IMAGE PROCESSING AND LOCALIZATION FOR DETECTING AND TRACKING WILDLAND FIRES

Anoop Sathyan  
Department of Aerospace Engineering  
University of Cincinnati  
Cincinnati, OH 45220  
Email: sathyaap@mail.uc.edu

Manish Kumar  
Department of Mechanical, Industrial, and Manufacturing Engineering  
University of Toledo  
Toledo, OH 43606  
Kelly Cohen  
Department of Aerospace Engineering  
University of Cincinnati  
Cincinnati, OH 45220  
Email: cohenky@ucmail.uc.edu

ABSTRACT

Unmanned Aerial Vehicles (UAVs) are being used for a wide variety of applications including detecting and tracking wildland fires. Using UAVs for fire-fighting purposes reduces the human involvement for this high risk job. Such a mission involves locating the wildland fire, tracking the direction of spread of the fire and searching for human presence in the region. This paper investigates the algorithmic development for the use of UAVs to detect and track wildland fires. This would involve using the fuzzy toolbox in MATLAB along with MICRODEM, a software which provides the Digital Elevation Model (DEM) for the region. The objective of this research is to accomplish the following: 1) use genetic fuzzy based image processing tools to identify fire from the video feed obtained from the camera attached to the UAV in real time 2) look for human presence in the region and 3) estimate the location of the fire based on the geological data available for the region.

Keywords: Image processing, fire, human detection, localization, DEMs.

INTRODUCTION

In the past decade, the U.S Federal Government has spent $19.3 billion to suppress wildland fires which has destroyed 68.3 million acres of land [1]. Nine of the 25 fires that cost the federal government the most in U.S. history were described as forest, wildland or wildland/urban interface fires [2]. The term wildland/urban interface (WUI) is typically used to describe areas where extensive vegetation mixes with numerous structures and their inhabitants. Around 32% of U.S. housing units and 10% of all land with housing are situated in the WUI regions, and WUI growth is expected to continue [3]. In windy regions, fire can be a threat to homes a mile or more away from the flame front making the neighboring regions prone to wildland fires [4]. Thus, wildfire can be the cause of economic and ecological losses and it poses a threat to people, property, and communities [5].

One of the main reasons for the inability to suppress wildland fires before it spreads over a large area is because of the delay in the fire crew reaching the scene of the fire. This delay is caused by the lack of knowledge of exact location of the fire in the wildland areas. We propose a mechanism to detect wildland fires using a quadcopter/UAV fitted with visual and infrared cameras, and transmitting the location of the fire and other infor-
mation about the region to the fire crew on the ground. This helps the fire crew understand the location as well as the exact nature of the fire thus helping them make an exact plan even before reaching the scene. This will help in minimizing the damage caused by the wildland fire. Fuzzy logic can be used for fusing and processing the video feeds obtained by the two cameras. The main reason behind using fuzzy logic for processing the video feed to detect the fire pixels is because Fuzzy Logic Systems (FLS) can be designed to be robust to noise which is an important criterion for our application. One of the main challenges facing fuzzy logic control designers is the tuning of the membership functions and the heuristics involved. There are several aspects in the design of an FLS. This includes the inputs, outputs, membership functions and the governing rulebase. A lot of trial and error goes into setting up an FLS. Genetic algorithm (GA), a branch of evolutionary algorithms, will be utilized in this study to provide an autonomous guided search of the design space to develop a more optimized FLS satisfying the design requirements.

The image processing system uses a cascaded FLS that uses both the color image as well as the thermal image to identify the fire pixels. The objective is to look for orange, red and yellow pixels that characterize fire pixels. Using only the color information would result in the system detecting objects that have similar color characteristics. This problem can be solved by using the thermal image as well. The thermal image shows the hot-spots in the image. The FLS can be designed to make use of both the color and thermal information to detect the fire pixels which will be more accurate than using just the color information.

MICRODEM [6] is a software that displays and merges the Digital Elevation Models (DEMs), satellite imagery, scanned maps, vector map data and Geographic Information Systems (GIS) databases. Based on the GPS location, camera angles, and the camera resolution, MICRODEM will be able to reproduce the elevation model of the images obtained from the camera mounted on the UAV. Thus, the image generated in MICRODEM will have the ground coordinates for every pixel. Hence, if the fire pixel locations are known from the image processing algorithm, an estimate of the ground coordinates of the fire can be obtained from MICRODEM.

