EVALUATION, DESIGN, AND TESTING OF PLC DATA LOGGING SYSTEM ON MODIFIED PULLING TRACTOR

by

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ABSTRACT

This senior project involves the design and implementation of a data logging system on a modified pulling tractor, Mustang Fever. The project starts out a continuation of a previous project. The original goal of the project was to keep the Cal Poly Tractor Pull on the leading edge of innovation. The implementation of a sensor array and logging system on a modified pull tractor assists with the maintenance and tuning of the machine. The collected data is stored on a USB drive to allow analysis in the future.

The parameters collected by the system are: pressures, temperatures, and rotational speeds. This project shows the steps from design to construction to testing of the equipment. The project concludes with a functioning system that stores data. The analysis of the data shows that most of it is accurate. The paper finally ends with recommendation on how to improve the system further.
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INTRODUCTION

The Cal Poly Tractor Pull club was established over 40 years ago. The club currently operates two modified pulling tractors, Mustang Fever and Poly thunder. These two tractors use high displacement engines that create tremendous amounts of horsepower. The extra horsepower allows the two tractors to be very competitive in their respective weight classes. In a continuously advancing competition, the best way to keep the tractors competitive is to keep the performance of each tractor at its maximum. In order to optimize performance, it is important to have feedback from each run of the tractor. Feedback allows the team, who is in charge of the maintenance, to perform checkups and tune-ups as necessary. Normally the feedback of each run is passed verbally from the team members who drive the tractors during the run. However most of the drivers are new to the sport and feedback can be in short supply. The goal of this senior project is to set up a system that will record temperatures, pressures and rotational speeds from each pull and allow a history of performance and maintenance to be set up.

The best way to keep track of and record temperatures, pressures, and speeds is through a monitoring device or PLC/HMI that will record the parameters. This will allow an operator to look back at the data and adjust engine timings air/fuel ratios and other settings to optimize performance. The data that is recorded will also help schedule regular maintenance and some special maintenance. The tractor that will be used in this project will be Mustang Fever.

The Tractor Pull Team has attempted, in the past, to install a few logging systems on Mustang Fever. The very first attempt at a logging system was a high speed camera mounted on the roll bar that filmed the gauges. This system proved useless due to high vibrations. The first successful logging system was set up by Jeff McGuire. This system was upgraded by Nicholas Darr who originally installed the PLC/HMI currently on the tractor. The Main goal of this project will be to analyze and get the existing system working 100% and then test it for consistency.

The system installed monitor's manifold pressure, exhaust gas temperatures, engine speed and drive line speeds. There are many issues with the currently installed system and many parameters and wiring changes will be made.

The data collected will be saved on a flash drive. The flash drive can then be plugged into a computer and looked at more closely. This system will allow for data to be recorded for years. The long term storage will help the team examine how the tractor performs at different tracks. This data acquisition system is another tool the tractor pull team will use along with soil and weather data, to optimize their performance and fine-tune the sport.
LITERATURE REVIEW

When working with high performance engines it is important to monitor engine parameters and temperatures in order to prevent damage and achieve optimal performance. The Cal Poly tractor pull team is developing a monitoring system to monitor engine parameters and performance. In order to implement a useful system it is important to design the system to monitor record and/or transmit engine performances.

Use of a Field Bus System for Monitoring and Data Collection. The modern field bus system allows a user to collect outputs of sensors and resistors. “The goal of field buses is the serial communication between primary elements of atomization implementing control and measurement functions, and control atomization elements of higher levels.” (Gonzalez-Romero, 2003) Sensors, counters, and other arrays can be set up to monitor many different parameters some of these parameters, used on Mustang Fever, include: temperature, pressure, and rotational speed.

Temperature is the most commonly monitored parameter of high performance engines. Mustang fever currently has a few existing temperature and pressure gauges installed on its dashboard. The parameters displayed on the gauges were deemed essential to the successful use of the machine. However, there are other parameters that, if monitored, will help the tractor pull team tune and optimize the performance of the tractor.

