EARLY WILDFIRE DETECTION USING TEMPORAL FILTERING AND
MULTI-BAND INFRARED ANALYSIS

A Thesis
presented to
the Faculty of California Polytechnic State University,
San Luis Obispo

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Engineering

by
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June, 2013

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ABSTRACT

Early Wildfire Detection using Temporal Filtering and Multi Band Infrared Analysis

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Every year wildfires threaten or destroy ecological habitats, man-made infrastructure and people's lives. Additionally millions of dollars are spent each year trying to prevent and control these fires. Ideally if a wildfire can be detected before it rages out of control it can be extinguished and avoid large scale devastation. Traditional manned fire lookout towers are neither cost effective nor particularly efficient at detecting wildfire. It is proposed that temporal filtering can be used to isolate the signals created at the beginnings of potential wildfires. Temporal filtering can remove any background image and any periodic signals created by the camera movement. Once typical signals are analyzed, digital filters can be designed to pass fire signals while blocking the unwanted signals. The temporal filter passes only fire signals and signals generated by moving objects. These objects can be distinguished from each other by analyzing the objects mid and long wave energy profile. This algorithm is tested on 17 data sources and its results analyzed.

Keywords: Forest Fires, Digital Image Processing, Digital Signal Processing, Cooled Mid Wave Infrared, Cooled Long Wave Infrared

ACKNOWLEDGMENTS

I acknowledge the following people for their efforts and contributions to my thesis. It would not have been completed without them.

Special thanks to my thesis advisors, Dr. John Saghri and Dr. John Jacobs, for their guidance, patience, support and encouragement in my graduate study.

Additional thanks for Dr. Jane Zhang for agreeing to be on my committee

I thank Raytheon Employees: Steve Botts, Marc Bauer, Chris Tracy, and Dana Schneider for their support during the June 2011 Fire Test as well as Gary Hughes from FLIR for his help with IR cameras.

I thank all the previous students who worked on this project: Ryan Radjabi, Timothy Davenport, Daniel Kohler, George Moussa and Alex Aldama. This thesis could not be completed without the foundation they built.

I thank my supervisors and co-workers who pushed me to pursue my educational goals while in the Air Force. Without them I would not be in this position today.

I thank my parents, sister and friends for their encouragement and support in helping me complete my thesis.

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CHAPTER 1

Introduction

Every year there thousands of wildfires cause damage across the United States. The United States spend on average 900 million dollars a year on fighting wildfires []. Due to southern California's hot dry summer it is especially vulnerable. According to Cal Fire in 2011 California alone there were 3,056 wildfires burning 51,889 acres of land costing the state of 100 million dollars [1]. The five largest California wildfires by acre took place in the southern half of the state. While most of these were away from populated areas it is not unheard of for a wildfire to cause significant damage to populated areas. The wildfires of late October of 2007 destroyed over 2,000 structures in San Diego County during the last quarter of 2007 [2]. Because of the fire's large size satellites in space could easily identify them. Figure 1 shows the progress of the San Diego fires on October 23, 2007 [3].

Figure 1 Satellite Image of 2007 San Diego Wildfires

A more cost effective way of fighting fires is to extinguish a small fire before it grows into a large one. If a fire is detected early enough, lives and property can be saved

at a reduced cost. The goal of this project is to automatically detect fires remotely and as small as possible so fire fighters can extinguish them before they grow out of control.

1.1 Thesis Outline

This thesis is structured as follows. Chapter 2 discusses previous work performed both at Cal Poly and elsewhere implemented solutions. Chapter 3 discusses the hardware used to capture data throughout the test fires. Chapter 4 analyzes the data captured during the burns. Chapter 5 covers the theory behind the proposed solution. Chapter 6 follows the design process using the theory explained in chapter 5. Chapter 7 analyzes the recorded results from the test burns using the proposed algorithm. Chapter 8 briefly discusses possible implementations of the system. Finally Chapter 9 looks at future work.

CHAPTER 2

Previous Work

There has been plenty of work done in the automatic detection of fires in recent years. Current implementations range from small scale, an indoor smoke detector to large scale, detection using satellite imagery. At Cal Poly forest fire detection has been an ongoing project mostly focused on daytime solutions identifying smoke. Finally Yasar Sahin discusses a very different proposed solution using active radar [5].

2.1 Current Implementations

The most traditional implementation of detecting forest fires is the manned fire watch tower. These towers are located in remote areas with a high fire risk. An individual watches the surrounding area looking for smoke from the start of a fire. This is an expensive and ineffective solution. Advanced sensors and computer vision algorithms can reduce cost and increase effectiveness.

The most common form of fire detection is the conventional smoke detector. These detectors introduced in the late 70s are now in 95% percent of all homes. These detectors work by ionized particles from the smoke breaking an internal beam. These are very effective in internal home fires and Cal Fire states a working smoke detector improves a person's survivability by 50 percent [6]. These detectors only work in an enclosed space close to the fire. They are not a practical solution for identifying fires in large open areas.

Multiple countries have optical based fire detection systems. Germany, South Africa, Canada, England and France all use systems based on detecting smoke in the visible range during the day and infrared data at night [7]. These systems generate many false positives due the atmospheric events and human disturbances. Constant human interaction is required the verify fire conditions. The desired system contains increased fire signals and fewer false positives.

Satellite imagery is probably the largest scale of all the fire detection techniques [8]. One of the satellites NASA current uses the TERRA and AQUA equipped with the MODIS (Moderate Resolution Imaging Spectroradiometer) for multi spectral analysis. Equipped to analyze 36 bands the MODIS sensor's supports a maximum ground resolution of 250 meters [9]. While this can be used to detect and track large fires, it does not provide high enough resolution to detect smaller fires. The fire generated in this testing never grew over 1 one squared meter and would never register on the MODIS sensor. Additionally these satellites are constantly in motion. It takes one to two days before the satellite can return the same spot. A fire can easily grow out of control between visits.

2.2 Research preformed at Cal Poly

Early fire detection is an ongoing project at Cal poly. Three previous theses designed algorithms to detect the presence of a forest fire. For the most part these efforts focused on detecting the smoke plume generated by the fire. Typically a smoke plume covers a much larger area than the actual heat of the fire.

In 2012 Timothy Davenport proposed on texture analysis of data put through a principal component analysis (PCA) to detect smoke from a fire [10]. A PCA is performed on images from red, blue, green, mid wave infrared and long wave infrared frames. Frames from two different times are taken per band for a total of 10 images. The smoke then appears on one of the higher order principal components. Texture analysis is performed via Gray Level Co-Occurrence Matrix. The principal component containing the smoke will contain noise everywhere except the smoke plume and this smoke plume can then be extracted.

At the same time Daniel Kohler produced his results on just identifying a fire off cooled mid wave infrared data [11]. Kohler proposed to classify the edge of the fire by mean, variance and principal component metrics as the fire expanded and contracted. These changes due to the fire's growth increase the number of outlying values along the edge of the fire which can be identified by comparing a pixels variance over time to its medium or mean. The effect of the outliers also appears in the principal component analysis of the frames over time. This method is unique as it is the first method studied at Cal Poly which uses only infrared data and may work for 24 hour coverage.

Later in 2012 George Moussa proposed a different take in using a principal component analysis [12]. In Moussa's approach a principal component analysis was performed on the blue image over nine different time frames. The smoke plume is then extracted by using a combination of blurring, median filtering, adaptive thresholding and Gaussian mixture model.

Alex Aldama is concurrently working on the same project fire detection project. His proposal also aims towards a 24 hour solution using mid and long wave infrared data. His proposal uses a neural network to classify pixels based on the difference in magnitude of the mid and long wave images. He also uses statistical information of each possible fire pixel's neighborhood to correctly classify the pixel.

2.3 Additional Current Research

Additional research has been done on an alternative form of fire detection. Instead of looking for the heat or smoke of the fire, the process explained in Early Forest Fire Detection Using Radio-Acoustic Sounding System [5] uses the change in frequency of a sound wave to detect heated air. As a sound wave travels through the air its frequency changes if the air temperature increases. A radar system can then identify this change in frequency. Of all the systems discussed this is the only active system. The radar component adds considerable cost to the system. The simulated results look to identify a fire with a resolution of 25 square meters. This is still much larger than the fires identified in this test but a much smaller fire than satellite imagery could ever detect.

CHAPTER 3

Hardware Setup

The data used for this analysis was captured on June 18th, 2011 at Raytheon Vision Systems (RVS) in Goleta, California. Data was captured using four different cameras: a visible light camera, a cooled mid-wave IR camera (CMWIR), a cooled long-wave IR (CLWIR) camera and an uncooled long-wave IR camera (UCLWIR). Figure 2 shows the configuration of the cameras on the mast.

Figure 2 Sensor Mast Configuration

This thesis aims to work towards a solution which can be implemented during both the day and night so only the CMWIR camera and CLWIR camera were used. The visible light camera is not sensitive enough during the low light conditions of night and the UCLWIR showed no advantages versus the cooled long-wave camera. Additionally the cooled mid wave and long wave were collocated so their pixels line up one for one; no additional registration is required to align frames. Table 1 below shows the specifications of the CMWIR and CLWIR sensors. Because the uncooled long wave

infrared source is never used, for the rest of this thesis mid wave or MWIR refers to the cooled mid wave infrared source and long wave or LWIR refers to the cooled long wave infrared source.

Table 1 Sensor Specifications

Band	CMWIR	CLWIR
Sensor Resolution	640x480	640X480
Pixel Size	20 μ	20 μ
Focal length	100mm	100mm
Aperture	F2.2	F2.3
Spectral Band	3.8-5 μ	8-12 μ
Bits	14	14
Technology	HgCdTe	HgCdTe
Frames Per Second	30	30

All four cameras were mounted on a tower 50 feet high and 875 yards (0.8 km) away from the source of the fire. Figure 3 shows the positioning of the camera mast and fire location with the locations surroundings. The map was downloaded from Google Earth.

Figure 3 Fire Test Location

3.1 Data Format

A total of 17 recordings were taken in both MWIR and LWIR on June 17, 2011. Table 1 shows all the different data sets in the order they were taken. The MWIR and LWIR data is combined in one raw file. These raw files were previously broken down into individual frames [10]. For the rest of this thesis all data generated from one raw file is considered a data set.

Table 2 Data Sources

Data Set	Raw Movie File	Number of Frames
Setup1	'2011-06-18_101158_LW-MW-14bit_setup.raw'	3753
Charcoal1	'2011-06-18_102125_LW-MW-14bit_charcoal1.raw'	4000
Oats1	'2011-06-18_102454_LW-MW-14bit_oats1.raw'	8000
Oats2	'2011-06-18_102925_LW-MW-	395

	14bit_oats2.raw'	
Oats2b	'2011-06-18_102949_LW-MW-14bit_oats2.raw'	8000
Oats3	'2011-06-18_103820_LW-MW-14bit_oats3.raw'	8000
Pine_needles	'2011-06-18_104857_LW-MW-14bit_pine_needles.raw'	14934
Pine_cones	'2011-06-18_105906_LW-MW-14bit_pine_cones.raw'	8000
Palm	'2011-06-18_110557_LW-MW-14bit_palm.raw'	8000
Thistle	'2011-06-18_110912_LW-MW-14bit_thistle.raw'	6670
Wet_leaves	'2011-06-18_111644_LW-MW-14bit_wet_leaves.raw'	6063
Wet_dry1	'2011-06-18_112306_LW-MW-14bit_wet_dry1.raw'	6117
Wet_dry2	'2011-06-18_112757_LW-MW-14bit_wet_dry2.raw'	6364
Rosemary	'2011-06-18_113916_LW-MW-14bit_rosemary.raw'	5609
Applewood1	'2011-06-18_114605_LW-MW-14bit_applewood1.raw'	6100
Applewood2	'2011-06-18_115209_LW-MW-14bit_applewood2.raw'	6100
Extinguish	'2011-06-18_121233_LW-MW-14bit_extinguish.raw'	6100

Each raw movie file was broken down into one raw image file for each MWIR and LWIR frame. Each MIWIR and LWIR frame held 14 bits of infrared data in a 16 bit frame. Humans require about 6 bits of grey information for an image to appear smooth while 8 bits of grey information is considered a high quality image [13]. The human eye cannot detect small changes in 14 bit information. This expanded bit depth can detect

small changes that people cannot perceive. These small changes can lead to frequencies that would go undetected in a lower bit depth system.

3.2 Long Wave vs. Mid Wave

The two data sources used in this algorithm is the mid wave infrared and long wave infrared. Both data sets were taken from the same camera so the pixels line up one for one between the two data sources. Both bands can be used to remotely detect fire but both do this in a slightly different way. LWIR does a better job of directly measuring heat of the fire while MWIR energy is released from excited CO₂ molecules. Heated CO₂ is a product of any fire burning an organic fuel. Figure 4 shows a good example of the difference between a LWIR and MWIR image at the source of a fire, in the case of a butane cigarette lighter [14].

Figure 4 LWIR Vs. MWIR Comparison [14]

The image on the left, the LWIR image, shows a smaller but well defined hot spot at the center of the fire. The image on the right, the MWIR image, shows a larger but

blurrier image of the fire. The fire has released excited CO_2 which glows in the image. This heated air then acts as a light source illuminating the person and his clothes behind him. The excited CO_2 in the air also releases mid wave energy back to the sensor. This CO_2 emission also plays a part in wildfire as CO_2 is the largest chemical product of burning organic matter from a wild fire [15]. In 2006 a group led by Han Sun performed a hyper spectral analysis using a land based and a satellite based sensor on an active forest fire to determine which spectral frequencies best identified a fire [16]. Figure 5 shows their results with the bandwidths of the MWIR and LWIR cameras used highlighted. The light grey line displays the fire measurements from a land sensor while the darker line displays the measurements from a sensor located on a satellite.

Figure 5 Spectral Energy from a Forest Fire [16]

In the case of a large forest fire the MWIR range appears to contain the most power but a large piece is missing from the center of the MWIR band. This experiment is not looking for a large fire but the beginnings of a small one. A small fire contains much

less power in both ranges which causes the transmission medium to play a much larger role.

The CO₂ in the air proves to be a larger factor as the camera is moved further and further away from the source. Figure 6 is a cutout of a larger Raytheon poster that shows how well the different bands transmit through the air [17]. The highlighted areas show the two data sources used.

Figure 6 Spectral Atmospheric Transmission [17]

The black line shows the percent transmitted along the ground at sea level for 1 km or slightly further than our test range of 0.8 km. At this distance almost 100% of the center MWIR energy gets absorbed by the atmosphere. This explains the missing piece for Figure 5. Once absorbed some of the energy of the MWIR signal will actually be retransmitted by the CO₂ in the air. This retransmission causes the MWIR image to blur in both the spatial and temporal domains. The LWIR energy on the other hand receives around 90% of its original energy transmitted across its entire band.

