'String',num2str(handles.model.structure.layersize.layer(val)));
set(handles.bias,'String',num2str(handles.model.structure.bias.layer(val)));
set(handles.transfer_function,'Value',handles.model.structure.transfcn.layer(val));

set(handles.save_model,'Enable','off'); % disable save Model button until Network created

guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function layer_CreateFcn(hObject, eventdata, handles)
% hObject    handle to layer (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

% Hint: popupmenu controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit29_Callback(hObject, eventdata, handles)
% hObject    handle to edit29 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit29 as text
%        str2double(get(hObject,'String')) returns contents of edit29 as a double

% --- Executes during object creation, after setting all properties.
function edit29_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit29 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.

```

```

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on button press in pushbutton6.
function pushbutton6_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton6 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% --- Executes on button press in pushbutton7.
function pushbutton7_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% --- Executes on button press in checkbox6.
function checkbox6_Callback(hObject, eventdata, handles)
% hObject    handle to checkbox6 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hint: get(hObject,'Value') returns toggle state of checkbox6

function min_u_Callback(hObject, eventdata, handles)
% hObject    handle to min_u (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of min_u as text
%        str2double(get(hObject,'String')) returns contents of min_u as a double

handles.model.structure.input_type.scaling.u_min = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function min_u_CreateFcn(hObject, eventdata, handles)
% hObject    handle to min_u (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%        See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```



```

function max_u_Callback(hObject, eventdata, handles)
% hObject   handle to max_u (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of max_u as text
%        str2double(get(hObject,'String')) returns contents of max_u as a double

handles.model.structure.input_type.scaling.u_max = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function max_u_CreateFcn(hObject, eventdata, handles)
% hObject   handle to max_u (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on button press in checkbox7.
function checkbox7_Callback(hObject, eventdata, handles)
% hObject   handle to checkbox7 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hint: get(hObject,'Value') returns toggle state of checkbox7


function min_yp_Callback(hObject, eventdata, handles)
% hObject   handle to min_yp (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of min_yp as text
%        str2double(get(hObject,'String')) returns contents of min_yp as a double

handles.model.structure.input_type.scaling.yp_min = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function min_yp_CreateFcn(hObject, eventdata, handles)
% hObject   handle to min_yp (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFns called

```

```

% Hint: edit controls usually have a white background on Windows.
%     See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit33_Callback(hObject, eventdata, handles)
% hObject    handle to edit33 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit33 as text
%        str2double(get(hObject,'String')) returns contents of edit33 as a double

```

```

% --- Executes during object creation, after setting all properties.
function edit33_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit33 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

```

```

% Hint: edit controls usually have a white background on Windows.
%     See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

% --- Executes on button press in scale_ym.
function scale_ym_Callback(hObject, eventdata, handles)
% hObject    handle to scale_ym (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

```

```

% Hint: get(hObject,'Value') returns toggle state of scale_ym

```

```

handles.model.structure.input_type.scaling.scale_ym = get(hObject,'Value');

```

```

handles.output = hObject;
guidata(hObject, handles);

```

```

function min_ym_Callback(hObject, eventdata, handles)
% hObject    handle to min_ym (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

```

```

% Hints: get(hObject,'String') returns contents of min_ym as text
%        str2double(get(hObject,'String')) returns contents of min_ym as a double

```

```

handles.model.structure.input_type.scaling.ym_min = str2double(get(hObject,'String'));

```

```

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes during object creation, after setting all properties.
function min_ym_CreateFcn(hObject, eventdata, handles)
% hObject    handle to min_ym (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit35_Callback(hObject, eventdata, handles)
% hObject    handle to edit35 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit35 as text
%        str2double(get(hObject,'String')) returns contents of edit35 as a double

% --- Executes during object creation, after setting all properties.
function edit35_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit35 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on selection change in popupmenu10.
function popupmenu10_Callback(hObject, eventdata, handles)
% hObject    handle to popupmenu10 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns popupmenu10 contents as cell array
%        contents{get(hObject,'Value')} returns selected item from popupmenu10

% --- Executes during object creation, after setting all properties.
function popupmenu10_CreateFcn(hObject, eventdata, handles)
% hObject    handle to popupmenu10 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))

```

```

    set(hObject,'BackgroundColor','white');
end

```

```

function edit36_Callback(hObject, eventdata, handles)
% hObject    handle to edit36 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit36 as text
%        str2double(get(hObject,'String')) returns contents of edit36 as a double

```

```

% --- Executes during object creation, after setting all properties.
function edit36_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit36 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit37_Callback(hObject, eventdata, handles)
% hObject    handle to edit37 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit37 as text
%        str2double(get(hObject,'String')) returns contents of edit37 as a double

```

```

% --- Executes during object creation, after setting all properties.
function edit37_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit37 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit38_Callback(hObject, eventdata, handles)
% hObject    handle to edit38 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

```

```

% Hints: get(hObject,'String') returns contents of edit38 as text
%      str2double(get(hObject,'String')) returns contents of edit38 as a double


% --- Executes during object creation, after setting all properties.
function edit38_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit38 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFns called


% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


% --- Executes on button press in save_model.
function save_model_Callback(hObject, eventdata, handles)
% hObject    handle to save_model (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

model = handles.model;

%setup_model;
%initialize_model_weights; % initializes weights

save model model;
handles.model = model;

uisave('model','model');

guidata(hObject, handles);


% --- Executes on button press in pushbutton9.
function pushbutton9_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton9 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)


% --- Executes on button press in new_model.
function new_model_Callback(hObject, eventdata, handles)
% hObject    handle to new_model (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

model = handles.model;
setup_model;
%initialize_model_weights; % initializes weights

save model model;
handles.model = model;
guidata(hObject, handles);

```

```

% --- Executes on button press in load_model_NN.
function load_model_NN_Callback(hObject, eventdata, handles)
% hObject    handle to load_model_NN (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

[filename, pathname, filterindex] = uigetfile('*.mat', 'Pick your model file');
load(filename);
update_GUI_model; % shows loaded settings on screen
handles.model = model;
save model model;
guidata(hObject, handles);

function num_layers_Callback(hObject, eventdata, handles)
% hObject    handle to num_layers (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of num_layers as text
%        str2double(get(hObject,'String')) returns contents of num_layers as a double

val = str2double(get(hObject,'String')); % val = number of layers in the network

% limit number of layers >= 2
if val <= 1
    set(handles.num_layers,'String','2');
end

% Store number of layers and setup layer pull down menu
set(handles.layer,'Value',1);
handles.model.structure.num_layers = val;
val2 = {};
for r = 1:val
    val2{r,1} = num2str(r);
end
set(handles.layer,'String',val2);

% Set layer size, bias, and transfer function if not already done (for each layer)
for r = 1:val
    if r <= length(handles.model.structure.layersize.layer) % test if value already stored
        set(handles.layer_size,'String',num2str(handles.model.structure.layersize.layer(r)));
    else
        handles.model.structure.layersize.layer(r) = 1; % default = 1
    end
    if r <= length(handles.model.structure.transfcn.layer)
        set(handles.transfer_function,'Value',handles.model.structure.transfcn.layer(r));
    else
        handles.model.structure.transfcn.layer(r) = 1; % default = 1
    end
    if r <= length(handles.model.structure.bias.layer)
        set(handles.bias,'String',num2str(handles.model.structure.bias.layer(r)));
    else
        handles.model.structure.bias.layer(r) = 1; % default = 1
    end
end