LITERATURE REVIEW

Chen et al [7] described a technique that uses an RGB model based chromatic and disorder measurement for extracting fire pixels and smoke pixels. The decision function of fire pixels is mainly deduced by the intensity and saturation of R component. The extracted fire pixels are then verified to check if it is a real fire by both dynamics of growth and disorder, and smoke. Based on an iterative checking on the growing ratio of flames, a fire-alarm is given when the alarm-raising condition is met. Experimental results showed that the developed technique can achieve fully automatic surveillance of fire accident with low false alarm rate. Marbach et al [8] presented an image processing technique for automatic real time fire detection in video based on the temporal variation of fire intensity captured by a visual image sensor. The full image sequences are analyzed to select a candidate flame region. Characteristic fire features are extracted from the candidate region and combined to determine the presence of fire or non-fire patterns. Tests showed that the method is effective under a variety of conditions. It has high reliability and a strong robustness towards false alarm in most critical environments. Kumar et al [9] developed a technique using visual and thermal image fusion for UAV based tracking. By using the thermal images, all weather and night operation are possible. Visual and thermal image fusion is done and the fused image is given for target tracking. This system has the benefit of enhanced target tracking application wherein only visual or thermal target tracking would not provide sufficient efficiency. A similar approach could be used for detecting and tracking humans in the region. Celik et al [10] used different color models to detect fire and smoke pixels. For fire detection, the concepts from fuzzy logic are used to make the classification more robust in effectively discriminating fire and fire like colored objects. The model achieved up to 99% correct fire detection rate with a 4.50% false alarm rate. For smoke detection, a statistical analysis was carried out using the idea that the smoke shows grayish color with different illumination. Garg et al [11] used fuzzy logic to combine fire and smoke detection into one single model. To keep the complexity low, only the color information is used. The technique can be applied during early stages of wildfire, when the fire has just started and the temperature of the smoke is very low. The results demonstrate that the method is fast and works very well if the color of the smoke is in the predefined range.

The problem of detecting humans from images is a challenging task. Davis and Sharma [12] presented a contour based background subtraction technique to detect people. The results indicate that the approach is very robust in detecting people over a wide range of thermal imagery. Dalal and Triggs [13] used feature sets for robust visual object recognition. They applied the same technique for detecting humans. The results indicate that the approach is able to provide near-perfect separation on the original MIT pedestrian dataset. Wang et al [14] presented an approach based on Shape Context Descriptor (SCD) with the Adaboost cascade classifier network. The results show that shape context features with boosting classification provide a significant improvement on human detection in thermal images.

Guth and Craven [15] used MICRODEM software, developed by Peter Guth himself, to use digital elevation models (DEMs) to register oblique photographs. After registration, the coordinates of every ground pixel in the image can be computed and image can be used for coordinate digitization and area measurement. Registration requires the camera location (GPS coordinates), and three angles: the azimuthal heading of the camera, the upward or downward pitch of the camera, and a sideways tilt.
Guth et al [16] developed a mechanism that estimates the fire location using MICRODEM along with an Osborne fire finder. The Osborne firefinder is a tool which consists of a calibrated compass and vertical angle dials, and can provide the horizontal azimuth and vertical pitch to a fire. The software determines fire location, estimates an error ellipse, provides a perspective view to compare with the observers vantage point, and displays the location on digital maps. The results were verified with tests at Vetter Mountain in southern California and from a number of towers in central Oregon, and have designed an improved telescope with inclinometer to use with the firefinder. This application can be extended to other cases with a pitch and azimuth sighting from a known location.

PROBLEM DESCRIPTION

In this paper, we propose to use genetic fuzzy logic to detect fire pixels from the image and then show how the knowledge of the fire pixels can be used to obtain the location of fire by using MICRODEM. We also introduce a novel approach to detecting humans from thermal images.

METHODOLOGY

Fire detection using genetic fuzzy logic

YCbCr color space is used for detecting the fire pixels. The knowledge of luma and chrominance components is important to detect fire pixels. A fire pixel is expected to have a dominant luma component (Y). The greater the difference between Y and Cb components, the greater the likelihood for it being a fire pixel [10]. For a fire pixel, Cr should be greater than Cb and the greater the difference between the two, the greater the likelihood. The conditions can be written mathematically as,

\[ Y \geq Cr \geq Cb \]  

(1)

The schematic for the FLS is shown in Fig. 1. The output of the first Fuzzy Inference System (FIS) is cascaded to a second FIS. The FISs are represented in the figure as FIS1 and FIS2. The inputs to FIS1 are normalized values. FIS1 processes the image by checking for fire-like colors which satisfy Eqn. (1). The output of FIS1 is a probability value (M1) representing the probability of a pixel being a fire colored pixel. This is inputted along with the luma value of the thermal image to FIS2 to obtain a new probability value (M2). The regions of high temperature will be shown as white in a thermal image. Hence, fire pixels will have higher luma value. Thus, M2 represents the probability of a pixel to be a fire pixel because it considers not just the color information, but also the temperature information.