CHAPTER 4

Frequency Analysis of Various Signals

In order to understand which frequencies need to be passed or blocked various signals need to be analyzed. In this chapter the following signal types are analyzed: a building fire signal, a saturated fire signal, a strong edge signal, a uniform surface signal, a textured surface signal and a moving object signal. A textured surface is defined as a pixel whose neighbors have a small degree of intensity variation. In all cases the DC signals or unchanging image contains much more power than any frequency. Because of this every frequency plot cuts off the top of the DC power to display the frequency information with greater resolution. All signals except the fire signals and the moving object signals are analyzed over the entire 8000 frames of the oats1 data set. Every pixel location is labeled by its row and column in parentheses in the following format: (row, column). The frequency magnitude display by the Discrete Fourier Transform (DFT) plot depends on the total number of samples so fire and moving object powers cannot be compared against the periodic signals analyzed over 8000 frames. The intensity value a pixel containing the desired signal is recorded for each frame of the data set. A DFT is performed on this recording to display the desired frequency information. When possible, more than one pixel is analyzed, multiple pixels' frequency responses are averaged together to create a better representation of the dominate frequency information. To start with we will investigate the two types of fire signals.

The fire signal can be broken into two different categories: a building fire signal and a saturated fire signal. Neither of these “fire” signals actually views the fire itself.

The barbeque and a small hill block the line of sight from the fire to the sensor. The signals under analysis actually view the heat plume generated by the fire. Figure 7 below show the time based signal of the center of the heat plume, pixel (367, 351) of long wave data.

Figure 7 MWIR and LWIR Intensities for Center of Fire in Oats1 Data Set

It is noticed that for large sections of long wave band the data appears clipped. The mid wave shows similar clipping but for much shorter periods of time. These sections need analysis to see if the signals are in fact clipped by the sensor or if at some point the environment limits the intensity of the fire. When looking at the early stages of the fire signal, a building fire, frames 1 through 1085 show an unsaturated signal while frames 2400 through 3050 show a saturated fire signal.

4.1 Saturated Fire signal

The center fire signal's frequency was analyzed using a DFT from frames 2400 to 3050 in the long wave band. These 650 frames create the frequency spectrum shown in

Figure 8. The results reveal that almost the entire signal is a constant value with nearly uniform power for all other frequencies.

Figure 8 Temporal and Frequency Profile of a Saturated Fire Pixel

This means the pixel is a constant intensity value with a small amount of uniform white noise [18]. This implies that the sensor is in fact saturated and doesn't contain any useful frequency information. This does not negatively affect the algorithm because when the fire grows to this size a simple magnitude decision can detect the fire.

4.2 Building fire signal

The most important signal to look for is a building fire signal. This signal occurs when a pixel sees a fire but the fire is not strong enough to saturate the pixel. Frames 1 through 1085 of the oats1 data display a good example of this type of signal. Figure 9 shows the time signal and frequency information of an unsaturated fire signal in both MWIR and LWIR. A DFT generates the frequency information.

Figure 9 Temporal and Frequency Profile of Unsaturated Center Fire Pixel

(MWIR is Green and LWIR is Blue)

In general the long wave fire signal is spread across the entire frequency spectrum with more power in the lower frequencies. The mid wave data generates a much smaller response. The mid wave data shows a much more constant value over the building fire frames. The mid wave data does show slightly more information in the lower frequencies. Next it is important to see how the signal changes further and further away from the center of the fire, pixel (367,351). Figure 10 shows the frequency information looking further and further away from the center fire pixel measured by their city block [13] distance from the center fire pixel. The center fire pixel is also reshownd on the same scale as the other plots for reference.

Figure 10 Frequency Profile of Pixels Moving Away From Center of Fire
(MWIR is Green and LWIR is Blue)

In the long wave data the further away from the center of the fire the fire signal becomes smaller and smaller. The high frequencies disappear first and the lower frequencies remain present further away. Spikes at .95 Hz and 2.84 Hz appear in both the long and mid wave data sets. This chapter identifies these signals later. The next three categories of non-fire pixels to look at are a uniform pattern, a textured pattern and a sharp edge pattern.

4.3 Uniform Pattern

The first non-fire pixel type to identify is one whose surrounding pixels are uniform. This pixel has the least amount of distortion due to the movement of the

camera. Figure 11 shows 20 pixels near row 316 displaying the center of one of the building's hot roof. A DFT analyzes the frequency information for these pixels.

Figure 11 Uniform Pattern Pixels

Figure 12 shows the frequency results. As expected the frequency information displays a large DC component with a little bit of white noise. Two small frequencies do appear present in the spectrum. These frequencies are identified later in this section.

Figure 12 Frequency Profile of Uniform Location

Next we look at a pixel near a sharp edge.

4.4 Textured Pixel Signal

Another type of signal to look for is a pixel looking at an area where the surrounding pixels have similar but not constant values. A good example of a textured pixel which generates a textured signal is the part of a frame looking at a tree. The pixels centered on pixel (410, 315) were analyzed as a textured surface. Figure 13 shows the selected region.

Figure 13 Location of Soft Edge Pixels

Figure 14 shows the frequency information of a textured surface. The plot on the right is set to the same scale as the other plots.

Figure 14 Frequency Profile of Textured Signals (MWIR is green and LWIR is Blue)

The textured edge's frequency appears very similar to that of a uniform signal. The movement of the tree leaves add very little if at all to the frequency spectrum. The same two frequency spikes appear and the next section explains their source.

4.5 Strong Edge Signal

The signal caused by a sharp edge proves to interfere the most with identifying the start of a fire. A pixel that alternatively looks at a hot pixel, like a roof top, and a cool pixel, like the side of a building in a shadow generates a sharp edge signal. As the camera moves in the wind a signal is created proportional to the resonate frequency of the tower that supports the camera. Any structure naturally resonates in multiple modes depending on their construction generating multiple frequencies [19]. Figure 15 shows 20 pixels that generate strong edge signals.

Figure 15 Location of Selected Strong Edge Pixels

An DFT was performed on these twenty pixels over 8000 frames to display their frequency information. Figure 16 shows the average frequency power of 20 of the strongest edges in the picture over the entire time period of the oats1 data set. The blue line is generated from the long wave data and the green line is generated from the mid wave data. The spectrum generated shows nearly the same amount of power for both the long and mid wave data across the entire frequency spectrum. Both wavelengths show the same frequency spikes due to the tower resonance. The largest spikes are at 0.95 Hz and 2.84 Hz. Smaller spikes are also found at 3.58 Hz, 5.30 Hz, 8.21 Hz and 10.75 Hz. These frequencies match the earlier detected frequencies just at a much larger power. All of these frequencies need be avoided when looking for fire information.

Figure 16 Frequency Profile of Strong Edge Signals (MWIR is green and LWIR is Blue)

4.6 Moving Car Pixel

The final type of pixel to analyze is the hardest to characterize in the frequency domain. All of the other pixel types had large consecutive run times and created steady state signals. Moving vehicles on the other hand were only visible by each pixel for a few frames at a time. They behave more like an impulse signal. During the time period between frame 1100 to 1300 the pixels around pixel 315, 400 witness two passing cars. Due to the short duration the frequency resolution is poor but there is some information that can still be gathered. Figure 18 shows the DFT of the data taken during these 200 frames. This plot is zoomed in to identify as much information about the signals as possible.

Figure 17 Frequency Profile of Moving Object Signals (MWIR is green and LWIR is Blue)

Most importantly the long and mid wave data have approximately the same amount of power throughout the frequency spectrum. This is similar to the edge results but very different from the fire pixel results. This makes sense knowing that a pixel observing a car passing in front of it is pretty much the same as a pixel observing an edge. The difference is an edge pixel creates periodic power while a moving object's has a flatter response. This fits the assumption that a moving object signal behaves similar to an impulse as the frequency response of an impulse has a constant value [20].

4.7 Conclusion of Frequency Analysis

A pixel with fire information contains frequency information in multiple sections in the frequency spectrum. The lower frequencies appear to contain more fire information in pixels further away from the center of the fire. Unfortunately signals generated by strong edges can overpower out any information about a small fire. A filter to best identify a fire needs to detect energy in a frequency area with minimal amount of edge frequencies and maximum amount of fire energy. Figure 18 shows two possible

locations for filters that are ideal for detecting fires. A high pass filter will block almost the entire camera movement signal but will also block most of the fire's signal. A more ideal filter would be a band pass filter that captures the low frequency information between the peak at 0.95 Hz and the peak at 2.9 Hz. This is a narrow band captures the most fire signal and a minimal amount of the tower movement signal. Unfortunately this lower frequency band contains more camera movement power than in the higher frequency area. Chapter 5 shows the design of filters for both of these frequency locations.

Figure 18 Location of Proposed Digital Filter Pass Bands

CHAPTER 5

Principals Used in Design of Fire Detection

This chapter explains the theory used in each stage of the fire detection algorithm. The algorithm requires the design of the following stages: FIR high pass filter, IIR band pass filter, spatial blurring filter and connected component analysis.

5.1 FIR High Pass Filter Design

The design flow of creating a FIR filters is shown in Figure 19 [20]. The first set creates a low pass prototype filter. Multiplying the coefficients of the low pass prototype by a window function then increases the stop band performance of the filter. A transformation function then converts the low pass filter into the desired high pass filter.

Figure 19 FIR High Pass Filter Design Procedure

5.1.1 Creation of a Low Pass Prototype Filter

The coefficients of any odd lengthened low pass filter of a given length can be found by using the following equations [20]:

$$h_{lowpass} = 2 * F_c * sinc(2 * n * F_c) \text{ where: } F_c = \text{cutoff frequency}$$

$$\text{where: } n = \left[\frac{-(M-1)}{2}, \frac{-(M-3)}{2}, \dots, 0, \dots, \frac{M-3}{2}, \frac{M-1}{2} \right],$$

given: $M = \text{filter length}$

Equation 1

5.1.2 Window Low Pass Prototype

Multiplying a window function to the low pass prototype helps improve the stop band performance of the filter. This is especially important for this filter as its job is to block the signals created by the edges. Any gain in stop band performance also causes an increase in the pass to stop band transition width. Table 3 shows the properties of 4 common window types where N is the filter length. Increasing the filter length improves the transition width but the pass band ripple and stop band attenuation can only improve by changing the window type.

Table 3 Window Function Characteristics [20]

Window	Peak Ripple $\delta_p = \delta_s$	Transition Width (Δf)	Stop Band Attenuation (dB)
Rectangle	0.0897	0.92/ N	-21
Hanning	0.0063	3.21/ N	-44
Hamming	0.0022	3.47/ N	-53
Blackman	0.00017	5.71/ N	-74

5.1.3 Convert Low Pass Prototype to a High Pass Filter

The following formulas convert an odd length FIR low pass filter to a high pass filter [21]:

$$h_{HP}\left(\frac{M+1}{2}\right) = -1 * h_{LP}\left(\frac{M+1}{2}\right) + 1, \quad \text{given: } M = \text{filter length}$$

$$h_{HP}\left(n \neq \frac{M+1}{2}\right) = -1 * h_{LP}\left(n \neq \frac{M+1}{2}\right), \quad \text{given: } M = \text{filter length}$$

Equation 2

5.2 IIR Filter Band Pass Design

The most common way to design an infinite impulse response digital filter is to first design the desired analog filter and convert it to a digital filter [20]. Figure 20 shows a block diagram of the IIR filter creation process

Figure 20 IIR Band Pass Design Procedure

5.2.1 Create Analog Low Pass Prototype

The creation of the analog low pass prototype is derived by using lookup tables for the desired filter type, Butterworth, Chebyshev, elliptical or others and the desired filter length [21]. Butterworth is characterized by a nominally flat pass and stop band while the Chebyshev contains variable ripple in the pass or stop band. Elliptical filter contain ripple in both the pass and stop band. In general the sharper the cutoff the greater the ripple in the pass and/or stop band.

5.2.2 Convert Analog Low Pass to Analog Band Pass

Once the transfer function for the prototype filter is generated the following transformation will convert the prototype low pass filter transfer function into the desired analog band pass filter transfer function.

$$H_{BP}(j\omega) = H_{LP}(j\omega)|_{j\omega=Q(\frac{j\omega+\omega_o}{\omega_o-j\omega})}$$

$$\text{where: } Q = \frac{\omega_o}{BW}, \omega_o = \sqrt{\omega_1 * \omega_2}, BW = \omega_2 - \omega_1$$

Equation 3

5.2.3 Bilinear Transform

The next step converts the analog filter into a digital filter using a bilinear transform [20].

$$H_{digital}(z) = H_{analog}(s)|_{s=C*\frac{z-1}{z+1}}, \quad \text{where } C = \tan[0.5(\Omega_2 - \Omega_1)]$$

$$\Omega_1 = 2 * \pi * F_1 = 2 * \pi * \frac{f_1}{\text{Sample Rate}}$$

Equation 4

The MATLAB commands “lp2bp” and “bilinear” perform the previous transformations. These commands were used when designing the IIR filters for this thesis.

5.3 Gaussian Blurring Spatial Filter

A Gaussian blurring spatial filter filters out any high noise in an image [22]. The filter itself is generated from a two dimensional Gaussian curve from the following function:

$$f(x, y) = \left(\frac{1}{2\pi * \sigma_x * \sigma_y} \right) * e^{-\left(\frac{(x-x_o)^2}{2\sigma_x^2} + \frac{(y-y_o)^2}{2\sigma_y^2} \right)}, \text{ where } (x_o, y_o) \text{ is the filter's center}$$

Equation 5

There are two inputs in to this filter: the standard deviation and the filter size. For blurring purposes it makes sense for $\sigma_x = \sigma_y$. This blurs the image the same amount in the x and y direction. The filter size needs to be about 6 times the size of the selected standard deviation. Three standard deviations contain 98% of the total power of the function. Figure 20 shows the values of a 5 x 5 Gaussian filter with a standard deviation of 1.

Table 4 Values for 5 x 5 Gaussian with $\sigma = 1$

0.003	0.0133	0.0219	0.0133	0.003
0.0133	0.0596	0.0983	0.0596	0.0133
0.0219	0.0983	0.1621	0.0983	0.0219
0.0133	0.0596	0.0983	0.0596	0.0133
0.003	0.0133	0.0219	0.0133	0.003

Figure 21 5 x 5 Gaussian with $\sigma = 1$

To complete the blurring process the Gaussian filter is convoluted across the image. Blurring allows for improved results in the next step segmentation.

5.4 Connected Component Analysis

Connected component analysis converts a binary image into a labeled image where each object contains a different value [23]. This is a two-step process. The first set goes pixel by pixel from the top left looking for a true pixel values. Once detected the algorithm looks to the left, top left, top and top right for labeled pixels. If they exist the current pixel assumes that label number. If they don't the pixel assumes a new label number. Once completed a second pass identifies two touching labels. The algorithm then classifies each label as the same object. Below shows an example of the connected component analysis process. Figure 22 starts with the binary image.

0	0	0	0	0	0	0	0	0	0
0	1	0	1	0	1	1	0	0	0
0	1	1	1	0	1	1	0	1	0
0	1	1	1	0	1	1	0	1	0
0	0	0	1	0	0	0	0	1	0
0	0	0	1	0	0	1	1	1	0
0	1	0	0	0	0	0	0	0	0
0	1	1	1	1	1	0	0	0	1

Figure 22 Original Binary Image

Pixels are analyzed starting at the top left and going row by row. Figure 23 shows the results of pass one.

Figure 23 Results of First Pass and Final Results of Connected Component Analysis

Pass two identifies 2 sets of labels sharing a common border. In this example labels 1 and 2 are the same as well as labels 4 and 5. Figure 23 shows the final results with the labels renumbered for continuity. Throughout this thesis connected component analysis is performed using the MATLAB bw2label function.