It is difficult to create simple systems that monitor many parameters using analog signals. Most of the industrial applications use the analog sensor with transmitters for sensing the process parameters particularly in harsh environments due to their strong mechanical packaging and ruggedness. (Anand, 2009) Because of their compact nature, Digital Field Bus Systems are much more desirable.

Field bus interfaces and number of inputs varies greatly from manufacture to manufacture. The current high end programmable logic controllers have upwards of one hundred inputs/outputs. This allows a system that can monitor many different parameters at the same time. This many input and output feature of the modern field bus allows for much simpler wiring and configuration than systems in the past. Pleinevaux (1988) summarizes the benefits of using field buses as follows:

- Cabling costs are reduced lowering the overall cost of a project.
- A single cable system allows for quicker diagnoses of a problem, as well as simpler maintenance
- There is a separation of the control part and the instrumentation to ensure amenability.
- Expansion of the system is quicker and easier than installing wire networks and laying new cabling.
- Cable faults are automatically detected and easily. This allows for quick diagnosis and fast remedies to be implemented.
- Noise is reduced from analog signals which allows quicker evaluation of data and signals.
• Finally information can be readily available at different places within the same system. Transmitters and networkers allow the signals to be transmitted to nearly anywhere the user desires.

**Use of Thermocouples for Temperature Measurement.** There are a few ways to monitor temperature of gases and fluids. The most common is a thermocouple resistor. This device allows the measurement of temperature differences based on resistance in the thermocouple. These devices can be difficult to calibrate but can be very accurate. Jie says about thermocouples, “Its thermoelectricity characteristics are changed after it is put in service because of the influence of measuring circumstance, medium, temperature, stain of isolation and protecting material. (Jie, 2009). Thermocouples are easily interfaced with Programmable systems but need to be continually calibrated. There are many techniques and methods for calibrating the thermocouples. Some systems have automatic built in calibration methods. Proper calibration is only achieved by having a know temperature source that has little error that can be used to compare readings. (Bethea, 1992).

**Use of Magnet Induction Sensors for Rotational Speed.** When measuring rotational speeds it is difficult to have direct contact with the object and have a sensor with longevity. Thermocouples have direct contact with fluids or gasses and therefore have very accurate measurements and maintain longevity. The easiest way to measure rotational speeds and maintain longevity is through magnetic inductance sensors. Sensors can be set up to read teeth of gears, keyways, and marks in objects. Figure 1 below shows the cross section of a magnetic inductance sensor. A metal object that is in close proximity to the sensor creates an electric current through the windings, which is read as the signal. The sensors can be calibrated according to the number of teeth per rotation or indents per rotation, to determine revolutions per minute of an object.

![Figure 1: Cross Section View of Magnetic Sensor](image)

**Use of Pressure and Vacuum Sensors.** Along with temperatures and speeds of engine components, the pressures of intakes and boosted airlines need to be monitored. There are many different types of pressure sensors. Some sensors read capacitive differences and others read actual distance changes in diaphragm. (Jeahyeong, 2009) It is important to have general ideas of the sensor requirements. Pressure sensors can be skewed easily and
give false readings if maxed out. It is important to keep these sensors calibrated and tested in order to have accurate readings and data.

**Calibration of sensors.** It is important to calibrate all sensors and compare readings throughout the use of a system. False readings defeat the purpose of using a sensor. There are many calibration techniques to create a true output of a sensor. Thermocouple calibration is important to perform often and using methods that compare readings to known temperature. Proper calibration is only achieved by having a known temperature source that has little error that can be used to compare readings. (Bethea, 1992).

The sensor output will be sinusoidal for a magnetic sensor. This data will need to be simplified to create timing difference to show when the object passes near the sensor. This will show the rotations per time period. The data can also be averaged and compiled to have running averages to have more accurate outputs. Figure two shows a graph of sensor output that is compared to a normalized graph to show the error that may exist for a sensor.

![Figure 2: Sinusoidal normalization of a magnetic sensor for calibration (Wegener, 2007)](image)
**PROCEDURES AND METHODS**

**Design Procedure**

**PLC Selection.** The PLC used on Mustang Fever was selected because of its expandability. This PLC features 4 slots that different cards can be utilized.