```

```

        end
    end

    set(handles.save_model,'Enable','off'); % disable save Model button until Network created

    handles.model.structure.layersize.layer(val) = 1;
    guidata(hObject, handles);

function layer_size_Callback(hObject, eventdata, handles)
% hObject    handle to layer_size (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of layer_size as text
%        str2double(get(hObject,'String')) returns contents of layer_size as a double

val = get(handles.layer,'Value');
if val == handles.model.structure.num_layers
    handles.model.structure.layersize.layer(val) = 1;
else
    handles.model.structure.layersize.layer(val) = str2double(get(hObject,'String'));
end
set(handles.layer_size,'String',num2str(handles.model.structure.layersize.layer(val)));

set(handles.save_model,'Enable','off'); % disable save Model button until Network created

guidata(hObject, handles);

function bias_Callback(hObject, eventdata, handles)
% hObject    handle to bias (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of bias as text
%        str2double(get(hObject,'String')) returns contents of bias as a double

val = get(handles.layer,'Value');
handles.model.structure.bias.layer(val) = str2double(get(hObject,'String'));

set(handles.save_model,'Enable','off'); % disable save Model button until Network created

guidata(hObject, handles);

% --- Executes on selection change in transfer_function.
function transfer_function_Callback(hObject, eventdata, handles)
% hObject    handle to transfer_function (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB

```

```

% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns transfer_function contents as cell array
%        contents{get(hObject,'Value')} returns selected item from transfer_function

val = get(handles.layer,'Value');
handles.model.structure.transfcn.layer(val) = get(hObject,'Value');

set(handles.save_model,'Enable','off'); % disable save Model button until Network created

guidata(hObject, handles);

% --- Executes on selection change in model_inputs.
function model_inputs_Callback(hObject, eventdata, handles)
% hObject    handle to model_inputs (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns model_inputs contents as cell array
%        contents{get(hObject,'Value')} returns selected item from model_inputs

val = get(hObject,'Value');
handles.model.structure.input_type.type = val;

switch(val)
case 1
    handles.model.structure.num_inputs = 1;
    handles.model.structure.NN_Type = 'FTDNN';
case 2
    handles.model.structure.num_inputs = 2;
    handles.model.structure.NN_Type = 'NARX';
case 3
    handles.model.structure.num_inputs = 2;
    handles.model.structure.NN_Type = 'NARXSP';
otherwise
end

set(handles.save_model,'Enable','off'); % disable save Model button until Network created

handles.output = hObject;
guidata(hObject, handles);

function model_u_delays_Callback(hObject, eventdata, handles)
% hObject    handle to model_u_delays (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of model_u_delays as text
%        str2double(get(hObject,'String')) returns contents of model_u_delays as a double

handles.model.structure.input_type.udelays = str2double(get(hObject,'String'));

set(handles.save_model,'Enable','off'); % disable save Model button until Network created

```



```
handles.output = hObject;
guidata(hObject, handles);
```

```
function model_yp_delays_Callback(hObject, eventdata, handles)
% hObject    handle to model_yp_delays (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of model_yp_delays as text
%        str2double(get(hObject,'String')) returns contents of model_yp_delays as a double

handles.model.structure.input_type.ypdelay = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);
```

```
function model_ym_delays_Callback(hObject, eventdata, handles)
% hObject    handle to model_ym_delays (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of model_ym_delays as text
%        str2double(get(hObject,'String')) returns contents of model_ym_delays as a double

handles.model.structure.input_type.ymdelay = str2double(get(hObject,'String'));

set(handles.save_model,'Enable','off'); % disable save Model button until Network created

handles.output = hObject;
guidata(hObject, handles);
```

```
% --- Executes on button press in scale_u.
function scale_u_Callback(hObject, eventdata, handles)
% hObject    handle to scale_u (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hint: get(hObject,'Value') returns toggle state of scale_u

handles.model.structure.input_type.scaling.scale_u = get(hObject,'Value');

handles.output = hObject;
guidata(hObject, handles);
```

```
% --- Executes on button press in scale_yp.
function scale_yp_Callback(hObject, eventdata, handles)
```

```

% hObject    handle to scale_yp (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hint: get(hObject,'Value') returns toggle state of scale_yp

handles.model.structure.input_type.scaling.scale_yp = get(hObject,'Value');

handles.output = hObject;
guidata(hObject, handles);

```

```

function max_yp_Callback(hObject, eventdata, handles)
% hObject    handle to max_yp (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of max_yp as text
%        str2double(get(hObject,'String')) returns contents of max_yp as a double

handles.model.structure.input_type.scaling.yp_max = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

function max_ym_Callback(hObject, eventdata, handles)
% hObject    handle to max_ym (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of max_ym as text
%        str2double(get(hObject,'String')) returns contents of max_ym as a double

handles.model.structure.input_type.scaling.ym_max = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

```

```

% --- Executes on selection change in model_weight_init_method.
function model_weight_init_method_Callback(hObject, eventdata, handles)
% hObject    handle to model_weight_init_method (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns model_weight_init_method contents as cell array
%        contents{get(hObject,'Value')} returns selected item from model_weight_init_method

handles.model.structure.weight_init.method = get(hObject,'Value');