CHAPTER 6

Design Process

Two different filters need to be designed to capture the fire signal while rejecting the camera movement signal and the DC signal. The two different regions are shown in Figure 18 in chapter 4. The high pass filter captures some of the fire signal while avoiding almost the entire camera movement signal. The band pass filter captures much more of the fire signal but will also catch some of the camera movement signal.

There are two different digital filter types to pick from when designing filters: a finite impulse response (FIR) filter and an infinite impulse response (IIR) filter. FIR filters have the advantage that they are always stable and can be designed with linear phase. IIR filters on the other hand can be designed with much sharper cutoffs with shorter filter lengths. The high pass filter is designed as a FIR filter and due to the small bandwidth the band pass filter is designed as an IIR filter.

6.1 FIR High Pass Filter Implementation

The FIR high pass filter requires three different parameters: -6dB cutoff frequency, filter length and window type. The most important parameter, and the one to look at first, is the window type. This is the only parameter that controls the stop band attenuation. The filter needs to block the signals generated by the edges. The Hamming window blocks stop band signals with -53 dB of attenuation. While the Blackman window performs better in the stop band performance its transition width is almost twice that of the Hamming window and would lead to a significantly longer filter length. The

longer filter length causes an increased number of computations and increased filter delay.

The next parameter for the high pass filter is the -6 dB cutoff frequency. A 6 dB cutoff frequency of 13 Hz passes enough high pass power while still blocking the highest edge created frequency spike at 11 Hz. This leads to a transition width of approximately 2 Hz analog frequency or 0.133 Hz in digital frequency. For a Hamming window with a transition width of 2 Hz requires a filter length of at least 25. Figure 23 shows the response from high pass filters with lengths 21 through 31 for comparison.

Table 5 FIR High Pass Filter Legend

Color	Filter Length
Blue	21
Green	23
Red	25
Cyan	29
Purple	31

Figure 24 FIR High Pass Filter of Different Lengths

Apon inspection of the different filter lengths a 29 length high pass filter is selected. The shorter transition width and flatter pass band gives improved performance. Figure 25 shows the final 29 length FIR high pass filter design.

Figure 25 Final FIR High Pass Filter Design

The group delay of a symmetric FIR filter is found using Equation 6.

$$\text{Group Delay} = \frac{\text{FilterLength} - 1}{2} = 14 \text{ frames} = .467 \text{ seconds}$$

Equation 6

Equation 7 displays the final FIR high pass filter equation.

$$y[0] = \sum_0^{28} B_k * x[-k] \text{ where:}$$

$$B_k =$$

k	B _k value	k	B _k value	k	B _k value
1	-0.00083	12	-0.09205	22	-0.00556
2	0.002179	13	0.113571	24	0.008271
3	-0.00423	14	-0.12817	25	-0.00855
4	0.006682	15	0.133333	26	0.006682
5	-0.00855	16	-0.12817	27	-0.00423
6	0.008271	17	0.113571	28	0.002179
7	-0.00407	18	-0.09205	29	-0.00083
8	-0.00556	19	0.067096		
9	0.021271	20	-0.04245		
10	-0.04245	21	0.021271		
11	0.067096	23	-0.00407		

Equation 7

6.2 IIR Band Pass filter Implementation

In creating the band pass filter, the two large frequency spikes at 0.9 Hz and 2.9 Hz need to be almost completely blocked. In order to block these frequencies a band pass filter need to have 3dB cutoff frequencies at 1.4 Hz and 2.2 Hz or a center frequency of 1.8 Hz and a bandwidth of 0.8 Hz. This bandwidth is impractical to achieve with a FIR band pass filter. From Table 1 a FIR band pass filter would require a filter length of at least 249 using a Hamming window.

$$\Delta f = \frac{BW}{2} (\text{minimum}) = \frac{0.8/2}{\text{sample rate}} = 0.0133, \quad \Delta f = \frac{3.3}{N}, \quad N = 247.5$$

Equation 8

An IIR filter can achieve a similar result with a much shorter filter length. The key performance parameters to look for are the stop band attenuation at the two edge spike frequencies, 0.9 Hz and 2.9 Hz, as well as the total group delay of the filter. The higher order filter will achieve a narrower pass band to stop band transition but will also increase the total filter group delay.

Before the order of the filter can be determined an analog prototype must be selected. For this filter a Butterworth prototype was selected. A Butterworth filter has a maximally flat response in both the pass and stop band [21]. This is ideal for our filter because all the frequencies in the pass band contribute to the fire's power equally. The maximally flat stop band ensures none of the frequency spikes pass. Other filter types have stop band ripple and if one of these ripples line up with one of the edge frequency spikes the filter will also pass the edge signal power to the output. An additional benefit of using a Butterworth prototype is it achieves a mostly linear phase response in the pass band region which leads to a more constant group delay.

After the analog prototype filter selection the next step sets the filter order. In general the higher the order leads to a quicker pass to stop band transition but also increases the filter length and group delay. Figure 26 shows the filter response of a 1st to 5th order band pass filter overlaid on top of the DFT of the edge pixels.

Table 6 Performance of IIR Band Pass Filters

Order	Color	Low Spike Gain	Low Spike Magnitude	High Spike Gain	High Spike Magnitude
1	Blue	0.3004	0.342756	0.3997	0.550787
2	Green	0.09872	0.11264	0.1868	0.25741
3	Red	0.03123	0.035633	0.0826	0.113823
4	Cyan	0.00984	0.011227	0.03611	0.04976
5	Purple	0.0031	0.003537	0.0157	0.021635

Figure 26 IIR Band Pass Filters of Different Orders

The most important region the filter needs to block is the large edge frequency spikes at 0.95 Hz and 2.84 Hz. The total power passed at these frequencies need to be significantly less than the power pass at the center of the pass band where the filter gain is 1. Using the long wave data the total power passes at the center frequency of 1.7 Hz is 0.04487. A fourth order or larger filter blocks enough of the edge frequency spikes. Figure 27 shows the group delay for a 1st through 5th order band pass filter.

Table 7 Band Pass Filter Group Delay

Order	Color	Max Pass Band Group Delay (sec)	Ave. Pass Band Group Delay (sec)
1	Blue	0.4165	0.2535
2	Green	0.8202	0.5459
3	Red	1.3687	0.8407
4	Cyan	1.9795	1.1334
5	Purple	2.6348	1.4241

Figure 27 Group Delay of IIR Band Pass Filters

Because of the properties of IIR filters the group delay is not going to be constant, instead each frequency passes through the filter in a different amount of time. As shown in Table 7 even changing the order length by one dramatically lengthens the delay of the filter. Between a fourth and fifth order filter the average pass band delay increases by a quarter second while the maximum delay increases by over half a second. A 4th order filter provides the best balance between performance and delay. Figure 28 shows the final design of the band pass filter.

Figure 28 Final Design of IIR Band Pass Filter

Equation 9 displays the final IIR band pass filter equation.

$$y[0] = \sum_{k=0}^9 B_k * x[-k] - \sum_{k=1}^9 A_k * y[-k], \quad \text{where:}$$

$$A_k$$

$$= [1.0000, -7.1113, 22.558, -41.6524, 48.9387, -37.4610, 18.2471, -5.1737, 0.6544]$$

$$B_k$$

$$= [0.0352, -0.0000, -0.1407, -0.0000, 0.2110, -0.0000, -0.1407, -0.0000, 0.0352]$$

Equation 9

6.3 Location Specific Gain

Unfortunately neither the high pass nor the band pass filter completely removes all of the edge signals in the image. Some pixels look at edge rich locations while others

look at more uniform areas. Because some of the edge power is passed the pixels in an edge filled area will always pass more power than a uniform area. Figure 29 show the frequency power for both long wave and mid wave bands over the first 250 frames (8 seconds) of the oats1 data generated using a DFT.

Figure 29 Expected Values for frequencies in the Band Pass Region for Both Long and Mid Wave

Unfortunately during these frames the fire is already present noted by the red dot near pixel (351, 367). We can simulate how the image would look by replacing the pixels contaminated by the fire with values of the surrounding areas. To ensure no false data is generated the altered values are set slightly higher than the surrounding areas.

Figure 30 Corrected Values for Both Long and Mid Wave

These images were then normalized so the power of an average pixel is 1. When the filter output is divided by these values the average power output of the filter needs to be approximately the same for each pixel in the frame allowing one threshold value for all pixels in the frame. This increases the sensitivity of the uniform areas, the red colored areas, while decreasing the sensitivity in the edge filled areas, the dark blue areas. The same procedure is performed for the high pass frequency range.

Figure 31 Pixel Specific Gain for both Long and Mid Wave band pass filter

6.4 Spatial Filter and Connected Component Analysis

The results of the location specific gain produce non-smooth images. This proves especially true for pixels displaying moving objects. For the connected component analysis to work correctly all pixels belonging to one object need to be connected. A spatial filter smooths out the images removing high frequency noise and which forms connected objects. Both the long wave and mid wave images are spatially filtered with a Gaussian filter with a standard deviation of 1.

Once blurred a threshold is then set to only keep pixel values above a certain level as objects creating a binary image. A connective component analysis then breaks the binary image is separate each distinct object. Features are then generated for each object. Figure 32 shows the process from temporal filtered image to blurred image and finally to binary image taken from the frame 4000 of the charcoal1 data set using the high pass filter.

Figure 32 High Pass Original Image, Blurred Image and Binary Image

6.5 Fire Detection by Features

Once the objects are defined through the threshold process each one needs to be classified as either a fire or non-fire object. Non-fire objects can include moving objects, edges or just noise. Figure 33 shows the decision flow for categorizing each object.

Figure 33 Decision Tree for Detected Objects

The first type of object to remove is small area noise. It is impossible to determine enough information about objects with small number of pixels. Because of this the algorithm assumes any object less than three pixels in size contain noise and can be safely ignored. If these pixels contain fact fire signals within a few frames the fire will grow large enough to pass this stage in the decision tree.

The next object to attempt to remove is a moving object. There are two different ways this algorithm removes moving objects. The first method makes a decision off the object's shape. Because a moving object travels across several pixels the object appears as a blur across the path that it travels. Figure 34 shows a plane moving across the frame after being filtered by both the FIR high pass filter and the IIR band pass filter.

Figure 34 Moving Object (High Pass on Right Band Pass on Left)

Moving objects create a much larger blur in lower frequencies, the band pass image, than higher frequencies, the high pass image.

Each moving object typically has a large major axis and a small minor axis. Eccentricity ratio of the foci points of the major and minor axis [24]. A circle's

eccentricity is zero and for a line it is one. For this algorithm if an objects eccentricity is greater than 0.85 the object is considered moving and rejected. This removes most of the moving objects but not all. Remaining areas containing edge signals also tend to have higher eccentricity and get rejected at this stage.

To remove the rest of the moving objects the mw wave data is used. As shown in chapter 4 earlier the pixels looking at the fire contain more long wave frequency information than the mid wave data. This means more long wave pixels will be above the threshold than mid wave pixels; the long wave object will contain more power than the mid wave object. Figure 35 show the power of the fire at frame 118 of the oats1 data set for both the long and mid wave images generated by the band pass filter.

Figure 35 Long Wave vs. Mid Wave Power of a Small Fire

Moving objects on the other hand produce close to the same amount of power in both the long and mid wave image. Figure 36 shows the power from a moving object in the same frame as above.

Figure 36 Long Wave Vs. Mid Wave Power of a Moving Object

This algorithm assumes that any object which contains more than 6 times the power in the long wave image over the mid wave image is a fire object. Any object failing this test contains signals generated by a moving object.

6.6 Time Averaging Filtering

The previous step removed almost all of the false positives but some still remain. These false positives usually disappear after one or a few frames. The last step remove the noise generate by these false positives. A running average removes most signals which only get passes for one or a few frames. The final stage filters the results using a 120 frame (4 seconds) running average filter.

An actual implementation should require an even longer averaging filter. A longer averaging filter eliminates more of the false positives and the delay would make little or no difference in fire fighter response time. The short four second running averaging filter better tests how well the detection method works and to identify what circumstances could generate a false positive.

CHAPTER 7

Results

Complete results for all the data sets are display in Appendix A. This section focuses on the results from the oats1 and charcoal1 data set. The charcoal1 data set is the first set taken on the day of the experiment and is the only set that changes from a completely cool site to a heated site. Every other data set has been preheated from the data taken before. The oats1 data set is analyzed because this is the set that all the previous algorithms were tested against. As one of the earlier runs the metal barbeque didn't have enough time to get too hot. This data set also includes a greater variety of fire conditions. It includes moments of minimal fire activity as well as times of a more intense raging fire.

To trigger a positive fire reading the algorithm needs to record at least 10 pixels of fire activity. The only time this really applies in the charcoal data. Every other data set contains an active fire at frame 1. The group delay of the filter causes to only delay in fire detection. The total number of fire pixels contains important information though; the more pixels detected means the further away the fire could be detected and how much of the fire could be block and still be detected.

The results graphs show the total number of fire pixels for the high pass filter, the band pass filter as well as a war LWIR result. The raw LWIR result display the total number of LWIR pixels 1.1 times the hottest non-fire pixel through the data det. As the day progressed the tops of the buildings heated up so the threshold had to change for each

data set. In practice this is an unreliable way to detect a fire but does work as a baseline for showing the effectiveness of the algorithm.

As the testing day progressed the LWIR/MWIR camera started to overheat and could not maintain its 30 frames per second frame rate. The frame rate dropped down to as low as 18 frames per second in some cases [11]. The digital filters cease to perform correctly once the sampling rate changes. Because of this only data up to the palm data set contains useful data. As the sampling rate changes the edge frequencies caused by the camera movement appear to change. Figure 37 shows the same 20 edge pixels from both the oats1, early in the day, and applewood1 data, late in the day.

Figure 37 Strong Edge Frequencies for Stable Sample Rate (Left) Vs. Failed Sample Rate (Right)

Due to the changing sampling rate the primary edge frequency appears to shift from 3.58 Hz to 4.7 Hz and considerable noise corrupts the rest of the temporal frequency spectrum. These conditions make it impossible to use frequency filtering to positively identify fire pixels. Figure 38 shows the results from a failed frame rate in the applewood1 data set. The edge signals overpower any other signals in the image.

Figure 38 Results due to Failed Frame Rate

7.1 Charcoal1 Results

The charcoal data set by far had the smallest and most difficult fire to detect.

Figure 39 shows the results from both the high pass and low pass filter.

Figure 39 Charcoal1 Results Band Pass is Green and High Pass is Blue

The high pass filter detects a fire at frame 1598 and the band pass first detects the fire at frame 1526. Even with the increased group delay of the filter the band pass filter detects the fire almost two and a half seconds quicker than the high pass filter. Both filters outperform the raw long wave intensity threshold which doesn't detect the fire until 2706. The band pass filter detects the fire almost 40 seconds before the raw long wave intensity threshold does. Once the fire becomes large enough to register on both filters, the filter results are similar.

7.2 Oats1 Results

The oats1 data set displays a much larger variety of fire conditions but has a visible fire starting at frame 1. Figure 40 shows the results from both filters and a raw long wave intensity threshold.