The normal inputs of the PLC are purely on/off switches that do not sense small changes. The insert able cards allow the PLC to monitor small changes in voltages or frequency to read sensitive data. The cards selected were: FO-04AD-2, F0-04 THM, and the H0-CTRIO

![Image of FO-04AD-2 Voltage Input Card](http://www.automationdirect.com, 2012)

![Image of F0-04 THM Thermocouple Input Card](http://www.automationdirect.com, 2012)
HMI Selection. The HMI used on Mustang Fever is a C-More touch panel. This Panel was selected because it will display the data as well as record it to a USB drive as desired. The C-More touch panels offer a customizable screen that can display parameters and graphics that are easily customizable by the user. The Graphics and Data options that should be displayed for Mustang Fever would easily be encompassed by the 6-inch black and White touchscreen, EA7-SM6.

Thermocouple Selection. The thermocouples selected for Mustang Fever are K-Type thermocouples that were installed prior to the project. The thermocouples were installed on the exhaust tubes just past the exhaust port on the Engine Head. This will give accurate temperature readings of the exhaust temperature exiting the engine.
Pressure Sensor Selections. The Pressure Sensor for Mustang Fever was selected to be compatible with the card selected for the PLC. The Sensor Selected was a Setra Gauge Pressure Sensor Model 206/207. These sensors range in sensing ability from 0-1000 psi. The Manifold pressures on Mustang Fever should never reach above 35 psi so the 0-50psi gauge was selected. This sensor was installed just upstream of the existing pressure gauge on the dashboard.

High Speed Counters. The High Speed counters that read the engine and drive line speeds are inductive proximity sensors. These sensors act as a switch that turn on when a ferrous metal is present near the sensor. The sensors selected were selected based on rugged use and sensing of ferrous metals. The Sensor Used for the engine RPM is a 12mm unshielded sensor, and the sensor used for the driveline is an 8mm unshielded sensor. The sensor for the Engine RPM’s is to be located on the clutch-can to read and count the clutch bolts as they pass.
The Drive Line RPM sensor will read a custom sleeve that will be made in the shops. The sleeve will be made from aluminum and have four steel screws threaded into it for the sensor to read. The custom sleeve can be seen in the Construction procedures.

Figure 10: Custom Drive Line Sleeve

Figure 11: Solid Works Design for Sleeve
Construction Procedure

**Wiring Diagram.** There has never been a wiring diagram created for the Tractor as a whole. With the added sensors and electronics it was easy to confuse wires and object functions. A wiring diagram was created to assist with debugging and troubleshooting. First the wires were traced and sketched on a piece of paper. Then the diagram was drawn in AutoCad to keep the diagram clean and easy to use. The diagram can be seen in the Appendix section.

**Rear Panel Enclosure.** The PLC and its components were mounted in a plastic, weatherproof case on the back of the tractor. The wires for the inputs and controls were run into the case thorough a small hole at the bottom.

![Hole in Weather Proof Case for Wire Loom](image)

Figure 12: Hole in Weather Proof Case for Wire Loom

The Panel has a see through cover so that it is a feature that the Tractor Pull club can showcase at events. The Rear Panel keeps the PLC and wires in place. There is also a spot for a short wave radio transmitter that was used in previous years. The Radio is not currently installed but future plans for use warranted a spot be saved in the rear panel.

![Rear Enclosure for PLC and Wires](image)

Figure 13: Rear Enclosure for PLC and Wires
**Wiring.** The Wiring of the system was completely redone since an accident in the previous year caused a wire to short and melt destroying the shielding on most of the wires to the system. The accident in the previous year could have been prevented by a fuse at the battery connection. When the wiring was rerun, a fuse was placed on each battery to prevent any further shorts from causing a melted wire or possible fire.