```

```
handles.output = hObject;  
guidata(hObject, handles);
```

```
% --- Executes on button press in model_init_weights.  
function model_init_weights_Callback(hObject, eventdata, handles)  
% hObject    handle to model_init_weights (see GCBO)  
% eventdata  reserved - to be defined in a future version of MATLAB  
% handles    structure with handles and user data (see GUIDATA)
```

```
% Hint: get(hObject,'Value') returns toggle state of model_init_weights
```

```
handles.model.structure.weight_init.initialize = get(hObject,'Value');
```

```
handles.output = hObject;  
guidata(hObject, handles);
```

```
% --- Executes on selection change in model_rand_weight_type.  
function model_rand_weight_type_Callback(hObject, eventdata, handles)  
% hObject    handle to model_rand_weight_type (see GCBO)  
% eventdata  reserved - to be defined in a future version of MATLAB  
% handles    structure with handles and user data (see GUIDATA)
```

```
% Hints: contents = get(hObject,'String') returns model_rand_weight_type contents as cell array  
%        contents{get(hObject,'Value')} returns selected item from model_rand_weight_type
```

```
handles.model.structure.weight_init.random.range = get(hObject,'Value');
```

```
handles.output = hObject;  
guidata(hObject, handles);
```

```
function model_nw_u_lower_Callback(hObject, eventdata, handles)  
% hObject    handle to model_nw_u_lower (see GCBO)  
% eventdata  reserved - to be defined in a future version of MATLAB  
% handles    structure with handles and user data (see GUIDATA)
```

```
% Hints: get(hObject,'String') returns contents of model_nw_u_lower as text  
%        str2double(get(hObject,'String')) returns contents of model_nw_u_lower as a double
```

```
handles.model.structure.weight_init.nw.u_lower = str2double(get(hObject,'String'));
```

```
handles.output = hObject;  
guidata(hObject, handles);
```

```
function model_nw_yp_lower_Callback(hObject, eventdata, handles)  
% hObject    handle to model_nw_yp_lower (see GCBO)
```

```

% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of model_nw_yp_lower as text
% str2double(get(hObject,'String')) returns contents of model_nw_yp_lower as a double

handles.model.structure.weight_init.nw.yp_lower = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes on button press in train_offline.
function train_offline_Callback(hObject, eventdata, handles)
% hObject handle to train_offline (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

model = handles.model;
save model model;

GUI_model_offline_training;

load model;

handles.model = model;

guidata(hObject, handles);

% --- Executes on button press in online_training_setup.
function online_training_setup_Callback(hObject, eventdata, handles)
% hObject handle to online_training_setup (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

model = handles.model;
save model model;
GUI_model_online_training;

load model;
handles.model = model;

handles.output = hObject;
guidata(hObject, handles);

% --- Executes when user attempts to close figure1.
function figure1_CloseRequestFcn(hObject, eventdata, handles)
% hObject handle to figure1 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

```

```

% model = handles.model;
% save model model;
%
% uiresume(handles.figure1);
%
% % Hint: delete(hObject) closes the figure
% delete(hObject);

% --- Executes on button press in ok_button.
function ok_button_Callback(hObject, eventdata, handles)
% hObject    handle to ok_button (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

model = handles.model;
%setup_model;
%initialize_model_weights; % initializes weights

save model model;
handles.model = model;

uiresume(handles.figure1);

% --- Executes on button press in Initialize_Weights.
function Initialize_Weights_Callback(hObject, eventdata, handles)
% hObject    handle to Initialize_Weights (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

model = handles.model;
save model model;

setup_model;

load model;

handles.model = model;

set(handles.save_model,'Enable','on') % Enable Save model button

handles.output = hObject;
guidata(hObject, handles);

% --- Executes on button press in Import_Training_Set.
function Import_Training_Set_Callback(hObject, eventdata, handles)
% hObject    handle to Import_Training_Set (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

[filename, pathname, filterindex] = uigetfile('*.*xlsx', 'Choose Excel 2007 file containing training set');

```

```

if filename ~= 0
    S = strcat(pathname, filename);
    handles.training_values.offline.model.training_set = xlsread(S);
    training_values = handles.training_values;
    save training_values training_values;
end

handles.output = hObject;
guidata(hObject, handles);

% --- Executes on button press in Train.
function Train_Callback(hObject, eventdata, handles)
% hObject    handle to Train (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

model = handles.model;
net = model.NN;

% Setup Levenberg Marquardt Training parameters
net.trainParam.mu = model.training_setup.offline.Levenberg_Marquardt.mu;
net.trainParam.mu_dec = model.training_setup.offline.Levenberg_Marquardt.mu_dec;
net.trainParam.mu_inc = model.training_setup.offline.Levenberg_Marquardt.mu_inc;
net.trainParam.mu_max = model.training_setup.offline.Levenberg_Marquardt.mu_max;
net.trainParam.epochs = model.training_setup.offline.Levenberg_Marquardt.epochs;
net.trainParam.show = model.training_setup.offline.Levenberg_Marquardt.plot_epochs;
net.trainParam.showWindow = 1;

% Get input and target ready
load training_values;
input = training_values.offline.model.training_set(:,1)';
input = con2seq(input); % convert to cell array
target = training_values.offline.model.training_set(:,2)';
target = con2seq(target); % convert to cell array
PT = [input;target];

%model.input = input;
%model.target = target;

switch(model.structure.NN_Type)
case 'FTDNN'
    [net,tr] = train(net,input,target);
case 'NARX'
    [net,tr] = train(net,input,target);
case 'NARXSP'
    [net,tr] = train(net,PT,target);
end

epoch = tr.epoch;
perf = tr.perf;

%plotperform(tr);
%nntraintool;

```

```

%Plot Network Output
%switch(model.structure.NN_Type)
% case 'FTDNN'
%     Y = sim(net,input);
% case 'NARX'
%     Y = sim(net,input);
% case 'NARXSP'
%     Y = sim(net,PT);
%end

%X = [1:length(input)];
%Y = seq2con(Y);
%target = seq2con(target);
%input = seq2con(input);
figure;
h = gca;
set(h,'FontWeight','bold','FontSize',16);
plot(epoch,perf,'LineWidth',2);
%plot(input{1},Y{1},'bo-',input{1},target{1},'gx--');
%legend('Network Output','Target','EastOutside');
title(['Performance';['(Final MSE = ',num2str(perf(end)),')']],'FontWeight','bold','FontSize',16);
xlabel('epoch','FontWeight','bold','FontSize',16);
ylabel('MSE (mean squared error)','FontWeight','bold','FontSize',16);

%Save Network

model.NN = net;
handles.model = model;
save model model;

handles.output = hObject;
guidata(hObject, handles);
% --

% --- Executes during object creation, after setting all properties.
function text58_CreateFcn(hObject, eventdata, handles)
% hObject    handle to text58 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% --- Executes during object creation, after setting all properties.
function train_offline_CreateFcn(hObject, eventdata, handles)
% hObject    handle to train_offline (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% --- Executes on button press in Simulate.
function Simulate_Callback(hObject, eventdata, handles)
% hObject    handle to Simulate (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

load training_values;