Figure 40 Oats1 Results, Band Pass is Green and High Pass is Blue

Frames 1 through 1080 display a small fire that is barely detectable using raw long wave data. The raw long wave data recorded on average 2.5 pixels of fire during this time. The band pass and high pass filtered data perform comparably and records on average 40 pixels of fire during the same time period. Due to the group delay of the filter the band pass result doesn't register until frame 60 or 2 seconds for the band pass filter and frame 35 or 1 second for the high pass filter.

During times of peak fire activity, frames 2200 through 3300, the band pass filter significantly outperforms the high pass filter. The band pass filter registers on average 450 fire pixels while the high pass registers on average 300 fire pixels.

7.3 Examining False Positives

The algorithm in this thesis is designed assuming no knowledge of where the center of the fire is. If implemented additional parameters can be added depending on the particular scene the camera is looking at. In general this algorithm is designed to look for forest fires away from civilization. In this setting most of the false positives due to traffic

movement and buildings would not apply. Regardless these false positives still need to be looked at. Every instance where the 30 frame filtered false positive peaks above 25 pixels is recorded. Table 8 lists the total number of false positives for each data set until the frame rate started to fail.

Table 8 Total Number of False Positives for Each Data Set

Data Set	Total Frames	High Pass False Positives	Band Pass False Positives	Comments
Setup1	3753	0	0	
Charcoal1	4000	1	1	
Oats1	8000	1	2	
Oats2	395	0	0	
Oats2b	8000	2	2	
Oats3	8000	2	2	
Pine_needles	14934	3	6	
Pine_cones	8000	2	2	Frame rate starts to fail
Palm	4405	0	3	
Thistle	6670	N/A	N/A	Frame rate failed
The frame rate continues to deteriorate for the remaining data sets. False positive readings are meaningless for the rest of the results				

There are several types of false positives. Common false positives get generated by initial movement frames, excessive random movement and high altitude signals. Most

peak false positive readings correspond to multiple occurrences in separate location is the frame.

7.3.1 Initial Movement Frames

The first or last movement of an object occasionally triggers a positive fire reading. The object appears in the long wave infrared image slightly before the mid wave image. Because the object is not present in the mid wave image the long wave power is considerable more. Frame 4580 and 4581 on the band pass implementation shows an example of this type of false positive in Figure 41.

Figure 41 Example of false positive due to movement

7.3.2 High Altitude False Positive

The third false positive in the oats1 data set around frame 7921 appears well above the horizon in the upper left corner, see Figure 42. This point cannot be a fire even though there is 300 times as much power in the long wave over the mid wave. This object appear on and off for about 30 frames without moving. Similar appearing objects appear in this same location in later data sets. This must either be something in space or

at a high altitude reflecting or generating long wave infrared energy. Another possibility is the pixels produce false measurements. Regardless the algorithm can be adjusted to ignore anything above the horizon.

Figure 42 False Positive due to High Altitude Source

7.3.3 False Positive due to Street Light

Figure 43 shows another type of false positive appears to be location orientated. The pixels around location (375, 350) generate a large number of false positives when moving vehicles pass. On closer review a street light shines a light form about this location. This light must add some long wave energy without the corresponding mid wave energy to trigger a false positive. In an actual implementation areas around stationary lights like this may need additional filtering.

Figure 43 False Positive due to Street Light

CHAPTER 8

Proposed Implementation

The goal of this thesis is to derive algorithms that can be used to accurately detect early forest fires. The next step is to implement these in a real time system. The implementation of this in a real world scenario depends on many factors outside to scope of this thesis like: sensor type, sensor data bus, processor type and how the data get to a user. This section briefly discusses some possible implementation issues that need addressing in the future.

These algorithms were designed and tested using MATLAB on previously recorded data. MATLAB simplifies the design process at the cost of performance. Because of this the current implementation can never run in real time. The current design uses the flow shown in Figure 44 and

Table 9 shows the current required time for each step in MATLAB. These times are an example and may change depending on how many objects need fire/no fire analysis.

Figure 44 Algorithm Block Diagram

Table 9 Algorithm Processing Time Requirements

Step:	Time:
Read in MWIR /LWIR Data	0.1840 seconds
Preform Filtering	0.1402 seconds
Generate Figures	0.0713 seconds
Generate Movie File	0.4165 seconds
Total	0.8120 seconds
Maximum Allowed Time Per Frame (30 fps)	0.0333 seconds

In the current implementation the algorithm uses 24 times that amount of time allowed to perform all steps. If only considering the filtering step the algorithm uses just over 4 times the maximum allowed time. MATLAB as an interpretive language cannot implement this algorithm in real time.

There are a couple of solutions to this, first is to use a compiled language like C/C++ instead of an interpretive one. Compilers convert code into a machine code once while optimizing the entire program. An interpreter, like MATLAB, must perform this action on each line of code as it run. Compiled code usually runs much quicker than interpreted code [25]. Using a compiled program alone should speed up the algorithm enough for real time use.

A second solution, if just using compiled code doesn't gain enough performance, is to perform the operations in parallel using a graphical processing unit (GPU) [26]. Almost every step in the filtering can be optimized to work in parallel. A GPU can process every pixel of a frame independently and at the same time. The pixels require no information about their neighbors until the spatial filtering stage. The only step that requires a serial process is the connected component analysis but there is currently research being done on parallel implementations [27]. A parallel implementation should meet the 30 frames per second requirement. This parallel implementation requires significant changes in code for best optimization.

CHAPTER 9

Future Work

The data analyzed in this thesis represents a very small and select range of fire data. The data analyzed always looks at the same scene, same fire location with the same environmental conditions. To truly create a robust fire detection system requires the analysis of additional variables. The variable that needs the most attention is the amount of ambient light. All of the fire data gathered took place during the middle of the day. Any fire detection system needs to have 24 hour coverage; forest fires don't only occur during the day. The cameras used for this thesis, MWIR and LWIR, were selected over the RGB camera for their performance in night time conditions. Using these cameras at night should yield similar results but this needs testing and verification.

Another concern involves the distance of the fire. As discussed in chapter 2 the atmosphere absorbs LWIR and MWIR signals differently. The algorithm may misclassify a very close fire and a further away fire due to the increased mid wave energy the sensor receives. As the fire moves further away the sensor receives less energy from both bands. Both of these conditions need testing.

Additionally neither this algorithm nor any others designed off these data sets can run on a real time system in their current implementation. The purpose of this thesis was to find algorithms that can detect forest fire. Implementing them in a real time system is a different project full of its own challenges. In order for this algorithm ever to detect a forest fire it needs to be adapted to a real time system.

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Appendices

A. Results for All Data Sets

B. MATLAB Code Used

APPENDIX A

Results for All Data Sets

Table 10 shows the file name for the movie results generated from each data set using b_batch_run.m script.

Table 10 Results Movie Files

Data Set	High Pass Movie File Name	Band Pass Movie File Name
Applewood1	dual_fir_highpass_applewood1.avi	dual_iir_bandpass_applewood1.avi
Applewood2	dual_fir_highpass_applewood2.avi	dual_iir_bandpass_applewood2.avi
Charcoal1	dual_fir_highpass_charcoal1.avi	dual_iir_bandpass_charcoal1.avi
Extinguish	dual_fir_highpass_extinguish.avi	dual_iir_bandpass_extinguish.avi
Oats1	dual_fir_highpass_oats1.avi	dual_iir_bandpass_oats1.avi
Oats2	dual_fir_highpass_oats2.avi	dual_iir_bandpass_oats2.avi
Oats2b	dual_fir_highpass_oats2b.avi	dual_iir_bandpass_oats2b.avi
Oats3	dual_fir_highpass_oats3.avi	dual_iir_bandpass_oats3.avi
Palm	dual_fir_highpass_palm.avi	dual_iir_bandpass_palm.avi
Pine_cones	dual_fir_highpass_pine_cones.avi	dual_iir_bandpass_pine_cones.avi
Pine_needles	dual_fir_highpass_pine_needles.avi	dual_iir_bandpass_pine_needles.avi
Rosemary	dual_fir_highpass_rosemary.avi	dual_iir_bandpass_rosemary.avi
Setup1	dual_fir_highpass_setup1.avi	dual_iir_bandpass_setup1.avi
Thistle	dual_fir_highpass_thistle.avi	dual_iir_bandpass_thistle.avi
Wet_dry1	dual_fir_highpass_wet_dry1.avi	dual_iir_bandpass_wet_dry1.avi
Wet_dry2	dual_fir_highpass_wet_dry2.avi	dual_iir_bandpass_wet_dry2.avi
Wet_leaves	dual_fir_bandpass_wet_leaves.avi	dual_iir_bandpass_wet_leaves.avi

Each movie file displays six different frames. From top left to bottom right displays the following:

Top left: Filtered MWIR Power Image

Top right: Threshold of filtered MWIR Image (not used, for reference only)

Middle left: Filtered LWIR Image

Middle right: Threshold of Filtered LWIR image (final results)

Bottom left: Raw LWIR Power Image

Bottom Right: Threshold of LWIR Image

The threshold of LWIR image frame includes three different markers one for each detected object explained in Table 11.

Table 11 Detected Object Markers

Symbol	Object Type
Red *	Fire Object
Green *	Non-Fire (Failed Eccentricity test)
Green O	Non-Fire (Failed LW vs. MW Power test)

The rest of the charts in this appendix display the total fire results and false positives for each data set.

Setup1:

Charcoal1:

Oats1:

Oats2:

Oats2b:

Oats3:

Pine Needles:

Pine Cones:

Palm:

Thistle:

Wet_leaves:

Wet_dry1:

Wet_dry2:

Rosemary:

Applewood1:

Applewood2:

Extinguish:

APPENDIX B

MATLAB Code Used

File Name:	Brief Description
b_generate_all.m	Generates Filter Coefficients for both band pass and high pass filter. It also generates the selective gain image
first_250_gen.m	Generate the selective gain image from the first 250 frames of charcoal data
b_fir_highpass.m	Generates the high pass filter coefficients
b_iir_bandpass.m	Generates the band pass filter coefficients
b_fir_highpass_length.m	Displays frequency response of high pass filter with different filter lengths
b_iir_bandpass_length.m	Displays frequency response of band pass filter with different filter lengths
small_pix_gen.m	Generates 128 by 128 by 8000 matrix with oats1 frames centered on the fire location
edge_freq_data.m	Generates all the signal type plots
b_fir_filter_test_dual.m	Runs the high pass filter on a set of data
b_iir_filter_test_dual.m	Runs the band pass filter on a set of data
b_batch_movie.m	Generates movies and results for all data sets
b_results_plots.m	Displays results for all data sets

b_generate_all.m

```
% this file generates all the variables required for the rest of the
files
% including filter coefficients and selective gain matrix
addpath('c:\matlab files\dsp');
% create baseline files
first_250_gen
```

```

baseline_bp_lw2_used_test = baseline_bp_lw2/mean(mean(
baseline_bp_lw2));
baseline_bp_mw2_used_test = baseline_bp_mw2/mean(mean(
baseline_bp_mw2));

baseline_hp_lw2_used_test = baseline_hp_lw2/mean(mean(
baseline_hp_lw2));
baseline_hp_mw2_used_test = baseline_hp_mw2/mean(mean(
baseline_hp_mw2));
% create fir hp coeff
w_len = 31;
b_fir_highpass
% create iir bp coeff
filter_len = 4;
b_iir_bandpass
% generate small picture matrix for mw and lw
%small_pix_gen
default_file_names = 1;
%b_iir_filter_test_dual_full
%b_fir_filter_test_dual_full
close all

```

first_250_gen.m

```

% This file generates the selective gain filter for both the FIR high
pass
% and IIR band pass filter

% Source files
%read_file1 = 'c:\matlab files\oats1_mw_png\oats1_';
%read_file2 = 'c:\matlab files\oats1_lw_png\oats1_';
read_file1 = 'C:\matlab files\png_images\cmwir\charcoal1\charcoal1_';
read_file2 = 'C:\matlab files\png_images\clwir\charcoal1\charcoal1_';

% generate vars
baseline_store_mw = zeros(480,640,250);
baseline_store_lw = zeros(480,640,250);

h1 = waitbar(0,'file progress');
%load 250 files
for z = 1:1:250
    %load image
    image1 = imread(strcat(read_file1,num2str(z),'.png'));
    image2 = imread(strcat(read_file2,num2str(z),'.png'));
    baseline_store_mw(:, :, z) = im2double(image1);
    baseline_store_lw(:, :, z) = im2double(image2);
    waitbar(z/250,h1,strcat('file # ',num2str(z), ' / ',num2str(250)))
end

```

```

delete(h1)
h1 = waitbar(0, 'fft progress');
%% create baseline_mw
pix_fft = fft(reshape(baseline_store_mw(:, :, 1:250), 480*640, 250)');
pix_fft2 = reshape(pix_fft', 480, 640, 250);
baseline_bp_mw = sum(abs(pix_fft2(:, :, 11:20)), 3);
baseline_hp_mw = sum(abs(pix_fft2(:, :, 105:125)), 3);
baseline_bp_small_mw = baseline_bp_mw(301:428, 301:428);
baseline_hp_small_mw = baseline_hp_mw(301:428, 301:428);
waitbar(1/5, h1, strcat('mw fft done'))
%% create corrected baseline_mw
baseline_bp_mw2 = baseline_bp_mw;
baseline_bp_mw2(63+300:71+300, 46+300:57+300) = .03;
baseline_bp_mw2(69+300, 46+300:57+300) = .07;
baseline_bp_small_mw2 = baseline_bp_mw2(301:428, 301:428);

baseline_hp_mw2 = baseline_hp_mw;
baseline_hp_mw2(63+300:71+300, 46+300:57+300) = .02;
baseline_hp_mw2(69+300, 46+300:57+300) = .04;
baseline_hp_small_mw2 = baseline_hp_mw2(301:428, 301:428);
waitbar(2/5, h1, strcat('mw fft corrected'))
%% create baseline_lw
pix_fft = fft(reshape(baseline_store_lw(:, :, 1:250), 480*640, 250)');
pix_fft2 = reshape(pix_fft', 480, 640, 250);
baseline_bp_lw = sum(abs(pix_fft2(:, :, 11:20)), 3);
baseline_hp_lw = sum(abs(pix_fft2(:, :, 105:125)), 3);
baseline_bp_small_lw = baseline_bp_lw(301:428, 301:428);
baseline_hp_small_lw = baseline_hp_lw(301:428, 301:428);
waitbar(3/5, h1, strcat('lw fft done'))
%% create corrected baseline_lw
baseline_bp_lw2 = baseline_bp_lw;
baseline_bp_lw2(63+300:71+300, 46+300:57+300) = .03;
baseline_bp_lw2(69+300, 46+300:57+300) = .07;
baseline_bp_small_lw2 = baseline_bp_lw2(301:428, 301:428);

baseline_hp_lw2 = baseline_hp_lw;
baseline_hp_lw2(63+300:71+300, 46+300:57+300) = .02;
baseline_hp_lw2(69+300, 46+300:57+300) = .04;
baseline_hp_small_lw2 = baseline_hp_lw2(301:428, 301:428);

waitbar(4/5, h1, strcat('lw fft corrected'))
%% clean up un wanted vars
clear('pix_fft')
clear('pix_fft2')
clear('baseline_store_mw')
clear('baseline_store_lw')
waitbar(5/5, h1, strcat('memory cleaned'))
delete(h1)