GA is used to tune a 19 element vector R. The membership functions for FIS1 and FIS2 are shown in Figs.2 and 3, respectively. R(1:10) represent the boundaries of the membership functions as shown in Figs 2 and 3. R(11:19) represent the rulebase for FIS1 as shown in Table 1. Rulebase for FIS2 is pre-defined as follows:

- IF M1 is LO OR M, THEN M2 is LO.
- IF M1 is H AND Y(IR) is P, THEN M2 is H.
Human detection

The luma component of humans in a thermal image is higher because of our body temperature. This property can be used to segment the images to obtain pixels with the luma component higher than a particular threshold. Hence, the YCbCr color map is used for analysis. The segmented image will also include non-humans as well. Each collection of connected pixels in the segmented image is called region of interest (ROI). Each ROI can be represented by a bounding box. Humans are detected based on the geometry of these bounding boxes. For a particular ROI to contain humans, we consider the following requirements:

\[ A \geq 200 \]  \hspace{1cm} (2)
\[ H \geq 1.5 \times W \]  \hspace{1cm} (3)

where \(H\) and \(W\) are the height and width of the bounding box, respectively and \(A\) is the area of the bounding box. This approach is represented as a flow chart in Fig. 4.

MICRODEM

The localization is done by interfacing the results obtained from the fuzzy logic toolbox in MATLAB with MICRODEM. Using the GPS location of the camera, camera orientation and fields of view, MICRODEM is able to reproduce the image obtained by the camera by making use of the GIS maps which need to be preinstalled. An example is shown in Fig. 5. Fig. 5(a) shows the original image and Fig. 5(b) shows the image reproduced in MICRODEM along with the roads and streams from the

<table>
<thead>
<tr>
<th>TABLE 1. RULEBASE FOR FIS1</th>
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<tbody>
<tr>
<td>Y-Cb</td>
</tr>
<tr>
<td>Cr-Cb</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>Z</td>
</tr>
<tr>
<td>P</td>
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</tbody>
</table>
(a) IMAGE OBTAINED FROM THE CAMERA

(b) REGISTERED IMAGE IN MICRODEM

FIGURE 5. IMAGE REGISTRATION IN MICRODEM [15]

Census Bureaus TIGER data base. The latitude and longitude of any pixel in Fig. 5(a) can be obtained from the corresponding pixel in Fig. 5(b) from MICRODEM. Thus, if we know the fire pixels from the image processing algorithm, then we can obtain the latitude and longitude of the location of the fire from MICRODEM. The parameters required in order to perform image registration in MICRODEM are described in Table 2.

RESULTS

The results are divided into two sections: (A) Image processing and (B) MICRODEM. Since actual tests are yet to be conducted, the two results cannot be integrated at this point. The results look promising nevertheless. Once actual tests are done, the interfacing should be complete and the actual location of the fire in the global coordinates can be estimated.

(A) FIRE DETECTION

The RGB color image is converted into YCbCr color space and is inputted into FIS1 and its output is fed to FIS2 along with the luma (Y) component of the thermal image to obtain the final probability measure M2. M2 is indicative of the probability of a pixel being a fire pixel which satisfies the color as well as the thermal radiation requirements.

GA trains the FIS by using an image whose fire pixels are known beforehand. The fitness function is given by the similarity of the processed image with the locations of the fire pixels of the given image. Thus, GA provides us a FIS that satisfies the necessary conditions for processing the image to obtain its fire pixels. The R vector for the membership function parameters that optimizes the image processing algorithm is given below and the rule base is shown in Table 3.

\[ R = [0.408 0.012 0.536 0.210 0.145 0.891 0.198 0.089 0.456 0.702] \]

The image processing algorithm is applied to three images and the corresponding computational times are shown in Table 4. The low computational times, even for large image sizes, indicate that the algorithm is very fast and efficient.