```

```

load model;

input = training_values.offline.model.training_set(:,1)';
input = con2seq(input); % convert to cell array
target = training_values.offline.model.training_set(:,2)';
target = con2seq(target); % convert to cell array
PT = [input;target];
fs = 2500; % sampling frequency in Hz

time = [1:length(input)];
time = time/fs; % convert to time (seconds)

net = model.NN;

switch(model.structure.NN_Type)
case 'FTDNN'
    Y = sim(net,input);
case 'NARX'
    Y = sim(net,input);
case 'NARXSP'
    Y = sim(net,PT); % PT = [input;target]
end

model.NN.IW{1,1} % print some weights

% Calculate mse (mean squared error)
e_squared = 0;
for i = 1:length(Y)
    e_squared = e_squared + (target{i} - Y{i})^2;
end
mse = e_squared/length(Y);

% Calculate root mean square deviation
rmsd = sqrt(mse);

% Calculate Root Mean Square (RMS) of Target
rms = 0;
for i = 1:length(target)
    rms = rms + (target{i})^2;
end
rms = rms/length(target);
rms = sqrt(rms);

% Calculate error = Root mean squared error / RMS target * 100%
error = rmsd/rms*100;

Y = seq2con(Y);
target = seq2con(target);
input = seq2con(input);
model.Simulation.Output = Y{1}; % store simulation results

% Calculate R squared value
r = corr(target{1}',Y{1}');

```



```

r_squared = r^2;

% Plot Simulation Results

if handles.holdPlot == 0
    figure;
end

subplot(2,1,1), plot(time,input{1});
h = gca;
set(h, 'FontWeight','bold','FontSize',16);
title(['Plant / Model Input'];['(Sampling Frequency fs = ',num2str(fs),'
Hz)'],'FontWeight','bold','FontSize',16);
xlabel('Time (seconds)');
ylabel('Voltage (volts)');

subplot(2,1,2), plot(time,Y{1},'b-',time,target{1},'g--','LineWidth',2);
legend('Network Output','Target','EastOutside','FontSize',16);
xlabel('Time (seconds)','FontWeight','bold','FontSize',16);
ylabel('Rate (rad/s)','FontWeight','bold','FontSize',16);
title(['Neural Network Output & Plant Output (Target)']; ['( MSE = ',num2str(mse),' Error =
',num2str(error),'%', ' R-Squared = ',num2str(r_squared),' )'],'FontWeight','bold','FontSize',16);
h = gca;
set(h, 'FontWeight','bold','FontSize',16);

% Place Figure on Hold for comparison purposes if desired

if handles.holdPlot == 1
    hold on;
else
    hold off;
end

% save model parameters
handles.model = model;
save model model;

handles.output = hObject;
guidata(hObject, handles);

% --- Executes on button press in Plot_Training_Set.
function Plot_Training_Set_Callback(hObject, eventdata, handles)
% hObject    handle to Plot_Training_Set (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

load training_values;

input = training_values.offline.model.training_set(:,1);
target = training_values.offline.model.training_set(:,2);

figure;
h = gca;
plot(input,target,'b-');

```

```

xlabel('Model Input','FontWeight','bold','FontSize',16);
ylabel('Model Target','FontWeight','bold','FontSize',16);
title('Plant Response','FontWeight','bold','FontSize',16);
set(h, 'FontWeight','bold','FontSize',16);

% --- Executes on button press in InputTargetPlotButton.
function InputTargetPlotButton_Callback(hObject, eventdata, handles)
% hObject    handle to InputTargetPlotButton (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

load training_values;

fs = 2500; % Sampling Frequency (Hz)
input = training_values.offline.model.training_set(:,1);
target = training_values.offline.model.training_set(:,2);
X = [1:length(input)];
time = X/fs;

figure;
h = gca;
plot(time,input,'b-',time,target,'g--','LineWidth',2);
legend('Plant Input','Plant Output','EastOutside','FontSize',16);
xlabel('Time (seconds)','FontWeight','bold','FontSize',16);
ylabel('Input: Voltage (volts)   Output: Rate (rad/sec)','FontWeight','bold','FontSize',16);
title('Plant Response','FontWeight','bold','FontSize',16);
set(h, 'FontWeight','bold','FontSize',16);

% --- Executes on button press in pushButtonFrequencyResponse.
function pushButtonFrequencyResponse_Callback(hObject, eventdata, handles)
% hObject    handle to pushButtonFrequencyResponse (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

load training_values;

input = training_values.offline.model.training_set(:,1);
target = training_values.offline.model.training_set(:,2);
X = [1:length(input)];
fs = 2500; % sampling frequency

% Compute the Frequency Domain Signal for the input
NFFT = 2^nextpow2(fs); % Next power of 2 from length of y
Y = fft(input,NFFT)/fs;
f = fs/2*linspace(0,1,NFFT/2+1);

% Plot the single-sided Frequency amplitude spectrum.
figure;

```

```

h = gca;
%set(h,'OuterPosition',[200,200,500,500]);
plot(f,2*abs(Y(1:NFFT/2+1)))
xlabel('Frequency (Hz)','FontWeight','bold','FontSize',16)
ylabel('|Mag|','FontWeight','bold','FontSize',16)
title('Input Signal: Single-Sided Amplitude Spectrum','FontWeight','bold','FontSize',16);
set(h, 'FontWeight','bold','FontSize',16);

% Compute the Frequency Domain Signal for the input
NFFT = 2^nextpow2(fs); % Next power of 2 from length of y
Y = fft(target,NFFT)/fs;
f = fs/2*linspace(0,1,NFFT/2+1);

% Plot the single-sided Frequency amplitude spectrum.
figure;
h = gca;
plot(f,2*abs(Y(1:NFFT/2+1)))
xlabel('Frequency (Hz)','FontWeight','bold','FontSize',16)
ylabel('|Mag|','FontWeight','bold','FontSize',16)
title('Target Signal: Single-Sided Amplitude Spectrum','FontWeight','bold','FontSize',16);
set(h, 'FontWeight','bold','FontSize',16);

% --- Executes on button press in PlotFreqResponsebutton.
function PlotFreqResponsebutton_Callback(hObject, eventdata, handles)
% hObject    handle to PlotFreqResponsebutton (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

model = handles.model;
save model model;

Plot_Frequency_Response;

% --- Executes on button press in Holdbutton.
function Holdbutton_Callback(hObject, eventdata, handles)
% hObject    handle to Holdbutton (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

holdPlot = handles.holdPlot;

if holdPlot == 0
    holdPlot = 1;
    set(handles.Holdbutton,'String','Hold On');
else
    holdPlot = 0;
    set(handles.Holdbutton,'String','Hold Off');
end