```

b_fir_highpass.m

```
% This file generates FIR high pass filter coeff. Requies filter
length
% (w_len) to be set out side (b_generate_all.m or
b_FIR_filter_length.m)
fc = 13/30;
win1 = window('hamming',w_len);
[h1] = FIR_Filter_By_Window(w_len,fc,win1);
[h2] = transform_lp2hp(h1);
[ poles, zeroes, HF_fir2, ~, ~, ~ ] = ...
    show_filter_responses(1,h2,30,1000,1000,1000);
f1 = h2;
```

b_iir_bandpass.m

```
% This file generates IIR band pass filter coeff. Requies filter
length
% (w_len) to be set out side (b_generate_all.m or
b_IIR_filter_length.m)
filter_movie = 0; % set to 1 to filter pix_small
filter_len = 4;
fc = 1.7; %in analog freq
bw = 0.8; % in analog freq
s_rate = 30; % sample rare (30 frames per second)

[z p k] = buttap(filter_len); % low pass proto at 1 rad/s
%[z p k] = cheblap(filter_len,rip1);
%[z,p,k] = ellipap(filter_len,rip1,rip2);
Bk = k * poly(z); % convert zeros to num vals
Ak = poly(p); % convert poles to denometers vals
[bt at] = lp2bp(Bk,Ak,2.*pi.*(fc),2.*pi.*(bw)); % convert to bandpass
[numd,dend] = bilinear(bt,at,30); % convert to digital
[ ~, ~, HF, Fd, ~, ~ ] =
show_filter_responses(dend,numd,30,1000,500,2000);

% to filter movie
if filter_movie
    filt_out = filter(numd,dend,reshape(pix_small,128*128,8000)');
    filt_out2 = reshape(filt_out',128,128,8000);
end
```

b_fir_highpass_length.m

```
% this file displays fir high pass filters of diffrent length
rip1 = 1;
rip2 = 50;
order_start = 21;
order_end = 29;
order_store_num = (order_end-order_start)/2 + 1;
HF_store = zeros(1000,order_store_num);
```

```

HF_store_phase = zeros(1000,order_store_num);

for z1 = order_start : 2 : order_end
    w_len = z1;
    index1 = (z1-order_start)/2 +1;
    b_fir_highpass
    HF_store(:,index1) = HF_fir2;
    HF_store_phase(:,index1) =unwrap(angle(HF_fir2));
end
f_dim = [0:15/(1000-1):15]*ones(1,order_store_num);
group_delay = -(1000./15).*(1./(2.*pi)).*diff(HF_store_phase,1,1);
figure(200); plot(f_dim,abs(HF_store));ylim([0 1.5]);
figure(201);
plot(f_dim(1:999),-(1000./15).*(1./(2.*pi)).*diff(HF_store_phase,1,1));
ylim([0 3]);xlabel('Frequency (Hz)');ylabel('Group Delay (s)');
title('High Pass Filter Group Delay');% group delay in seconds?
figure(202);
plot(f_dim(1:999),-
(1000./15).*(1./(2.*pi)).*diff(HF_store_phase,1,1).*30;
ylim([0 60]);xlabel('Frequency (Hz)');
ylabel('High Pass Group Delay (samples)');
%group delay in samples (*30 samp/sec)

pass_band_delay_ave = mean(group_delay(81:168,:),1);
pass_band_delay_max = max(group_delay(81:168,:),[],1);

```

b_iir_bandpass_length.m

```

% this file shows the results of iir bandpass filters of different
lengths
%iir bandpass var len
rip1 = 1;
rip2 = 50;
max_order = 5;
HF_store = zeros(1000,max_order);
HF_store_phase = zeros(1000,max_order);

for z1 = 1:1:max_order
    filter_len = z1;
    b_iir_bandpass
    HF_store(:,z1) = HF;
    HF_store_phase(:,z1) = unwrap(angle(HF));
end
f_dim = [0:15/(1000-1):15]*ones(1,max_order);
group_delay = -(1000./15).*(1./(2.*pi)).*diff(HF_store_phase,1,1);
figure(200); plot(f_dim,abs(HF_store));ylim([0 1.2]);
figure(201);
plot(f_dim(1:999),-(1000./15).*(1./(2.*pi)).*diff(HF_store_phase,1,1));
ylim([0 3]);
xlabel('Frequency (Hz)');ylabel('Group Delay (s)');

```



```

title('Band Pass Filter Group Delay');% group delay in seconds?

figure(202);
plot(f_dim(1:999),-
(1000./15).*(1./(2.*pi)).*diff(HF_store_phase,1,1).*30);
ylim([0 60]);xlabel('Frequency (Hz)');ylabel('Group Delay (samples)');
%group delay in samples (*30 samp/sec)

pass_band_delay_ave = mean(group_delay(81:168,:),1);
pass_band_delay_max = max(group_delay(81:168,:),[],1);

```

small_pix_gen.m:

```

% This file generates a 128 X 128 X 8000 matrix with an image for each
% frame of oats1 data focused on the fire region
% generate vars
pix_small_mw = zeros(128,128,8000);
pix_small_lw = zeros(128,128,8000);

pix_small_mw2 = zeros(128,128,8000);
pix_small_lw2 = zeros(128,128,8000);

image_diff = zeros(1,8000);
read_file1 = 'c:\matlab files\oats1_mw_png\oats1_';
read_file2 = 'c:\matlab files\oats1_lw_png\oats1_';
%read_file1 = 'c:\matlab
files\png_images\cmwir\applewood1\applewood1_';
%%read_file2 = 'c:\matlab
files\png_images\clwir\applewood1\applewood1_';

h1 = waitbar(0,'file progress');
%image1_old = imread(strcat(read_file1,num2str(1),'.png'));
for z = 1:1:8000
    %load image
    image1 = imread(strcat(read_file1,num2str(z),'.png'));
    image2 = imread(strcat(read_file2,num2str(z),'.png'));
    % procedure to reject bad files
    % image_diff(z) = sum(sum(abs(double(image1) -
double(image1_old))));
    % if image_diff(z) > (7 * 10^10)
    %     %image1 = image1_old;
    %     %z
    % end
    %
    % image1_old = image1;
    % end procedure to reject bad files
    pix_small_mw(:,:,z) = im2double(image1(301:428,301:428));
    pix_small_lw(:,:,z) = im2double(image2(301:428,301:428));

```

```

    pix_small_mw2(:, :, z) = im2double(image1(101:228, 101:228));
    pix_small_lw2(:, :, z) = im2double(image2(101:228, 101:228));

    waitbar(z/8000, h1, strcat('file # ', num2str(z), ' / ', num2str(8000)))

end
delete(h1)

clear('image1')
clear('image2')

```

edge_freq_data.m

```

% this file generates frequency plots for the following pixel types:
% strong edge, fire pixel, center fire pixel, uniform pixel, textured
pixel
% and moving object pixel

edge_pix = [119 39;...
            119 40;...
            119 41;...
            120 39;...
            120 40;...
            120 41;...
            110 31;...
            111 31;...
            112 31;...
            120 97;...
            120 98;...
            121 97;...
            121 96;...
            122 95;...
            119 107;...
            120 107;...
            119 106;...
            110 42;...
            110 43;...
            110 44];

[s1 s2] = size(edge_pix);
fft_ave_lw = zeros(1, 8000);
fft_ave_mw = zeros(1, 8000);
for z = 1 : 1 : s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw(edge_pix(z, 1), edge_pix(z, 2), :), 1, 8000)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw(edge_pix(z, 1), edge_pix(z, 2), :), 1, 8000)));
end
fft_ave_lw = fft_ave_lw./s1;

```

```

fft_ave_mw = fft_ave_mw./s1;

figure(100)
plot([0:15/(4000-1):15],fft_ave_lw(1:1:4000),...
      [0:15/(4000-1):15],fft_ave_mw(1:1:4000))
ylim([0 .5])
title('Average Power of 20 Roof Edge Pixels')
xlabel('Frequency (Hz)')
ylabel('Power')

figure(201)
imshow(pix_small_lw(:, :, 1), [.06 .087])
hold on
for z1 = 1:1:s1
    plot(edge_pix(z1,2),edge_pix(z1,1), '.', 'color', 'red');
end
hold off

tree_pix = [100 5;...
            101 5;...
            102 5;...
            103 5;...
            104 5;...
            100 6;...
            101 6;...
            102 6;...
            103 6;...
            104 6;...
            100 7;...
            101 7;...
            102 7;...
            103 7;...
            104 7;...
            100 8;...
            101 8;...
            102 8;...
            103 8;...
            104 8];
[s1 s2] = size(edge_pix);
fft_ave_lw = zeros(1,8000);
fft_ave_mw = zeros(1,8000);
for z =1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw(tree_pix(z,1),tree_pix(z,2),:),1,8000)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw(tree_pix(z,1),tree_pix(z,2),:),1,8000)));
end
fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;
figure(101)
plot([0:15/(4000-1):15],fft_ave_lw(1:1:4000),...
      [0:15/(4000-1):15],fft_ave_mw(1:1:4000))
ylim([0 .5])
title('Average Power of 20 Tree Pixels')

```

```

xlabel('Frequency (Hz)')
ylabel('Power')

figure(202)
imshow(pix_small_lw(:, :, 1), [.06 .087])
hold on
for z1 = 1:1:s1
    plot(tree_pix(z1,2),tree_pix(z1,1),'.','color','red');
end
hold off

%% define circles out of center (chebcheve dist)
fire_ylim = .5;
fire_pix_ch_1 = [68 50];
fire_pix_ch_2 = [67 49;...
    67 50;...
    67 51;...
    68 49;...
    68 51;...
    69 49;...
    69 50;...
    69 51];
fire_pix_ch_3 = [66 48;...
    66 49;...
    66 50;...
    66 51;...
    66 52;...
    67 48;...
    67 52;...
    68 48;...
    68 52;...
    69 48;...
    69 52;...
    70 48;...
    70 49;...
    70 50;...
    70 51;...
    70 52];
fire_pix_ch_4 = [65 47;...
    65 48;...
    65 49;...
    65 50;...
    65 51;...
    65 52;...
    65 53;...
    66 47;...
    66 53;...
    67 47;...
    67 53;...
    68 47;...
    68 53;...
    69 47;...
    69 53;...
    70 47;...

```

```

70 53;...
71 47;...
71 48;...
71 49;...
71 50;...
71 51;...
71 52;...
71 53];

t_start = 1;
t_end = 1080;
time_len = t_end - t_start + 1;
time_len2 = time_len/2;

[s1 s2] = size(fire_pix_ch_1);
fft_ave_lw = zeros(1,time_len);
fft_ave_mw = zeros(1,time_len);
for z = 1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw(fire_pix_ch_1(z,1),fire_pix_ch_1(z,2),...
            t_start:t_end),1,time_len)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw(fire_pix_ch_1(z,1),fire_pix_ch_1(z,2),...
            t_start:t_end),1,time_len)));
end
fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;
figure(102)
plot([0:15/(time_len2-1):15],fft_ave_lw(1:1:time_len2),...
    [0:15/(time_len2-1):15],fft_ave_mw(1:1:time_len2))
ylim([0 fire_ylim])
title('Power of Center Fire Pixel (368, 350)')
xlabel('Frequency (Hz)')
ylabel('Power')

[s1 s2] = size(fire_pix_ch_2);
fft_ave_lw = zeros(1,time_len);
fft_ave_mw = zeros(1,time_len);
for z = 1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw(fire_pix_ch_2(z,1),fire_pix_ch_2(z,2),...
            t_start:t_end),1,time_len)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw(fire_pix_ch_2(z,1),fire_pix_ch_2(z,2),...
            t_start:t_end),1,time_len)));
end
fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;
figure(103)
plot([0:15/(time_len2-1):15],fft_ave_lw(1:1:time_len2),...
    [0:15/(time_len2-1):15],fft_ave_mw(1:1:time_len2))
ylim([0 fire_ylim])
title('Average Power of 8 Fire Pixels (Chebyshev Distance From Center =
1)')

```

```

xlabel('Frequency (Hz)')
ylabel('Power')

[s1 s2] = size(fire_pix_ch_3);
fft_ave_lw = zeros(1,time_len);
fft_ave_mw = zeros(1,time_len);
for z =1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw(fire_pix_ch_3(z,1),fire_pix_ch_3(z,2),...
            t_start:t_end),1,time_len)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw(fire_pix_ch_3(z,1),fire_pix_ch_3(z,2),...
            t_start:t_end),1,time_len)));
end
fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;
figure(104)
plot([0:15/(time_len2-1):15],fft_ave_lw(1:1:time_len2),...
    [0:15/(time_len2-1):15],fft_ave_mw(1:1:time_len2))
ylim([0 fire_ylim])
title('Average Power of 16 Fire Pixels (Chebyshev Distance From Center
= 2)')
xlabel('Frequency (Hz)')
ylabel('Power')

[s1 s2] = size(fire_pix_ch_4);
fft_ave_lw = zeros(1,time_len);
fft_ave_mw = zeros(1,time_len);
for z =1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw(fire_pix_ch_4(z,1),fire_pix_ch_4(z,2),...
            t_start:t_end),1,time_len)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw(fire_pix_ch_4(z,1),fire_pix_ch_4(z,2),...
            t_start:t_end),1,time_len)));
end
fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;
figure(105)
plot([0:15/(time_len2-1):15],fft_ave_lw(1:1:time_len2),...
    [0:15/(time_len2-1):15],fft_ave_mw(1:1:time_len2))
ylim([0 fire_ylim])
title('Average Power of 24 Fire Pixels (Chebyshev Distance From Center
= 3)')
xlabel('Frequency (Hz)')
ylabel('Power')

%% define circles out of center (city block dist)
fire_pix_cb_1 = [68 50];
fire_pix_cb_2 = [67 50;...
    69 50;...
    68 49;...
    68 51];

```

```

fire_pix_cb_3 = [66 50;...
                67 51;...
                68 52;...
                69 51;...
                70 50;...
                69 49;...
                68 48;...
                67 49];
fire_pix_cb_4 = [65 50;...
                66 51;...
                67 52;...
                68 53;...
                69 52;...
                70 51;...
                71 50;...
                70 49;...
                69 48;...
                68 47;...
                67 48;...
                66 49];

fire_pix_cb_5 = [64 50;...
                65 51;...
                66 52;...
                67 53;...
                68 54;...
                69 53;...
                70 52;...
                71 51;...
                72 50;...
                71 49;...
                70 48;...
                69 47;...
                68 46;...
                67 47;...
                66 48;...
                65 49];

t_start = 1;
t_end = 1080;
time_len = t_end - t_start + 1;
time_len2 = time_len/2;

[s1 s2] = size(fire_pix_cb_1);
fft_ave_lw = zeros(1,time_len);
fft_ave_mw = zeros(1,time_len);
for z =1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw(fire_pix_cb_1(z,1),fire_pix_cb_1(z,2),...
            t_start:t_end),1,time_len)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw(fire_pix_cb_1(z,1),fire_pix_cb_1(z,2),...
            t_start:t_end),1,time_len)));
end