![Figure 14: Fuse for 12V Battery Supply](image)

![Figure 15: Fuse for 24V Battery Supply](image)

The wiring for the PLC System interfaces directly with the wiring of the dashboard. Over the years, many different modifications and changes have been made to the wiring resulting in many unneeded splices and connection in the system. For this reason, the entire wiring of the tractor was analyzed and changed to simplify the number of connections and upgrade the entire system to use the fuses that will protect all components.

The tractor also had two existing connection rails that were not fully utilized. These rails make the wiring simple and pleasing to the eye. The rails were used more extensively during the rewiring process which resulted in a cleaner, simpler wiring that is noted
accurately in the wiring diagram. Using the Rails and labeling the wiring diagram allows any problems to be diagnosed quickly and problems reconciled with accuracy.

**Drive Line Couple Sleeve.** The Sleeve that the driveline sensor reads is made from a solid stock of aluminum that was recycled in the BRAE shops. The inside diameter for the sleeve was measured to the outside of the driveline coupler. The outside dimension of the sleeve was decided to be 3/8 inch larger than the inside diameter of the sleeve to leave enough material to thread for screws. The stock was first lathed down to the correct outside diameter. Then the inside of the sleeve was bored out to the correct dimension making sure the sleeve was a tight fit on the coupler. After the inside and outside were machined to the correct inside and outside diameter, the front of the sleeve was faced. The coupler was cut off the rest of the stock using a parting tool to make sure both faces were concentric. The entire machining of inside, outside, and faces of the sleeve was done without removing the part from the chuck ensuring that all planes were consistent.

The sleeve was then hand filed to remove any burrs and blemishes from the edges and make it safe to handle before drilling the holes for the alignment bolt and the four sensing screws. The sleeve was chucked up in a dividing head on the mill bench. The part was centered using the edge finder. The holes for the sensing screws and alignment bolt were first center drilled to ensure proper placement. The holes for the sensing screw were drilled through with a number eight drill bit (proper size for a ¼-20 tap). The hole for the alignment bolt was drilled through with a 3/8” drill bit. The holes were then tapped using a ¼-20 tap using the mill for proper alignment. The sleeve was removed from the chuck of the dividing head and filed by hand to remove burrs. The screws were tightened into place and the sleeve installed onto the driveline coupler.

![Figure 16: Coupler Sleeve in Dividing Head](image)
The Programming of the PLC involved many hours of trial and error to find a final solution. There are many different coding types and locations that data can be stored in a PLC along with virtual switches, timers and output options. The Data from the sensors needs to be coded in a way that the HMI screen can recognize it. If the communication between the PLC and HMI is different, the numbers and data displayed are useless.

The first step with creating the program was to look through the manuals for each expansion slot card. Each manual shows the ladder logic required to code the inputs to a readable data point. Each coded point is then stored in a memory location on the PLC to
be read by the HMI. The memory location for each sensor must be different in order for the HMI to be able to record it.

The IBox features in the DirectSOFT 5 Programming suite were used in a few places in the Ladder Logic to code the data and make it available to the HMI. The Voltage card reader uses the IB-460 IBox to code the data from the pressure transducer. The data from the IBox is coded into a Binary number and stored in location V4000. This Number is a voltage read by the card. The logging of the voltage as a data point is difficult to analyze without being scaled. The voltage reading is therefore scaled to make it a pressure reading. The IBox “Analog Scale 12 bit Binary to Binary” feature was used to change the voltage reading to a coded pressure reading. This “Math Box” allows the voltage stored in location V4000 to be scaled into a pressure reading between 0-50 psi. The corresponding pressure reading is then stored in location V6000. This location is then read by the HMI and logged as it is read.

There is no IBox for the thermocouples. Therefore the ladder logic is longer. There is a series of Load and Output boxes that code the numbers for the Thermocouple readings. The thermocouple readings are also coded in Binary and stored in memory locations to be read by the HMI. The data for the Thermocouples is stored in locations V3000, V3002, V3004, and V3006; each for a single thermocouple. The Numbers stored are without a decimal place and therefore need to be scaled using a math feature. Each memory location is separately read and scaled by a factor of 10 to move the decimal place where is should be. The resulting numbers are then stored in V5000, V5002, V5004, and V5006; each for a single thermocouple corresponding to the V3000 numbers.