```

```
handles.holdPlot = holdPlot;
```

```
handles.output = hObject;  
guidata(hObject, handles);
```

Initialize GUI Model:

File: initialize_GUI_model.m

Description: Initialize model settings and structure.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
% structure  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
  
model.structure.NN_Type = 'FTDNN';  
model.structure.num_inputs = 2;  
model.structure.num_layers = 2;  
model.structure.layersize.layer(1) = 1;  
model.structure.layersize.layer(2) = 1;  
model.structure.transfcn.layer(1) = 3;  
model.structure.transfcn.layer(2) = 1;  
model.structure.bias.layer(1) = 0;  
model.structure.bias.layer(2) = 0;  
model.structure.input_type.type = 2;  
model.structure.input_type.udelays = 0;  
model.structure.input_type.yodelays = 0;  
model.structure.input_type.ymdelays = 0;  
model.structure.input_type.scaling.scale_u = 0;  
model.structure.input_type.scaling.scale_yp = 0;  
model.structure.input_type.scaling.scale_ym = 0;  
model.structure.input_type.scaling.u_min = 0;  
model.structure.input_type.scaling.u_max = 0;  
model.structure.input_type.scaling.yp_min = 0;  
model.structure.input_type.scaling.yp_max = 0;  
model.structure.input_type.scaling.ym_min = 0;  
model.structure.input_type.scaling.ym_max = 0;  
  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
% weight_init  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
  
model.structure.weight_init.method = 1;  
model.structure.weight_init.initialize = 1;  
model.structure.weight_init.random.range = 2;  
model.structure.weight_init.random.range_value = 1;  
model.structure.weight_init.nw.u_lower = 0;  
model.structure.weight_init.nw.u_upper = 0;  
model.structure.weight_init.nw.yp_lower = 0;  
model.structure.weight_init.nw.yp_upper = 0;  
model.structure.weight_init.nw.ym_lower = 0;  
model.structure.weight_init.nw.ym_upper = 0;  
  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
% initialize GUI model offline training variables
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

% Levenberg Marquardt

```
model.training_setup.offline.Levenberg_Marquardt.mu = .001;
model.training_setup.offline.Levenberg_Marquardt.mu_dec = .1;
model.training_setup.offline.Levenberg_Marquardt.mu_inc = 10;
model.training_setup.offline.Levenberg_Marquardt.mu_max = 1e10;
model.training_setup.offline.Levenberg_Marquardt.epochs = 100; % epochs
model.training_setup.offline.Levenberg_Marquardt.plot_epochs = 5; % plot every one epoch
```

% offline input

% General settings

```
model.training_setup.offline.input_setup.type = 1;
model.training_setup.offline.input_setup.samp_freq = 1;
model.training_setup.offline.input_setup.SMSF.num_samples = 0;
model.training_setup.offline.input_setup.signal = 0;
```

% SMSF settings

```
model.training_setup.offline.input_setup.SMSF.amplitude = 0;
model.training_setup.offline.input_setup.SMSF.num_freq = 1;
model.training_setup.offline.input_setup.SMSF.freq(1) = 0;
model.training_setup.offline.input_setup.SMSF.freq(2) = 0;
model.training_setup.offline.input_setup.SMSF.freq(3) = 0;
model.training_setup.offline.input_setup.SMSF.freq(4) = 0;
model.training_setup.offline.input_setup.SMSF.freq(5) = 0;
model.training_setup.offline.input_setup.SMSF.freq(6) = 0;
```

% SMSF_w_MFE settings

```
model.training_setup.offline.input_setup.SMSF_w_MFE.single_freq.num_freq = 1;
model.training_setup.offline.input_setup.SMSF_w_MFE.single_freq.num_samples = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.single_freq.amplitude = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.single_freq.freq(1) = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.single_freq.freq(2) = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.single_freq.freq(3) = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.single_freq.freq(4) = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.single_freq.freq(5) = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.single_freq.freq(6) = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.mult_freq.num_freq = 1;
model.training_setup.offline.input_setup.SMSF_w_MFE.mult_freq.num_samples = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.mult_freq.amplitude = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.mult_freq.freq(1) = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.mult_freq.freq(2) = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.mult_freq.freq(3) = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.mult_freq.freq(4) = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.mult_freq.freq(5) = 0;
model.training_setup.offline.input_setup.SMSF_w_MFE.mult_freq.freq(6) = 0;
```

% MFW settings

```
model.training_setup.offline.input_setup.MFW.num_samples = 0;
model.training_setup.offline.input_setup.MFW.amplitude = 0;
model.training_setup.offline.input_setup.MFW.num_freq = 1;
model.training_setup.offline.input_setup.MFW.freq(1) = 0;
```

```

model.training_setup.offline.input_setup.MFW.freq(2) = 0;
model.training_setup.offline.input_setup.MFW.freq(3) = 0;
model.training_setup.offline.input_setup.MFW.freq(4) = 0;
model.training_setup.offline.input_setup.MFW.freq(5) = 0;
model.training_setup.offline.input_setup.MFW.freq(6) = 0;

```

% chirp settings

```

model.training_setup.offline.input_setup.chirp.amplitude = 0;
model.training_setup.offline.input_setup.chirp.time = 0;

```

% NSCRS settings

```

model.training_setup.offline.input_setup.NSCRS.num_samples = 0;
model.training_setup.offline.input_setup.NSCRS.min_amp = 0;
model.training_setup.offline.input_setup.NSCRS.max_amp = 0;
model.training_setup.offline.input_setup.NSCRS.interval = 0;

```

% RSLC settings

```

model.training_setup.offline.input_setup.RSLC.num_samples = 0;
model.training_setup.offline.input_setup.RSLC.min_amp = 0;
model.training_setup.offline.input_setup.RSLC.max_amp = 0;
model.training_setup.offline.input_setup.RSLC.min_interval = 0;
model.training_setup.offline.input_setup.RSLC.max_interval = 0;

```

%RSLC_w_DAS settings

```

model.training_setup.offline.input_setup.RSLC_w_DAS.num_segments = 1;
model.training_setup.offline.input_setup.RSLC_w_DAS.min_interval = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.max_interval = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.seg(1).min_amp = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.seg(2).min_amp = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.seg(3).min_amp = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.seg(4).min_amp = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.seg(1).max_amp = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.seg(2).max_amp = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.seg(3).max_amp = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.seg(4).max_amp = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.seg(1).num_samples = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.seg(2).num_samples = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.seg(3).num_samples = 0;
model.training_setup.offline.input_setup.RSLC_w_DAS.seg(4).num_samples = 0;