```

```

fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;
figure(106)
plot([0:15/(time_len2-1):15],fft_ave_lw(1:1:time_len2),...
      [0:15/(time_len2-1):15],fft_ave_mw(1:1:time_len2))
ylim([0 fire_ylim])
title('Power of Center Fire Pixel (368, 350)')
xlabel('Frequency (Hz)')
ylabel('Power')

[s1 s2] = size(fire_pix_cb_2);
fft_ave_lw = zeros(1,time_len);
fft_ave_mw = zeros(1,time_len);
for z =1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw(fire_pix_cb_2(z,1),fire_pix_cb_2(z,2),...
            t_start:t_end),1,time_len)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw(fire_pix_cb_2(z,1),fire_pix_cb_2(z,2),...
            t_start:t_end),1,time_len)));
end
fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;
figure(107)
plot([0:15/(time_len2-1):15],fft_ave_lw(1:1:time_len2),...
      [0:15/(time_len2-1):15],fft_ave_mw(1:1:time_len2))
ylim([0 fire_ylim])
title('Average Power of 4 Fire Pixels (City Block Distance From Center = 1)')
xlabel('Frequency (Hz)')
ylabel('Power')

[s1 s2] = size(fire_pix_cb_3);
fft_ave_lw = zeros(1,time_len);
fft_ave_mw = zeros(1,time_len);
for z =1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw(fire_pix_cb_3(z,1),fire_pix_cb_3(z,2),...
            t_start:t_end),1,time_len)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw(fire_pix_cb_3(z,1),fire_pix_cb_3(z,2),...
            t_start:t_end),1,time_len)));
end
fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;
figure(108)
plot([0:15/(time_len2-1):15],fft_ave_lw(1:1:time_len2),...
      [0:15/(time_len2-1):15],fft_ave_mw(1:1:time_len2))
ylim([0 fire_ylim])
title('Average Power of 8 Fire Pixels (City Block Distance From Center = 2)')
xlabel('Frequency (Hz)')
ylabel('Power')

```



```

[s1 s2] = size(fire_pix_cb_4);
fft_ave_lw = zeros(1,time_len);
fft_ave_mw = zeros(1,time_len);
for z =1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw(fire_pix_cb_4(z,1),fire_pix_cb_4(z,2),...
            t_start:t_end),1,time_len)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw(fire_pix_cb_4(z,1),fire_pix_cb_4(z,2),...
            t_start:t_end),1,time_len)));
end
fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;
figure(109)
plot([0:15/(time_len2-1):15],fft_ave_lw(1:1:time_len2),...
    [0:15/(time_len2-1):15],fft_ave_mw(1:1:time_len2))
ylim([0 fire_ylim])
title('Average Power of 12 Fire Pixels (City Block Distance From Center
= 3)')
xlabel('Frequency (Hz)')
ylabel('Power')

[s1 s2] = size(fire_pix_cb_5);
fft_ave_lw = zeros(1,time_len);
fft_ave_mw = zeros(1,time_len);
for z =1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw(fire_pix_cb_5(z,1),fire_pix_cb_5(z,2),...
            t_start:t_end),1,time_len)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw(fire_pix_cb_5(z,1),fire_pix_cb_5(z,2),...
            t_start:t_end),1,time_len)));
end
fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;
figure(110)
plot([0:15/(time_len2-1):15],fft_ave_lw(1:1:time_len2),...
    [0:15/(time_len2-1):15],fft_ave_mw(1:1:time_len2))
ylim([0 fire_ylim])
title('Average Power of 16 Fire Pixels (City Block Distance From Center
= 4)')
xlabel('Frequency (Hz)')
ylabel('Power')

far_edge_pix = [80 5;...
                80 6;...
                80 7;...
                80 8;...
                80 9;...
                80 10;...
                80 11;...
                80 12;...
                80 13;...

```

```

80 14;...
80 15;...
80 16;...
80 17;...
80 18;...
80 19;...
80 20;...
80 21;...
80 22;...
80 23;...
80 24];

[s1 s2] = size(far_edge_pix);
fft_ave_lw = zeros(1,time_len);
fft_ave_mw = zeros(1,time_len);
for z =1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw2(far_edge_pix(z,1),far_edge_pix(z,2),...
            t_start:t_end),1,time_len)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw2(far_edge_pix(z,1),far_edge_pix(z,2),...
            t_start:t_end),1,time_len)));
end
fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;
figure(111)
plot([0:15/(time_len2-1):15],fft_ave_lw(1:1:time_len2),...
    [0:15/(time_len2-1):15],fft_ave_mw(1:1:time_len2))
ylim([0 .2])
title('Average Power of 20 Background Edges')
xlabel('Frequency (Hz)')
ylabel('Power')

%% moving car pix
% car moves at frame 445
mov_car_pix = [15 90;...
    15 91;...
    15 92;...
    15 93;...
    15 94;...
    15 95;...
    15 96;...
    15 97;...
    15 98;...
    15 99;...
    16 90;...
    16 91;...
    16 92;...
    16 93;...
    16 94;...
    16 95;...
    16 96;...
    16 97;...
    16 98;...
```

```

16 99];
t_start = 1145;
t_end = 1235;

t_start = 1100;
t_end = 1300;

time_len = t_end - t_start + 1;
time_len2 = time_len/2;
%time_len2 = 50;
[s1 s2] = size(mov_car_pix);
fft_ave_lw = zeros(1,time_len);
fft_ave_mw = zeros(1,time_len);
for z = 1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw2(far_edge_pix(z,1),far_edge_pix(z,2),...
            t_start:t_end),1,time_len)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw2(far_edge_pix(z,1),far_edge_pix(z,2),...
            t_start:t_end),1,time_len)));
end
fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;
figure(112)
plot([0:15/(time_len2-1):15],fft_ave_lw(1:1:time_len2),...
    [0:15/(time_len2-1):15],fft_ave_mw(1:1:time_len2))
ylim([0 .002])
title('Average Power of 20 Moving Car Pixels, Frames 1100 to 1300')
xlabel('Frequency (Hz)')
ylabel('Power')

[s1 s2] = size(uni_area);
fft_ave_lw = zeros(1,8000);
fft_ave_mw = zeros(1,8000);
for z = 1 : 1 :s1
    fft_ave_lw = fft_ave_lw + abs(fft(...
        reshape(pix_small_lw(uni_area(z,1),uni_area(z,2),:),1,8000)));
    fft_ave_mw = fft_ave_mw + abs(fft(...
        reshape(pix_small_mw(uni_area(z,1),uni_area(z,2),:),1,8000)));
end
fft_ave_lw = fft_ave_lw./s1;
fft_ave_mw = fft_ave_mw./s1;

figure(113)
plot([0:15/(4000-1):15],fft_ave_lw(1:1:4000),...
    [0:15/(4000-1):15],fft_ave_mw(1:1:4000))
ylim([0 .5])
title('Average Power of 20 Uniform Pixels')
xlabel('Frequency (Hz)')
ylabel('Power')

figure(205)
imshow(pix_small_lw(:,:,1),[.06 .087])
hold on

```

```

for z1 = 1:1:s1
    plot(uni_area(z1,2),uni_area(z1,1),'.','color','red');
end
hold off
figure(300);

```

b_fir_filter_test_dual.m:

```

% This file runs the FIR band high filter.  First run b_generate_all.m.

if default_file_names ~= 0
    mov_write_file = 'c:\matlab files\movies2\charcoal1_prebatch2';
    % Source files
    read_file1 = 'C:\matlab
files\png_images\cmwir\charcoal1\charcoal1_';
    read_file2 = 'C:\matlab
files\png_images\clwir\charcoal1\charcoal1_';
    mov_len = 4000;
    raw_thr_lw = [.06 .087]; % pine cones
end

%mov_len = 8000;
comp = 0;
lw_thr = 1e-8;
mw_thr = 1e-8;
mw_lw_diff = 6; % diff between mw and lw image to be fire
Ecc_val = .9; %
d_mw2lw_val = 5;
d_time_val = 7;

frame_row = 480/(2^comp);
frame_col = 640/(2^comp);
line_len = 10+20/(2^comp);

raw_hit = zeros(1,mov_len);
filt_hit = zeros(1,mov_len);
filt_hit_bad = zeros(1,mov_len);

aviobj = VideoWriter(mov_write_file);
open(aviobj);
%data_source = 1; % 1 ==lw else == mw
%raw_thr_lw = [.06 .0805];
raw_thr_mw = [.09 .11];

[s1 s2] = size(f1);
x_old_mw = zeros(frame_row,frame_col,s2);
%y_old_mw = zeros(128,128,s2);

```

```

x_old_lw = zeros(frame_row,frame_col,s2);
%y_old_lw = zeros(128,128,s2);
y_out_mw = zeros(frame_row,frame_col);
y_out_lw = zeros(frame_row,frame_col);

filter_B = zeros(frame_row,frame_col,s2);
filter_A = zeros(frame_row,frame_col,s2);
y_out = zeros(frame_row,frame_col);
%iir_filter_out = zeros(128,128,mov_len);
%iir_filter_out2 = zeros(128,128,mov_len);
mw_image = im2double(imread(strcat(read_file1,num2str(1),'.png')));
lw_image = im2double(imread(strcat(read_file2,num2str(1),'.png')));

mw_image = b_dist_scale(mw_image,comp);
lw_image = b_dist_scale(lw_image,comp);

baseline_bp_mw2_used = b_dist_scale(baseline_bp_mw2,comp);
baseline_bp_lw2_used = b_dist_scale(baseline_bp_lw2,comp);

for z =1 :1 :s2
    filter_B(:,:,z) = ones(frame_row,frame_col).*f1(z);
    %filter_A(:,:,z) = ones(128,128).*dend(z);
    x_old_mw(:,:,z) = mw_image;
    %y_old_mw(:,:,z) = zeros(128,128);
    x_old_lw(:,:,z) = lw_image;
    %y_old_lw(:,:,z) = zeros(128,128);
end

h_mw = fspecial('gaussian',[5 5],1); %spacial filter
h_lw = fspecial('gaussian',[5 5],1); %spacial filter

hit_num = zeros(1,mov_len);
hit_num_base = zeros(1,mov_len);
%s_f1 = fspecial('gaussian',5,.5);

%Center value
s_list1 = 50; % num of objects
s_list2 = 5; % num of frames to look back
stat_r_list_mw = zeros(s_list1,s_list2);
stat_c_list_mw = zeros(s_list1,s_list2);
stat_r_list_lw = zeros(s_list1,s_list2);
stat_c_list_lw = zeros(s_list1,s_list2);

h_waitbar = waitbar(0,'file progress');

figure(2)
close figure 2
h_pic = figure(2);
set(h_pic,'Visible','off','PaperPositionMode','auto');

```

```

figure(1)
close figure 1

h2 = figure(1);
set(gcf, 'Visible', 'off', 'Position', ...
    [100,100,1500,1000], 'PaperPositionMode', 'auto');
for z = 1:1:mov_len
    % load mw data
    mw_image = im2double(imread(strcat(read_file1,num2str(z),'.png')));
    lw_image = im2double(imread(strcat(read_file2,num2str(z),'.png')));
    mw_image = b_dist_scale(mw_image,comp);
    lw_image = b_dist_scale(lw_image,comp);

    x_old_mw(:, :, 2:s2) = x_old_mw(:, :, 1:s2-1);
    x_old_mw(:, :, 1) = mw_image;
    % process mw data
    y_out_mw = sum(x_old_mw .* filter_B,3);
    y_out_mw_test = imfilter((y_out_mw .* y_out_mw) ./...
        baseline_hp_mw2_used_test,h_mw);
    y_out_mw_test_bw = im2bw(y_out_mw_test,mw_thr);

    %y_out_mw_test_bw = sign(y_out_mw_test);
    %y_out_mw_test_bw(y_out_mw_test_bw == -1) = 0;

    y_out_bw_mw = y_out_mw_test_bw;
    y_out2_mw = y_out_mw_test;
    %y_out2_mw =
    imfilter(abs(y_out_mw./(100.*baseline_hp_mw2_used)),h);
    %y_out_bw_mw = im2bw(y_out2_mw,.0045);
    [lab_image_mw num_obj_mw] = bwlabel(y_out_bw_mw);

    % load lw data
    x_old_lw(:, :, 2:s2) = x_old_lw(:, :, 1:s2-1);
    x_old_lw(:, :, 1) = lw_image;
    % process lw data
    y_out_lw = sum(x_old_lw .* filter_B,3);
    y_out_lw_test = imfilter((y_out_lw .* y_out_lw) ./
baseline_hp_lw2_used_test,h_lw);
    y_out_lw_test_bw = im2bw(y_out_lw_test,lw_thr);

    %y_out_lw_test_bw = sign(y_out_lw_test);
    %y_out_lw_test_bw(y_out_lw_test_bw == -1) = 0;

    y_out_bw_lw = y_out_lw_test_bw;
    y_out2_lw = y_out_lw_test;
    %y_out2_lw =
    imfilter(abs(y_out_lw./(100.*baseline_hp_lw2_used)),h);

```

```

%y_out_bw_lw = im2bw(y_out2_lw,.005);
[lab_image_lw num_obj_lw] = bwlabel(y_out_bw_lw);
stat_lw = regionprops(lab_image_lw,y_out2_lw,...
    'Centroid','Area','Eccentricity','MeanIntensity');
stat_mw = regionprops(lab_image_lw,y_out2_mw,...
    'centroid','Area','MeanIntensity');

%% mw filtered display
subplot(3,2,1)
%imagesc(abs(y_out),[0.000 .0001])
%imagesc(abs(y_out),[0.000 .1]) %non thr display
imagesc(y_out2_mw,[0 mw_thr])
title('mw filtered image')
hold on
plot([10 30],[10 10],'red')
text(1,20, strcat('current frame: ',num2str(z)))
hold off

subplot(3,2,2)
%imagesc(im2bw(abs(y_out),.1),[0 1]) %non thr display
%imagesc(im2bw(abs(y_out./(100.*pix_small_thr2)),.0001),[0 1])
imagesc(y_out_bw_mw,[0 1])
title('mw binary image')
hold on
plot([10 30],[10 10],'red')

% internet code start
%shift last three frames of data

total_frame_hit_mw = 0;
%stat1_new = zeros(numel(stat),2);
stat_r_new_mw = zeros(s_list1,1);
stat_c_new_mw = zeros(s_list1,1);
for x = 1: min([50 numel(stat_mw)])
    d = min(sum(abs(stat_r_list_mw - stat_mw(x).Centroid(1).*...
        ones(s_list1,s_list2)) + abs(stat_c_list_mw -...
    if stat_mw(x).Area > 100
        plot(stat_mw(x).Centroid(1),stat_mw(x).Centroid(2),'ro');
        total_frame_hit_mw = total_frame_hit_mw + stat_mw(x).Area;
    elseif d < 5
        plot(stat_mw(x).Centroid(1),stat_mw(x).Centroid(2),'ro');
        total_frame_hit_mw = total_frame_hit_mw + stat_mw(x).Area;
    else
        plot(stat_mw(x).Centroid(1),stat_mw(x).Centroid(2),...
            'ro','color','green');
    end
    stat_r_new_mw(x) = stat_mw(x).Centroid(1);
    stat_c_new_mw(x) = stat_mw(x).Centroid(2);
end
stat_r_list_mw(:,2:s_list2) = stat_r_list_mw(:,1:s_list2-1);
stat_c_list_mw(:,2:s_list2) = stat_c_list_mw(:,1:s_list2-1);