The last feature of the programming was the high speed counters. The counters are setup using the DS Launch tool CTRIO Setup. This tool allows the number of counts that the card receives to be converted into a rotational speed number that can be read by the HMI. The two counters are set up by the number of counts that constitute a rotation and the interval that the count is taken at. The resulting rotation number is stored as a binary number in the V2000 location for the engine RPM and V2002 for driveline RPM.

**HMI Programming.** The HMI was programmed to have a sleek look as well as display all necessary data while logging it for future use. There are a series of 4 screens of display to capture the necessary data and displays. The first screen features many numeric display boxes that show a current reading of each parameter. This screen is the default as it is the most useful while running the tractor. The other three screens are graphs to log the data that the screen reads from the PLC. The HMI will only log data that is displayed in the graphs and will not log the data displayed in numeric displays. The data is constantly logged onto a USB thumb drive that is plugged into the bottom of the HMI itself. The figure below shows a screen shot of the HMI Home Screen display.
Figure 19: Home Screen of HMI Display
**Testing Procedure**

**Testing Pressure Transducer.** The Pressure Transducer was tested using a pressurized hose with a gauge that the reading of the PLC could be compared to. The pressure regulator was connected just in front of the pressure transducer as seen in the figures below.

![Figure 20: Quick Fitting Connection on Pressure Transducer](image1)

![Figure 21: Pressure Regulator Installed to Test Transducer](image2)

The Pressure regulator was adjusted to certain pressures and the HMI reading was display to cross reference. The resulting pressures were recorded and listed in the results section.

**Testing Thermocouples.** The thermocouples were tested using an electric heat gun. The Heat gun blows air that is near 200°F. The card used to collect the thermocouple data has a built in thermostat that reads ambient temperatures to automatically calibrate the thermocouples. The heat gun test was merely to make sure the thermocouples were functioning.
**Testing High Speed Counters.** The readings for the high speed counters were best tested while the tractor was running. The Tractor was started and the data recorded to see if the readings were true to the engine and driveline speeds.
RESULTS

Lab testing data, data from test runs and data from an actual competitive pull were compiled in this project. The amount of data and contents of data for each component are listed below.

**Pressure Transducer.** Data from the Pressure transducer was collected from lab testing as well as a competitive pull. The lab testing of the pressure transducer showed that the module was very accurate. The percent differences between the gauge readings of the regulator and the displayed value were very low. The only problems that occur are when the pressure is out of the 4-40 psi range. Outside of its middle range the percent error is much higher. This is not of consequence since the pressures of concern are within its optimal range. The Table below shows the lab testing data.

<table>
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<tr>
<th>Gauge Pressure</th>
<th>Displayed Pressure</th>
<th>% error</th>
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<tr>
<td>5</td>
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<td>-40%</td>
</tr>
<tr>
<td>11</td>
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<td>9%</td>
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<tr>
<td>43</td>
<td>45</td>
<td>5%</td>
</tr>
<tr>
<td>48</td>
<td>52</td>
<td>8%</td>
</tr>
</tbody>
</table>

Table 1: Pressure Transducer Test Data

Along with lab testing there was also data collected at a competitive pull. The Data collected at the tractor pull in Ukiah, California on June 2, 2012 was copied to excel and charted to yield the following graph

Figure 22: Manifold Pressure Data Graphed
The Data logged shows that there is an obvious leak in the system between the gauge and manifold since there is very low boost recorded. The data recorded during lab testing shows that the boost generated by the tractors blower should have registered a much higher reading of pressure.

**Testing Thermocouples.** The thermocouples were tested for function in the lab as well as the tractor pull in Ukiah. The data tested in the lab is difficult to make conclusions on since there is no secondary way to measure the temperatures generated by the heat gun. Although the lab test data is inconclusive besides pure function, the thermocouples seemed very accurate. The data logged during the tractor pull in Ukiah show definite trends in heat cycles when the operator was heavy or light on the throttle. The Data graphed below is from the Tractor Pull in Ukiah.