<table>
<thead>
<tr>
<th>TABLE 3. RULEBASE FOR FIS1</th>
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<tbody>
<tr>
<td>Y-Cb</td>
</tr>
<tr>
<td>Cr-Cb</td>
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<tr>
<td>Z</td>
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<td>P</td>
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<table>
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<tr>
<th>TABLE 4. COMPUTATIONAL TIMES</th>
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<tr>
<td>Image resolution</td>
</tr>
<tr>
<td>------------------</td>
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<tr>
<td>Fig. 6 275 x 184</td>
</tr>
<tr>
<td>Fig. 7 900 x 526</td>
</tr>
<tr>
<td>Fig. 8 858 x 536</td>
</tr>
</tbody>
</table>

It can be seen from Fig. 6 that the processed image does not show the red colored pixels indicating the roofs of those houses present near the fire. This is because of the cascaded fuzzy system used which checks not only the color but also the thermal radiation obtained from the IR camera. Similarly, from Fig. 7, it can be seen that the red stripes on helicopter is ignored by the algorithm. Also, from Fig. 8, it can be noted that the yellow
TABLE 2. PARAMETERS REQUIRED FOR IMAGE REGISTRATION IN MICRODEM [15]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Where is it obtained from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude and longitude</td>
<td></td>
<td>GPS</td>
</tr>
<tr>
<td>Elevation</td>
<td>Height above the terrain</td>
<td>Altimeter</td>
</tr>
<tr>
<td>Pitch</td>
<td>Up/down tilt angle of the camera from the horizontal</td>
<td>Gimbal</td>
</tr>
<tr>
<td>Roll</td>
<td>Sideways tilt of the camera</td>
<td>Gimbal</td>
</tr>
<tr>
<td>Horizontal &amp; vertical field of view</td>
<td></td>
<td>Camera specifications</td>
</tr>
</tbody>
</table>

colored uniforms of the fire crew are all undetected. Thus, the algorithm is very effective in detecting the fire pixels.

FIGURE 6. FIRE DETECTION IN SMALL IMAGE

FIGURE 7. FIRE DETECTION IN LARGE IMAGE
(B) Human detection

Fig. 9 shows the process of detecting humans from thermal image. The original image shown in Fig. 9(a) is segmented based on the luma components to obtain Fig. 9(b). The bounding boxes that satisfy the requirements in Eqns. 2 and 3 are identified as humans as shown in Fig. 9(c). Because of Eqn. 3, the algorithm will identify people who are in an upright position. Because of the simplicity of the approach, the processing time is only 0.2s for an image of size 640x480. Hence, this approach is very effective for processing videos in real time.

(C) MICRODEM

MICRODEM uses DEMs to create the maps. DEMs provide the elevation details of the region of interest. As mentioned before, using the GPS location of the camera, camera angles and other camera parameters, MICRODEM can be used to reproduce the image in a digital elevation framework as shown in Fig. 10.
Fig. 10(a) shows an image of Mt. Shasta in California. The DEM for this region is downloaded for use in MICRODEM. Using the GPS coordinates of the camera, the camera angles and the camera specifications, the image can be registered in MICRODEM as shown in Fig. 10(b). Thus, each pixel in Fig. 10(a) can be mapped onto Fig. 10(b) from which we can obtain the global coordinates of the corresponding pixel. Hence, if the fire pixels in an image are known, then this same technique can be used to obtain the location of the fire in the global reference frame. The results depend on the accuracy with which the GPS location and the camera angles can be obtained.

CONCLUSIONS & FUTURE WORK

Genetic fuzzy has been used to design a cascaded FLS capable of detecting fire pixels from image. This has been shown to be fast and effective. The algorithm is able to distinguish fire pixels from fire-like colored pixels. The processing time for small images is around 3 seconds and around 10 seconds for large images on a computer with an Intel i3 2.3GHz processor and 4GB of RAM. A simple approach to human detection in thermal images was presented and it was shown to be fast and effective. The algorithm is able to detect humans in an upright position. There is a chance for false alarms if there are any tall and slender objects that show up brightly in a thermal image. Deep learning algorithms could be used to reduce the false alarms by training the computer vision system to a dataset of thermal images with ground truth of human detections.

The image registration in MICRODEM is shown and it has been explained how this could be used to effectively localize the fire in the global reference. This mechanism will be very useful to fire fighters who will obtain a perfect idea regarding the location of the fire. The algorithms have not been tested in real scenarios. This will be done next. Once the data from outdoor testing is obtained, the image processing algorithm can be interfaced with MICRODEM to localize the fire.

ACKNOWLEDGMENT

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REFERENCES