```

```

stat_r_list_mw(:,1) = stat_r_new_mw;
stat_c_list_mw(:,1) = stat_c_new_mw;
%internet code end
text(1,20, strcat('current frame: ', num2str(z), ...
    '      number of hits: ', num2str(total_frame_hit_mw)))
hold off

%% lw filtered display
lw_sp = subplot(3,2,3);
%imagesc(abs(y_out),[0.000 .0001])
%imagesc(abs(y_out),[0.000 .1]) %non thr display
imagesc(y_out2_lw,[0 lw_thr])
title('lw filtered image')
hold on
plot([10 30],[10 10],'red')
text(1,20, strcat('current frame: ', num2str(z)))
hold off
subplot(3,2,4);
%imagesc(im2bw(abs(y_out),.1),[0 1]) %non thr display
%imagesc(im2bw(abs(y_out./(100.*pix_small_thr2)),.0001),[0 1])
imagesc(y_out_bw_lw,[0 1])
title('lw binary image')
[lab_image_lw num_obj_lw] = bwlabel(y_out_bw_lw);
hold on
plot([10 30],[10 10],'red')

% internet code start
%shift last three frames of data

%stat1_new = zeros(numel(stat),2);
stat_r_new_lw = zeros(s_list1,1);
stat_c_new_lw = zeros(s_list1,1);
total_frame_hit_lw = 0;
total_frame_hit_lw_bad = 0;
for x = 1: min([50 numel(stat_lw)])
    d = min(sum(abs(stat_r_list_lw - stat_lw(x).Centroid(1).*...
        ones(s_list1,s_list2)) + abs(stat_c_list_lw -...
        stat_lw(x).Centroid(2).*ones(s_list1,s_list2)),2)...
        - max(abs(stat_r_list_lw - stat_lw(x).Centroid(1).*...
        ones(s_list1,s_list2)) + abs(stat_c_list_lw -...
        stat_lw(x).Centroid(2).*ones(s_list1,s_list2)),[],2));
    dist_mat = abs(stat_r_list_lw - stat_lw(x).Centroid(1).*...
        ones(s_list1,s_list2)) + abs(stat_c_list_lw -...
        stat_lw(x).Centroid(2).*ones(s_list1,s_list2));
    d_time = sum(min(dist_mat));
    c_distances = abs(stat_r_new_mw - stat_lw(x).Centroid(1).*...
        ones(s_list1,1)) + abs(stat_c_new_mw -...
        stat_lw(x).Centroid(2).*ones(s_list1,1));
    d_mw2lw = min(c_distances);
    [mw_zero_check ~] = size(stat_mw);

```



```

        if (d_mw2lw < 8) && (mw_zero_check > 0)
            mw_area = stat_mw(find(c_distances == d_mw2lw,1)).Area;
            mw_mag = stat_mw(find(c_distances ==
d_mw2lw,1)).MeanIntensity;
        else
            mw_area = 0;
        end

        if stat_lw(x).Eccentricity > Ecc_val
            plot(stat_lw(x).Centroid(1),stat_lw(x).Centroid(2),...
                '*', 'color', 'green');
        elseif stat_lw(x).Area < 3
            % do nothing
        elseif d_mw2lw > d_mw2lw_val
            if d_time < d_time_val

plot(stat_lw(x).Centroid(1),stat_lw(x).Centroid(2),...
    'ro', 'color', 'red');
            if (stat_lw(x).Centroid(1) > 300) &&...
                (stat_lw(x).Centroid(1) < 400) &&...
                (stat_lw(x).Centroid(2) > 300) &&...
                (stat_lw(x).Centroid(2) < 400)
                total_frame_hit_lw = total_frame_hit_lw +
stat_lw(x).Area;
            else
                total_frame_hit_lw_bad =
total_frame_hit_lw_bad...
                    + stat_lw(x).Area;
            end
            stat_r_new_lw(x) = stat_lw(x).Centroid(1);
            stat_c_new_lw(x) = stat_lw(x).Centroid(2);
        else

plot(stat_lw(x).Centroid(1),stat_lw(x).Centroid(2),...
    'ro', 'color', 'k')
            text(stat_lw(x).Centroid(1)+2,...
                stat_lw(x).Centroid(2),num2str(d_time));
            stat_r_new_lw(x) = stat_lw(x).Centroid(1);
            stat_c_new_lw(x) = stat_lw(x).Centroid(2);
        end
        elseif (mw_lw_diff * mw_area * mw_mag) < stat_lw(x).Area *...
            stat_lw(x).MeanIntensity
            plot(stat_lw(x).Centroid(1),stat_lw(x).Centroid(2),...
                '*', 'color', 'red');

text(stat_lw(x).Centroid(1)+2,stat_lw(x).Centroid(2),...
    num2str((stat_lw(x).Area *
stat_lw(x).MeanIntensity)...
        / (stat_mw(x).Area * stat_mw(x).MeanIntensity)));
        if (stat_lw(x).Centroid(1) > 300) &&...
            (stat_lw(x).Centroid(1) < 400) &&...
            (stat_lw(x).Centroid(2) > 300) &&...
            (stat_lw(x).Centroid(2) < 400)

```

```

        total_frame_hit_lw = total_frame_hit_lw...
            + stat_lw(x).Area;

    else
        total_frame_hit_lw_bad = ...
            total_frame_hit_lw_bad + stat_lw(x).Area;

    end
    stat_r_new_lw(x) = stat_lw(x).Centroid(1);
    stat_c_new_lw(x) = stat_lw(x).Centroid(2);

else
    plot(stat_lw(x).Centroid(1),stat_lw(x).Centroid(2),...
        'ro','color','green');

end

end
filt_hit(z) = total_frame_hit_lw;
filt_hit_bad(z) = total_frame_hit_lw_bad;
stat_r_list_lw(:,2:s_list2) = stat_r_list_lw(:,1:s_list2-1);
stat_c_list_lw(:,2:s_list2) = stat_c_list_lw(:,1:s_list2-1);
stat_r_list_lw(:,1) = stat_r_new_lw;
stat_c_list_lw(:,1) = stat_c_new_lw;
stat_r_old_lw = stat_r_new_lw;
stat_c_old_lw = stat_c_new_lw;
%internet code end
text(1,20, strcat('current frame: ', num2str(z), ...
    '   number of hits: ', num2str(total_frame_hit_lw), ...
    '   number bad:', num2str(total_frame_hit_lw_bad)))
hold off
% lw raw data
subplot(3,2,5)
imagesc(lw_image, raw_thr_lw)
title('raw lw data')
hold on
plot([10 30],[10 10], 'red')
text(1,20, strcat('current frame: ', num2str(z)))
hold off

subplot(3,2,6)
raw_image_bw = im2bw(lw_image, raw_thr_lw(2));
imagesc(raw_image_bw, [0 1])
title('raw lw binary')
hold on
plot([10 30],[10 10], 'red')
text(1,20, strcat('current frame: ', num2str(z), ...
    '   number of hits: ', num2str(sum(sum(raw_image_bw)))))
hold off
raw_hit(z) = sum(sum(raw_image_bw));
% copy lw subplot
hand_1 = copyobj(lw_sp, h_pic);
set(hand_1, 'Position', get(0, 'DefaultAxesPosition'));
axis normal
print('-djpeg', strcat(...
    'c:\matlab files\prints\frame', num2str(z), '.jpg'), h_pic);
clf(h_pic);

print('-djpeg', 'e:\temp_pix.jpg', gcf); % saves image to ram disk

```

```

    %saveas(gcf,'c:\matlab files\pic_temp.jpg');
    frame = im2frame(imread('e:\temp_pix.jpg'));
    writeVideo(aviobj,frame)
    clf
    waitbar(z/mov_len,h_waitbar,strcat(...
        'file # ',num2str(z),' / ',num2str(mov_len)))

end
close(aviobj);
delete(h_waitbar);

```

b_iir_filter_test_dual.m:

```

% This file runs the IIR band pass filter.  First run b_generate_all.m.
% This load filter coeffiecents.

if default_file_names ~= 0
    mov_write_file = ...
        'c:\matlab files\movies2\dual_iir_bandpass_char1_junk_break';
    % Source files
    read_file1 = 'C:\matlab
files\png_images\cmwir\applewood1\applewood1_';
    read_file2 = 'C:\matlab
files\png_images\clwir\applewood1\applewood1_';
    mov_len = 4000;
    raw_thr_lw = [.06 .087]; % pine cones
    raw_thr_mw = [.09 .11];
end

%read_file1 = 'c:\matlab files\oats1_mw_png\oats1_';
%read_file2 = 'c:\matlab files\oats1_lw_png\oats1_';
% parameters

comp = 0;
lw_thr = 5e-8; % threshhold to create LW objects
mw_thr = 3.5e-8; % MW threshhold (display purposes only)
mw_lw_diff = 6; % diff between mw and lw image to be fire
Ecc_val = 0.85; % Enccentricity threshhold value
d_mw2lw_val = 5; % not used
d_time_val = 7; %not used

s_list1 = 50; % num of objects
s_list2 = 5; % num of frames to look back

frame_row = 480/(2^comp);
frame_col = 640/(2^comp);
line_len = 10+20/(2^comp);

```

```

aviobj = VideoWriter(mov_write_file);
open(aviobj);

%raw_thr_lw = [.06 .0805]; %original oats

raw_hit = zeros(1,mov_len);
filt_hit = zeros(1,mov_len);
filt_hit_bad = zeros(1,mov_len);

[s1 s2] = size(numd);
% create in and out buffers
x_old_mw = zeros(frame_row,frame_col,s2);
y_old_mw = zeros(frame_row,frame_col,s2);
x_old_lw = zeros(frame_row,frame_col,s2);
y_old_lw = zeros(frame_row,frame_col,s2);
y_out_mw = zeros(frame_row,frame_col);
y_out_lw = zeros(frame_row,frame_col);

% create empty filters
filter_B = zeros(frame_row,frame_col,s2);
filter_A = zeros(frame_row,frame_col,s2);
% create empty output matrix
y_out = zeros(frame_row,frame_col); %time 320 of filtered result

% load initial image
mw_image = im2double(imread(strcat(read_file1,num2str(1),'.png')));
lw_image = im2double(imread(strcat(read_file2,num2str(1),'.png')));

mw_image = b_dist_scale(mw_image,comp);
lw_image = b_dist_scale(lw_image,comp);
% load selective gain matrix
baseline_bp_mw2_used = b_dist_scale(baseline_bp_mw2,comp);
baseline_bp_lw2_used = b_dist_scale(baseline_bp_lw2,comp);

% build filter and load previous inputs and results
for z = 1 : 1 : s2
    filter_B(:, :, z) = ones(frame_row,frame_col).*numd(z);
    filter_A(:, :, z) = ones(frame_row,frame_col).*dend(z);
    x_old_mw(:, :, z) = mw_image;
    y_old_mw(:, :, z) = zeros(frame_row,frame_col);
    x_old_lw(:, :, z) = lw_image;
    y_old_lw(:, :, z) = zeros(frame_row,frame_col);
end

% create spatial filter LW/MW
h_mw = fspecial('gaussian',[5 5],1); %spacial filter
h_lw = fspecial('gaussian',[5 5],1); %spacial filter

hit_num = zeros(1,mov_len);
hit_num_base = zeros(1,mov_len);

```

```

%s_f1 = fspecial('gaussian',5,.5);

%Center value

stat_r_list_mw = zeros(s_list1,s_list2);
stat_c_list_mw = zeros(s_list1,s_list2);
stat_r_list_lw = zeros(s_list1,s_list2);
stat_c_list_lw = zeros(s_list1,s_list2);

% set figure settings
h_waitbar = waitbar(0,'file progress');
figure(2)
close figure 2
h_pic = figure(2);
set(h_pic,'Visible','off','PaperPositionMode','auto');

figure(1)
close figure 1
h2 = figure(1);
set(gcf,'Visible','off',...
    'Position',[100,100,1500,1000],'PaperPositionMode','auto');

gcf
%figure(2)
display(read_file1);
display(read_file2);
for z = 1:1:mov_len

    if mod(z,1000) == 0
        display(z);
    end
    %read in files
    tic
    mw_image = im2double(imread(strcat(read_file1,num2str(z),'.png')));
    lw_image = im2double(imread(strcat(read_file2,num2str(z),'.png')));
    mw_image = b_dist_scale(mw_image,comp);
    lw_image = b_dist_scale(lw_image,comp);
    file_read_time = toc;
    tic
    % load mw data
    x_old_mw(:, :, 2:s2) = x_old_mw(:, :, 1:s2-1);
    x_old_mw(:, :, 1) = mw_image;
    y_old_mw(:, :, 2:s2) = y_old_mw(:, :, 1:s2-1);
    y_old_mw(:, :, 1) = y_out_mw;
    % process mw data
    y_out_mw = sum(x_old_mw .* filter_B,3) - ...
        sum(y_old_mw(:, :, 1:s2-1) .* filter_A(:, :, 2:s2),3);
    % adding test code
    y_out_mw_test = imfilter((y_out_mw .* y_out_mw) ./...
        baseline_bp_mw2_used_test,h_mw);
    y_out_mw_test_bw = im2bw(y_out_mw_test,mw_thr);

```

```

%y_out_mw_test_bw = sign(y_out_mw_test);
%y_out_mw_test_bw(y_out_mw_test_bw == -1) = 0;

y_out_bw_mw = y_out_mw_test_bw;
y_out2_mw = y_out_mw_test;

%end test code

%y_out2_mw =
imfilter(abs(y_out_mw./(100.*baseline_bp_mw2_used)),h);
%y_out_bw_mw = im2bw(y_out2_mw,.00008);
[lab_image_mw num_obj_mw] = bwlabel(y_out_bw_mw);
%%
% load lw data
x_old_lw(:, :, 2:s2) = x_old_lw(:, :, 1:s2-1);
x_old_lw(:, :, 1) = lw_image;
y_old_lw(:, :, 2:s2) = y_old_lw(:, :, 1:s2-1);
y_old_lw(:, :, 1) = y_out_lw;
% process lw data
y_out_lw = sum(x_old_lw .* filter_B,3) - ...
    sum(y_old_lw(:, :, 1:s2-1) .* filter_A(:, :, 2:s2),3);

% adding test code
y_out_lw_test = imfilter((y_out_lw .* y_out_lw) ./...
    baseline_bp_lw2_used_test,h_lw);
y_out_lw_test_bw = im2bw(y_out_lw_test,lw_thr);

%y_out_lw_test_bw = sign(y_out_lw_test);
%y_out_lw_test_bw(y_out_lw_test_bw == -1) = 0;

y_out_bw_lw = y_out_lw_test_bw;
y_out2_lw = y_out_lw_test;

%end test code

[lab_image_lw num_obj_lw] = bwlabel(y_out_bw_lw);
% get objects statistics
stat_lw = regionprops(lab_image_lw,y_out2_lw,...
    'Centroid','Area','Eccentricity','MeanIntensity');
stat_mw = regionprops(lab_image_lw,y_out2_mw,...
    'centroid','Area','MeanIntensity');
filter_time = toc;
tic
%iir_filter_out(:, :, z) = y_out;
%iir_filter_out2(:, :, z) = abs(y_out./(100.*pix_small_thr2));

%size(sum(x_old .* filter_B,3))
%size(sum(y_old(2:s2) .* filter_A(2:s2),3))

%test_im = abs(y_out) - pix_small_thr2;