![Exhaust Gas Temperatures Logged at Ukiah Tractor Pull](image)

Figure 23: Thermocouple Data Logged at Tractor Pull in Ukiah

**Testing High Speed Counters.** The Lab testing of the sensors was inconclusive since the tractor must be running for proper data capture. During one test run, however, the tractor was started and the data recorded. These results were graphed and analyzed to find that the counter was set up with a wrong multiplier in its programming. This data is therefore not included in this report. The number was changed and the tractor was run a second time during the tractor pull in Ukiah. The data from the High speed counters showed that both the sensors are working but not the entire time of the run. There seems to be some sort of shut off issue with the driveline sensor since the data drops off and the engine data is consistent. The data from the engine seems consistent to the run. The resulting data is graphed below.
Figure 24: Driveline and Engine RPM Data Logged at Ukiah Tractor Pull
DISCUSSION

The data logging system is sure to prove very useful to the Cal Poly Tractor Pull Team. The data collected with a system like this will help fine tune the performance of the engine. The data, if organized, will also help create a log of performance at different tracks and different weather conditions to help the team fine tune the tire pressure, fuel mixture, and clutch settings. The data logging system is also easily repaired and/or repeatable. The parts and wiring are installed in a way that they are easily accessed and serviceable. These things will also help ensure the longevity of the system.

Although the data collected seems promising, the results of any and all runs should be scrutinized. There are many components to the system and any single reading could contain error. The results should always be carefully analyzed and discussed with others before recorded into the history of the tractor.
RECOMMENDATIONS

As with any system, there is always room for improvement. The following are some brief recommendations for the system installed on Mustang Fever

- PLC system is still expandable. This means that more inputs are available to be logged and more information can be collected.
- The High Speed Counters should be reevaluated. There is obvious error in the data for the Driveline and Engine speeds.
- The leak in the manifold pressure sensing line should be eliminated. There is a very small reading in the data and there is an obvious problem with the line feeding the pressure transducer.
- There should be a program implemented by the tractor pull team to keep the logged data organized with the data recorded by the weather and soil testing equipment.
- A new thermocouple should be purchased and installed to replace the non-functioning one.
- The USB slot should be routed to a more convenient location.
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APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR
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Major Design Experience

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes fundamental elements as outlined below. This project addresses these issues as follows.

Establishment of Objectives and Criteria. Project objectives are established to meet the needs and expectations of the Cal Poly Tractor Pull Team.

Synthesis and Analysis. This project incorporates electronics analysis, programming, and complex wiring solutions.

Construction, Testing and Evaluation. The PLC and components were specified, purchased, installed, and tested for accuracy.

Incorporation of Applicable Engineering Standards. The project utilizes IEEE standards for instrumentation and project wiring.

Capstone Design Experience

The BRAE senior project is an engineering design project based on the knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses).

- BRAE 129 lab Skills/Safety
- BRAE 151 AutoCAD
- BRAE 152 Solid Works
- BRAE 216 Fundamentals of Electricity
- BRAE 328 Measurement and Computer Interfacing
- BRAE 421/422 Equipment Engineering
- EE 321 Electronics
- ENGL 149 Technical Writing

Design Parameters and Constraints

This project addresses a significant number of the categories of constraints listed below.

Physical. The PLC system must be contained within the enclosure, 1 ft x 1 ft. The measurement of EGT’s will be greater than 1800°F. The driveline sensors will need to read speed in excess of 4500 RPMs.

Economic. The project must not exceed $1500
Environmental. N/A

Sustainability. N/A

Manufacturability. N/A

Health and Safety. The wiring must not allow for electrical shock.

Ethical. N/A

Social. N/A

Political. N/A

Aesthetic. Loose wires and components will take away from the beauty of the tractor itself. The tractor is a high performance machine but is also a work of art that is often displayed to represent the school.

Other-. N/A
APPENDIX B

WIRING DIAGRAM
Figure 25: Wiring Diagram Mustang Fever
APPENDIX C

PART DRAWINGS