```

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

% Initialize GUI_model_online_training variables

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

% General

```

model.training_setup.online.algorithm = 1;
model.training_setup.online.calc_cont_error = 1;

```

% BPM

```

model.training_setup.online.BPM.learning_rate.layer(1) = 0;

```

```

model.training_setup.online.BPM.learning_rate.layer(2) = 0;
model.training_setup.online.BPM.momentum_factor.layer(1) = 0;
model.training_setup.online.BPM.momentum_factor.layer(2) = 0;

% RP
model.training_setup.online.RP.init_wt_change = 0;
model.training_setup.online.RP.max_wt_change = 0;
model.training_setup.online.RP.inc_wt_change = 0;
model.training_setup.online.RP.dec_wt_change = 0;

% LRLS
model.training_setup.online.LRLS.forget_factor = 0;
model.training_setup.online.LRLS.A.layer(1) = 0;
model.training_setup.online.LRLS.A.layer(2) = 0;

% IGLS
model.training_setup.online.IGLS.forget_factor = 0;
model.training_setup.online.IGLS.A.layer(1) = 0;
model.training_setup.online.IGLS.learning_rate.layer(2) = 0;
model.training_setup.online.IGLS.momentum_factor.layer(2) = 0;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Initialize GUI model Simulation Results
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

model.Simulation.Output = 0;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Initialize GUI model Plotting Variables
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

model.Plotting.Freq.DataType = 1;
model.Plotting.Freq.StartFreq = 1;
model.Plotting.Freq.EndFreq = 1250;

```


Update GUI model:

File: update_GUI_model.m

Description: Update GUI model variables

```
% structure
val = {};
for r = 1:model.structure.num_layers
    val{r,1} = num2str(r);
end
set(handles.layer,'String',val); set(handles.layer,'Value',1);
set(handles.layer_size,'String',num2str(model.structure.layersize.layer(1)));
set(handles.bias,'String',num2str(model.structure.bias.layer(1)));
set(handles.transfer_function,'Value',model.structure.transfcn.layer(1));

set(handles.num_layers,'String',num2str(model.structure.num_layers));
set(handles.model_inputs,'Value',model.structure.input_type.type);
set(handles.model_u_delays,'String',num2str(model.structure.input_type.udelays));
set(handles.model_yp_delays,'String',num2str(model.structure.input_type.ypdelays));
set(handles.model_ym_delays,'String',num2str(model.structure.input_type.ymdelays));
set(handles.scale_u,'Value',model.structure.input_type.scaling.scale_u);
set(handles.scale_yp,'Value',model.structure.input_type.scaling.scale_yp);
set(handles.scale_ym,'Value',model.structure.input_type.scaling.scale_ym);
set(handles.min_u,'String',num2str(model.structure.input_type.scaling.u_min));
set(handles.max_u,'String',num2str(model.structure.input_type.scaling.u_max));
set(handles.min_yp,'String',num2str(model.structure.input_type.scaling.yp_min));
set(handles.max_yp,'String',num2str(model.structure.input_type.scaling.yp_max));
set(handles.min_ym,'String',num2str(model.structure.input_type.scaling.ym_min));
set(handles.max_ym,'String',num2str(model.structure.input_type.scaling.ym_max));

% Weight Initialization
set(handles.model_weight_init_method,'Value',model.structure.weight_init.method);
set(handles.model_init_weights,'Value',model.structure.weight_init.initialize);
set(handles.model_rand_weight_type,'Value',model.structure.weight_init.random.range);
set(handles.model_rand_value,'String',num2str(model.structure.weight_init.random.range_value));
set(handles.model_nw_u_lower,'String',num2str(model.structure.weight_init.nw.u_lower));
set(handles.model_nw_u_upper,'String',num2str(model.structure.weight_init.nw.u_upper));
set(handles.model_nw_yp_lower,'String',num2str(model.structure.weight_init.nw.yp_lower));
set(handles.model_nw_yp_upper,'String',num2str(model.structure.weight_init.nw.yp_upper));
set(handles.model_nw_ym_lower,'String',num2str(model.structure.weight_init.nw.ym_lower));
set(handles.model_nw_ym_upper,'String',num2str(model.structure.weight_init.nw.ym_upper));
```

Setup model:

File: setup_model.m

Description: Creates and Initializes neural network model

% creates model network:

```
net = 0;
```

% load saved input & target training set

```
load training_values;  
load model;  
input = training_values.offline.model.training_set(:,1);  
input = con2seq(input); % convert to cell array  
target = training_values.offline.model.training_set(:,2);  
target = con2seq(target); % convert to cell array
```

% setup transfer function matrix

```
transfer_functions = {};  
for q = 1:model.structure.num_layers  
    switch(model.structure.transfcn.layer(q))  
        case 1  
            transfer_functions{q} = 'purelin';  
        case 2  
            transfer_functions{q} = 'logsig';  
        case 3  
            transfer_functions{q} = 'tansig';  
    end  
end
```

% Setup Layer size matrix

```
layersize = [model.structure.layersize.layer(1)];  
if model.structure.num_layers > 1;  
    for r = 2:model.structure.num_layers - 1 %  
        layersize(r) = model.structure.layersize.layer(r);  
    end  
end
```

% Setup Input Delay vector

```
switch(model.structure.NN_Type)  
    case 'FTDNN'  
        ID = [0:model.structure.input_type.udelays];  
    case 'NARX'  
        ID = [0:model.structure.input_type.udelays];  
    case 'NARXSP'  
        ID = [0:model.structure.input_type.udelays]; % 0 means current time step, 1 means 1 delay (n-1)  
end
```

% Setup Output Delay vector

```
OD = [1:model.structure.input_type.ymdelays];
```