```

```

%% mw filtered display
subplot(3,2,1)
%imagesc(abs(y_out),[0.000 .0001])
%imagesc(abs(y_out),[0.000 .1]) %non thr display

imagesc(y_out2_mw,[0 mw_thr])

title('mw filtered image')
hold on
plot([10 line_len],[10 10],'red')
text(1,20, strcat('current frame: ', num2str(z)))
hold off

subplot(3,2,2)
%imagesc(im2bw(abs(y_out),.1),[0 1]) %non thr display
%imagesc(im2bw(abs(y_out./(100.*pix_small_thr2)),.0001),[0 1])
imagesc(y_out_bw_mw,[0 1])
title('mw binary image')
hold on
plot([10 line_len],[10 10],'red')

% internet code start
%shift last three frames of data

total_frame_hit_mw = 0;
%stat1_new = zeros(numel(stat),2);
stat_r_new_mw = zeros(s_list1,1);
stat_c_new_mw = zeros(s_list1,1);
for x = 1: min([50 numel(stat_mw)])
    d_mw = min(sum(abs(stat_r_list_mw - stat_mw(x).Centroid(1).*...
        ones(s_list1,s_list2)) + abs(stat_c_list_mw - ...
        stat_mw(x).Centroid(2).*ones(s_list1,s_list2)),2));
    if stat_mw(x).Area > 100
        plot(stat_mw(x).Centroid(1),stat_mw(x).Centroid(2),'ro');
        total_frame_hit_mw = total_frame_hit_mw + stat_mw(x).Area;
    elseif d_mw < 5
        plot(stat_mw(x).Centroid(1),stat_mw(x).Centroid(2),'ro');
        total_frame_hit_mw = total_frame_hit_mw + stat_mw(x).Area;
    else
        plot(stat_mw(x).Centroid(1),stat_mw(x).Centroid(2),...
            'ro','color','green');
    end
    stat_r_new_mw(x) = stat_mw(x).Centroid(1);
    stat_c_new_mw(x) = stat_mw(x).Centroid(2);
end
stat_r_list_mw(:,2:s_list2) = stat_r_list_mw(:,1:s_list2-1);
stat_c_list_mw(:,2:s_list2) = stat_c_list_mw(:,1:s_list2-1);
stat_r_list_mw(:,1) = stat_r_new_mw;
stat_c_list_mw(:,1) = stat_c_new_mw;
%internet code end
text(1,20, strcat('current frame: ', num2str(z), ...
    '    number of hits: ', num2str(total_frame_hit_mw)))

```

```

hold off

%% lw filtered display
subplot(3,2,3);
%imagesc(abs(y_out),[0.000 .0001])
%imagesc(abs(y_out),[0.000 .1]) %non thr display
%imagesc(y_out2_lw,[-.01 0])
imagesc(y_out2_lw,[0 lw_thr])

title('lw filtered image')
hold on
plot([10 line_len],[10 10],'red')
text(1,20, strcat('current frame: ', num2str(z)))
hold off
lw_sp = subplot(3,2,4);
%imagesc(im2bw(abs(y_out),.1),[0 1]) %non thr display
%imagesc(im2bw(abs(y_out./(100.*pix_small_thr2)),.0001),[0 1])
imagesc(y_out_bw_lw,[0 1])
title('lw binary image')
[lab_image_lw num_obj_lw] = bwlabel(y_out_bw_lw);
hold on
plot([10 line_len],[10 10],'red')

% internet code start
%shift last three frames of data

total_frame_hit_lw = 0;
total_frame_hit_lw_bad = 0;
%stat1_new = zeros(numel(stat),2);
stat_r_new_lw = zeros(s_list1,1);
stat_c_new_lw = zeros(s_list1,1);
for x = 1: min([50 numel(stat_lw)])
    dist_mat = abs(stat_r_list_lw - stat_lw(x).Centroid(1).*...
        ones(s_list1,s_list2)) + abs(stat_c_list_lw - ...
        stat_lw(x).Centroid(2).*ones(s_list1,s_list2));
    d_time = sum(min(dist_mat)) - max(min(dist_mat));
    c_distances = abs(stat_r_new_mw - stat_lw(x).Centroid(1).*...
        ones(s_list1,1)) + abs(stat_c_new_mw - ...
        stat_lw(x).Centroid(2).*ones(s_list1,1));
    d_mw2lw = min(c_distances);
    [mw_zero_check ~] = size(stat_mw);
    if (d_mw2lw < 8) && (mw_zero_check > 0)
        mw_area = stat_mw(find(c_distances == d_mw2lw,1)).Area;
        mw_mag = stat_mw(find(c_distances ==
d_mw2lw,1)).MeanIntensity;
    else
        mw_area = 0;
    end

    if stat_lw(x).Eccentricity > Ecc_val

```



```

        plot(stat_lw(x).Centroid(1),stat_lw(x).Centroid(2),...
            '*', 'color', 'green');
    elseif stat_lw(x).Area < 3
        % do nothing
    elseif d_mw2lw > d_mw2lw_val
        if d_time < d_time_val

plot(stat_lw(x).Centroid(1),stat_lw(x).Centroid(2),...
    'ro', 'color', 'red');
    if (stat_lw(x).Centroid(1) > 300) && ...
        (stat_lw(x).Centroid(1) <400) && ...
        (stat_lw(x).Centroid(2) > 300) && ...
        (stat_lw(x).Centroid(2) <400)
        total_frame_hit_lw = total_frame_hit_lw + ...
            stat_lw(x).Area;
    else
        total_frame_hit_lw_bad =
total_frame_hit_lw_bad...
            + stat_lw(x).Area;
    end
    stat_r_new_lw(x) = stat_lw(x).Centroid(1);
    stat_c_new_lw(x) = stat_lw(x).Centroid(2);
else
plot(stat_lw(x).Centroid(1),stat_lw(x).Centroid(2),...
    'ro', 'color', 'k')
    text(stat_lw(x).Centroid(1)+2,...
        stat_lw(x).Centroid(2),num2str(d_time));
    stat_r_new_lw(x) = stat_lw(x).Centroid(1);
    stat_c_new_lw(x) = stat_lw(x).Centroid(2);
end
elseif (mw_lw_diff * mw_area * mw_mag) < stat_lw(x).Area *...
    stat_lw(x).MeanIntensity
    plot(stat_lw(x).Centroid(1),stat_lw(x).Centroid(2),...
        '*', 'color', 'red');
%text(stat_lw(x).Centroid(1)+2,stat_lw(x).Centroid(2),...
%num2str((stat_lw(x).Area * stat_lw(x).MeanIntensity)...
%/(stat_mw(x).Area * stat_mw(x).MeanIntensity)));
    if (stat_lw(x).Centroid(1) > 300) &&...
        (stat_lw(x).Centroid(1) < 400) &&...
        (stat_lw(x).Centroid(2) > 300) &&...
        (stat_lw(x).Centroid(2) <400)
        total_frame_hit_lw = total_frame_hit_lw +...
            stat_lw(x).Area;
    else
        total_frame_hit_lw_bad=total_frame_hit_lw_bad...
            + stat_lw(x).Area;
    end
    stat_r_new_lw(x) = stat_lw(x).Centroid(1);
    stat_c_new_lw(x) = stat_lw(x).Centroid(2);
else
    plot(stat_lw(x).Centroid(1),stat_lw(x).Centroid(2),...
        'ro', 'color', 'green');
end
end
end

```

```

filt_hit(z) = total_frame_hit_lw;
filt_hit_bad(z) = total_frame_hit_lw_bad;
stat_r_list_lw(:,2:s_list2) = stat_r_list_lw(:,1:s_list2-1);
stat_c_list_lw(:,2:s_list2) = stat_c_list_lw(:,1:s_list2-1);
stat_r_list_lw(:,1) = stat_r_new_lw;
stat_c_list_lw(:,1) = stat_c_new_lw;
stat_r_old_lw = stat_r_new_lw;
stat_c_old_lw = stat_c_new_lw;
%internet code end
text(1,20, strcat('current frame: ', num2str(z), ...
    ' number of hits: ', num2str(total_frame_hit_lw), ...
    ' number bad: ', num2str(total_frame_hit_lw_bad)))
hold off
%% lw raw data
subplot(3,2,5)
lw_image_filt = lw_image;
imagesc(lw_image_filt, raw_thr_lw)
title('raw lw data')
hold on
plot([10 line_len], [10 10], 'red')
text(1,20, strcat('current frame: ', num2str(z)))
hold off

subplot(3,2,6)
raw_image_bw = im2bw(lw_image_filt, raw_thr_lw(2));
imagesc(raw_image_bw, [0 1])
title('raw lw binary')
hold on
plot([10 line_len], [10 10], 'red')
text(1,20, strcat('current frame: ', num2str(z), ...
    ' number of hits: ', num2str(sum(sum(raw_image_bw)))))
raw_hit(z) = sum(sum(raw_image_bw));
hold off
fig_time = toc;
% copy lw subplot
hand_1 = copyobj(lw_sp, h_pic);
set(hand_1, 'Position', get(0, 'DefaultAxesPosition'));
axis normal
print('-djpeg', strcat('c:\matlab files\prints\frame', ...
    num2str(z), '.jpg'), h_pic);
clf(h_pic);
%%build movie
% set(gcf, 'Visible', 'on', 'Position', ...
% [100,100,1500,1000], 'PaperPositionMode', 'auto');
% frame = getframe(gcf);
tic
%print('-djpeg', 'e:\temp_pix.jpg', gcf); % saves image to ram disk
%saveas(gcf, 'c:\matlab files\pic_temp.jpg');
%frame = im2frame(imread('e:\temp_pix.jpg'));
%writeVideo(aviobj, frame)
mov_time = toc;
clf

waitbar(z/mov_len, h_waitbar, strcat('file # ', num2str(z), ...

```

```

        ' / ', num2str(mov_len)))

end
close(aviobj);
delete(h_waitbar);

```

b_batch_movie_gen.m:

```

% This file generates movie files and results files for all data sets.
% To switch between the fir and iir filter change the comment line 67.

mov_base = 'c:\matlab files\movies2\batch_run\dual_fir_highpass_';
lw_source_path = 'c:\matlab files\png_images\clwir\';
mw_source_path = 'c:\matlab files\png_images\cmwir\';

% generate in order burnt
dir_names = {'setup1',...
    'charcoal1',...
    'oats1',...
    'oats2',...
    'oats2b',...
    'oats3',...
    'pine_needles',...
    'pine_cones',...
    'palm',...
    'thistle',...
    'wet_leaves',...
    'wet_dry1',...
    'wet_dry2',...
    'rosemary',...
    'applewood1',...
    'applewood2',...
    'extinguish'};

mov_len_store = [3753,...
    4000,...
    8000,...
    395,...
    8000,...
    8000,...
    14934,...
    8000,...
    4405,...
    6670,...
    6063,...
    6117,...
    6364,...

```

```

        5609,...
        6100,...
        6100,...
        6100];
default_file_names = 0;
for z_batch = 14 :1:length(mov_len_store)

    mov_len = mov_len_store(z_batch);
    read_file1 = char(strcat(...
        mw_source_path,dir_names(z_batch),'\\',dir_names(z_batch),'_'));
    read_file2 = char(strcat(...
        lw_source_path,dir_names(z_batch),'\\',dir_names(z_batch),'_'));
    temp_image_max = im2double(imread(char(strcat(...
        read_file2,num2str(mov_len_store(z_batch)),'.png'))));
    temp_image_max(300:400,300:400) = zeros(101,101);
    lw_max = 1.1 .* max(max(temp_image_max));
    raw_thr_lw = [0.06 lw_max];
    mov_write_file = char(strcat(mov_base,dir_names(z_batch)));
    b_fir_filter_test_dual_full
    %b_iir_filter_test_dual_full
    save(char(strcat('c:\matlab files\results\lowpass\',...
        dir_names(z_batch),'.mat')), 'raw_hit','filt_hit','filt_hit_bad');
    display(strcat(dir_names(z_batch),' done!'))
end
default_file_names = 1;

```

b_results_plots.m:

```

% This scripts displays preiously gerneated results
% Results are expected in the c:\matlab files\results\lowpass\
% and c:\matlab files\results\highpass\ directories.  These results are
% generated using b_batch_movie_gen.m

close all
f_len = 120; % determines how many points toi average
z_results = 11; % determines which data set to run

dir_names = {'Setup1',...
    'Charcoal1',...
    'Oats1',...
    'Oats2',...
    'Oats2b',...
    'Oats3',...
    'Pine_needles',...
    'Pine_cones',...
    'Palm',...
    'Thistle',...
    'Wet_leaves'...
    'Wet_dry1',...

```

```

    'Wet_dry2',...
    'Rosemary',...
    'Applewood1',...
    'Applewood2',...
    'Extinguish'};

mov_len_store = [3753,...
                 4000,...
                 8000,...
                 395,...
                 8000,...
                 8000,...
                 14934,...
                 8000,...
                 4405,...
                 6670,...
                 6063,...
                 6117,...
                 6364,...
                 5609,...
                 6100,...
                 6100,...
                 6100];

load(char(strcat(...
    'c:\matlab files\results\lowpass\',dir_names(z_results),'.mat')));
fir_filt_hit = filt_hit;
fir_filt_bad = filt_hit_bad;
load(char(strcat(...
    'c:\matlab files\results\bandpass\',dir_names(z_results),'.mat')));
iir_filt_hit = filt_hit;
iir_filt_bad = filt_hit_bad;
timel = 1:1:mov_len_store(z_results);
figure(1000+z_results); % plot hits
plot(timel,fir_filt_hit,timel,iir_filt_hit,timel,raw_hit);
xlim([0 mov_len_store(z_results)]);
title(strcat({'High Pass, Band Pass and Raw LW Results '},...
    dir_names(z_results), {' Non-Averaged'}), 'Interpreter', 'none');
xlabel('Frame');ylabel('Number of Fire Pixels');
figure(2000+z_results); % plot hits
plot(timel,fir_filt_bad,timel,iir_filt_bad);
xlim([0 mov_len_store(z_results)]);ylim([0 70]);
title(strcat({'High Pass, Band Pass False Postives For '},...
    dir_names(z_results), {' Non-Averaged'}), 'Interpreter', 'none');
xlabel('Frame');ylabel('Number of False Postive Pixels');

%filtered results

figure(3000+z_results); % plot hits
plot(timel,filter(1/f_len*ones(f_len,1),1,fir_filt_hit),...
    timel,filter(1/f_len*ones(f_len,1),1,iir_filt_hit),timel,raw_hit)
xlim([0 mov_len_store(z_results)]);
title(strcat({'High Pass, Band Pass and Raw LW Results '},...
    dir_names(z_results), 'Interpreter', 'none');

```

```

xlabel('Frame');ylabel('Number of Fire Pixels');
figure(4000+z_results); % plot hits
plot(time1,filter(1/f_len*ones(f_len,1),1,fir_filt_bad),...
      time1,filter(1/f_len*ones(f_len,1),1,iir_filt_bad))
xlim([0 mov_len_store(z_results)]);ylim([0 35]);
title(strcat({'High Pass, Band Pass False Postives For '},...
            dir_names(z_results)), 'Interpreter', 'none');
xlabel('Frame');ylabel('Number of Fales Postive Pixels');

```