% Create Network

```
switch(model.structure.NN_Type)  
    case 'FTDNN'
```

```

        net = newfftd(input,target,ID,layersize,transfer_functions,'trainlm','learngdm','mse');
    case 'NARX'
        net = newnarx(input,target,ID,OD,layersize,transfer_functions,'trainlm','learngdm','mse');
    case 'NARXSP'
        net = newnarxsp(input,target,ID,OD,layersize,transfer_functions,'trainlm','learngdm','mse');
    end

% Set Number of Inputs
    %net.numinputs = model.structure.num_inputs;

% Input Connect matrix (row = layer, column = input)
    %net.inputConnect = zeros(model.structure.num_layers,model.structure.num_inputs);
    %for q = 1:model.structure.num_inputs
        % net.inputConnect(1,q) = 1; % input q gets connected to layer 1
    %end

% Input Bias connect Matrix & Bias values
    %net.biasConnect = [0];
    %for q = 1:model.structure.num_layers
        % if model.structure.bias.layer(q) ~= 0
        %     net.biasConnect(q,1) = 1;
        %     net.biases{q,1} = model.structure.bias.layer(q);
        % else
        %     net.biasConnect(q) = 0;
        % end
    %end

%

%If net.biasConnect(i) is 1 then the layer i has a bias and
% net.biases{i} is a structure describing that bias.

%model.structure.bias.layer(val)

% Input Weight delays matrix
    %net.inputWeights{1,1}.delays = [0:model.structure.input_type.udelays]; % u
    % switch(model.structure.input_type.type)
    %     case 2 % yp
    %         net.inputWeights{1,2}.delays = [0:model.structure.input_type.ypdelay]; % yp
    %     case 3 % yp,ym
    %         net.inputWeights{1,2}.delays = [0:model.structure.input_type.ypdelay]; % yp
    %         net.inputWeights{1,3}.delays = [0:model.structure.input_type.ymdelay]; % ym
    %     case 4 % ym
    %         net.inputWeights{1,2}.delays = [0:model.structure.input_type.ymdelay]; % ym
    % end
    % val = model.structure.num_inputs;
    % for r = 2:model.structure.num_layers
    %     net.inputWeights{r,r+val}.delays = 0; % bias delays
    % end

model.NN = net;
save model model;

```

Training Parameter Setup GUI:

File: GUI_model_offline_training.m

Description: Graphical User Interface used to set neural network training parameters

```
function varargout = GUI_model_offline_training(varargin)
% GUI_MODEL_OFFLINE_TRAINING M-file for GUI_model_offline_training.fig
%   GUI_MODEL_OFFLINE_TRAINING, by itself, creates a new
%   GUI_MODEL_OFFLINE_TRAINING or raises the existing
%   singleton*.
%
%   H = GUI_MODEL_OFFLINE_TRAINING returns the handle to a new
%   GUI_MODEL_OFFLINE_TRAINING or the handle to
%   the existing singleton*.
%
%   GUI_MODEL_OFFLINE_TRAINING('CALLBACK',hObject,eventData,handles,...) calls the local
%   function named CALLBACK in GUI_MODEL_OFFLINE_TRAINING.M with the given input
%   arguments.
%
%   GUI_MODEL_OFFLINE_TRAINING('Property','Value',...) creates a new
%   GUI_MODEL_OFFLINE_TRAINING or raises the
%   existing singleton*. Starting from the left, property value pairs are
%   applied to the GUI before GUI_model_offline_training_OpeningFunction gets called. An
%   unrecognized property name or invalid value makes property application
%   stop. All inputs are passed to GUI_model_offline_training_OpeningFcn via varargin.
%
%   *See GUI Options on GUIDE's Tools menu. Choose "GUI allows only one
%   instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Copyright 2002-2003 The MathWorks, Inc.

% Edit the above text to modify the response to help GUI_model_offline_training

% Last Modified by GUIDE v2.5 22-Apr-2007 21:44:02

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                  'gui_Singleton',   gui_Singleton, ...
                  'gui_OpeningFcn', @GUI_model_offline_training_OpeningFcn, ...
                  'gui_OutputFcn',  @GUI_model_offline_training_OutputFcn, ...
                  'gui_LayoutFcn',  [], ...
                  'gui_Callback',    []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
```

```

% End initialization code - DO NOT EDIT

% --- Executes just before GUI_model_offline_training is made visible.
function GUI_model_offline_training_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to GUI_model_offline_training (see VARARGIN)

load model;
handles.model = model;
update_GUI_model_offline;

% Choose default command line output for GUI_model_offline_training
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% Make the GUI modal
set(handles.figure1, 'WindowStyle', 'modal')

% Determine the position of the dialog - centered on the callback figure
% if available, else, centered on the screen
FigPos=get(0, 'DefaultFigurePosition');
OldUnits = get(hObject, 'Units');
set(hObject, 'Units', 'pixels');
OldPos = get(hObject, 'Position');
FigWidth = OldPos(3);
FigHeight = OldPos(4);
if isempty(gcbf)
    ScreenUnits=get(0, 'Units');
    set(0, 'Units', 'pixels');
    ScreenSize=get(0, 'ScreenSize');
    set(0, 'Units', ScreenUnits);

    FigPos(1)=1/2*(ScreenSize(3)-FigWidth);
    FigPos(2)=2/3*(ScreenSize(4)-FigHeight);
else
    GCBFOldUnits = get(gcbf, 'Units');
    set(gcbf, 'Units', 'pixels');
    GCBFPos = get(gcbf, 'Position');
    set(gcbf, 'Units', GCBFOldUnits);
    FigPos(1:2) = [(GCBFPos(1) + GCBFPos(3) / 2) - FigWidth / 2, ...
        (GCBFPos(2) + GCBFPos(4) / 2) - FigHeight / 2];
end
FigPos(3:4)=[FigWidth FigHeight];
set(hObject, 'Position', FigPos);
set(hObject, 'Units', OldUnits);

% UIWAIT makes GUI_model_offline_training wait for user response (see UIRESUME)
uiwait(handles.figure1);

```

```

% --- Outputs from this function are returned to the command line.
function varargout = GUI_model_offline_training_OutputFcn(hObject, eventdata, handles)
% varargout cell array for returning output args (see VARARGOUT);
% hObject handle to figure
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
%varargout{1} = handles.output;

%model = handles.model;
%save model model;

% Hint: delete(hObject) closes the figure
%delete(hObject);

% --- Executes on button press in create_input_button.
function create_input_button_Callback(hObject, eventdata, handles)
% hObject handle to create_input_button (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

input_setup = handles.model.training_setup.offline.input_setup;
save input_setup input_setup;
GUI_Create_i;

load input_setup;
handles.model.training_setup.offline.input_setup = input_setup;

handles.output = hObject;
guidata(hObject, handles);

% --- Executes on button press in Train_button.
function Train_button_Callback(hObject, eventdata, handles)
% hObject handle to Train_button (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

function epochs_Callback(hObject, eventdata, handles)
% hObject handle to epochs (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of epochs as text
% str2double(get(hObject,'String')) returns contents of epochs as a double

handles.model.training_setup.offline.Levenberg_Marquardt.epochs = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function epochs_CreateFcn(hObject, eventdata, handles)
% hObject handle to epochs (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB

```

```

% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes during object creation, after setting all properties.
function offline_axes_CreateFcn(hObject, eventdata, handles)
% hObject    handle to offline_axes (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: place code in OpeningFcn to populate offline_axes

% --- Executes on selection change in plot_model_offline.
function plot_model_offline_Callback(hObject, eventdata, handles)
% hObject    handle to plot_model_offline (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns plot_model_offline contents as cell array
%    contents{get(hObject,'Value')} returns selected item from plot_model_offline

contents = get(hObject,'String');
item = contents{get(hObject,'Value')};
switch item
    case 'plant input u'

    case 'plant input u, plant output yp'

    case 'plant output yp, model output ym'

    case 'Mean Squared Error (MSE)'

end

% --- Executes during object creation, after setting all properties.
function plot_model_offline_CreateFcn(hObject, eventdata, handles)
% hObject    handle to plot_model_offline (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```
end
```

```
% --- Executes on button press in plot_button.  
function plot_button_Callback(hObject, eventdata, handles)  
% hObject    handle to plot_button (see GCBO)  
% eventdata  reserved - to be defined in a future version of MATLAB  
% handles    structure with handles and user data (see GUIDATA)
```

```
% --- Executes when user attempts to close figure1.  
function figure1_CloseRequestFcn(hObject, eventdata, handles)  
% hObject    handle to figure1 (see GCBO)  
% eventdata  reserved - to be defined in a future version of MATLAB  
% handles    structure with handles and user data (see GUIDATA)
```

```
model = handles.model;  
save model model;
```

```
uiresume(handles.figure1);
```

```
% Hint: delete(hObject) closes the figure  
delete(hObject);
```

```
function mu_Callback(hObject, eventdata, handles)  
% hObject    handle to mu (see GCBO)  
% eventdata  reserved - to be defined in a future version of MATLAB  
% handles    structure with handles and user data (see GUIDATA)
```

```
% Hints: get(hObject,'String') returns contents of mu as text  
%        str2double(get(hObject,'String')) returns contents of mu as a double
```

```
handles.model.training_setup.offline.Levenberg_Marquardt.mu = str2double(get(hObject,'String'));
```

```
handles.output = hObject;  
guidata(hObject, handles);
```

```
% --- Executes during object creation, after setting all properties.  
function mu_CreateFcn(hObject, eventdata, handles)
```



```

% hObject   handle to mu (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function mu_dec_Callback(hObject, eventdata, handles)
% hObject   handle to mu_dec (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of mu_dec as text
%       str2double(get(hObject,'String')) returns contents of mu_dec as a double

handles.model.training_setup.offline.Levenberg_Marquardt.mu_dec = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function mu_dec_CreateFcn(hObject, eventdata, handles)
% hObject   handle to mu_dec (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function mu_inc_Callback(hObject, eventdata, handles)
% hObject   handle to mu_inc (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of mu_inc as text
%       str2double(get(hObject,'String')) returns contents of mu_inc as a double

handles.model.training_setup.offline.Levenberg_Marquardt.mu_inc = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function mu_inc_CreateFcn(hObject, eventdata, handles)
% hObject   handle to mu_inc (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB

```

```

% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function mu_max_Callback(hObject, eventdata, handles)
% hObject    handle to mu_max (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of mu_max as text
%    str2double(get(hObject,'String')) returns contents of mu_max as a double

handles.model.training_setup.offline.Levenberg_Marquardt.mu_max = str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function mu_max_CreateFcn(hObject, eventdata, handles)
% hObject    handle to mu_max (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on button press in OK.
function OK_Callback(hObject, eventdata, handles)
% hObject    handle to OK (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

model = handles.model;
%setup_model;
%initialize_model_weights; % initializes weights

save model model;
close;

function plot_epochs_Callback(hObject, eventdata, handles)
% hObject    handle to plot_epochs (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of plot_epochs as text

```

```

%      str2double(get(hObject,'String')) returns contents of plot_epochs as a double

handles.model.training_setup.offline.Levenberg_Marquardt.plot_epochs =
str2double(get(hObject,'String'));

handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function plot_epochs_CreateFcn(hObject, eventdata, handles)
% hObject    handle to plot_epochs (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

Create and Simulate LTI Model:

File: SimulateLTIModel.m

Description: Brings up dialog for importing plant input/output data. Creates LTI model transfer function. Simulates output of model in the time-domain and plots the model output and plant output. Calculates the mean squared error, error % and R-Squared values.

```
% import plant data 1 column = input, 2nd column = output

[filename, pathname, filterindex] = uigetfile('*.xlsx', 'Choose Excel 2007 file containing training set');
if filename ~= 0
    S = strcat(pathname, filename);
    training_set = xlsread(S);
end

input = training_set(:,1)';
target = training_set(:,2)';
n = [1:length(input)];
fs = 2500; % sampling frequency

% Define LTI (Linear Time-Invariant) Transfer Function

num = 1;
den = [.06 1];
sys = tf(num,den);

time = 1:length(input);
time = time/fs; % convert to seconds (fs = 2500 Hz)

% Simulate time-domain response

output = lsim(sys,input,time);

% Calculate mse (mean squared error)

e_squared = 0;
for i = 1:length(input)
    e_squared = e_squared + (target(i) - output(i))^2;
end
mse = e_squared/length(input);

% Calculate root mean square deviation

rmsd = sqrt(mse);

% Calculate Root Mean Square (RMS) of Target

rms = 0;
for i = 1:length(input)
    rms = rms + (target(i))^2;
end
rms = rms/length(input);
rms = sqrt(rms);
```

```

% Calculate error = Root mean squared error / RMS target * 100%
error = rmsd/rms*100;

% Calculate R squared value
r = corr(target,output);
r_squared = r^2;

% plot results

figure;

subplot(2,1,1), plot(time,input);
h = gca;
set(h, 'FontWeight','bold','FontSize',16);
title(['Plant/Model Input'];['(Sampling Frequency fs = ',num2str(fs),'
Hz)'],'FontWeight','bold','FontSize',16);
xlabel('Time (seconds)');
ylabel('Voltage (volts)');

subplot(2,1,2), plot(time,output,'b-',time,target,'g--','LineWidth',2);
legend('Model Output','Target','EastOutside','FontSize',16);
xlabel(['Time (seconds)';' '];['model numerator coefficients = ', num2str(num)];['model denominator
coefficients = ', num2str(den)]],'FontWeight','bold','FontSize',16);
ylabel('Rate (rad/s)','FontWeight','bold','FontSize',16);
title(['LTI Model Output and Plant Output (Target)']; ['( MSE = ', num2str(mse),' Error =
',num2str(error),'%', ' R-Squared = ',num2str(r_squared),' )'],'FontWeight','bold','FontSize',16);
h = gca;
set(h, 'FontWeight','bold','FontSize',16);

```