UAV and GIS Based Real-time Display System for Forest Fire

Jingxian Wang
Institute of public safety, Tsinghua University
jingxian19@mails.tsinghua.edu.cn

Lida Huang
Institute of public safety, Tsinghua University
huanglida@tsinghua.edu.cn

Guofeng Su
Institute of public safety, Tsinghua University
sugf@tsinghua.edu.cn

Tao Chen
Institute of public safety, Tsinghua University
chentao.b@tsinghua.edu.cn

ABSTRACT

When a forest fire occurs, the commander cannot obtain information in time, and the rescue command is like groping in the dark. In order to solve the problem, this research establishes a near real-time forest fire display system based on UAV and GIS. The UAV is equipped with visible light and thermal imaging cameras to transmit back forest fire scenes. Based on GIS, the system can extract the boundary of the fire field through image processing and 3D modeling technology, and display various forest fire information on the screen. Through image processing and 3D modeling technology, the boundary of the fire field can be extracted and displayed on the screen. We conducted several experiments to test the accuracy and the reliability of the system. The result shows that the accuracy, reliability and near real-time capability can be guaranteed in small-scale forest fires.

Keywords

Forest fire, forest fire boundary extraction, UAV, GIS, 3D modeling.

INTRODUCTION

In recent years, with the increase of human forest activities, forest fires are becoming more and more frequent. Large-scale forest fires not only bring great economic losses and casualties to the local people, but also cause serious damage to the ecological environment (Jiang & Jiang, 2013). For example, the Australian wildfire in 2019 influenced by continuous high temperature, drought and windy weather conditions, lasted for many months and spread to 6 states across Australia. In addition, due to the incorrect command and decisions and insufficient investment in firefighting forces, it caused serious consequences (Zhang & Xu, 2020). China is also one of the countries with serious forest fires. According to statistics (Zhang, 2018), during the ten years from 2009 to 2018, an average of 4,440 fires occurred every year in China, with 68 casualties and economic losses of up to 140 million yuan due to forest fires, as shown in Figure 1.
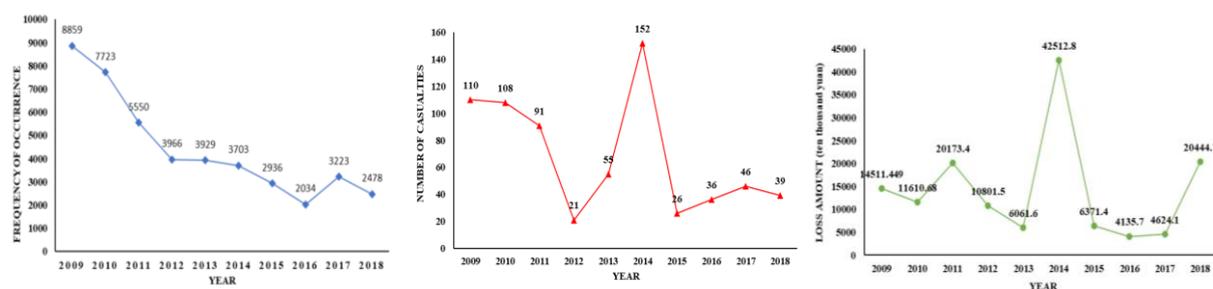

Figure 1. Statistics of the number of forest fires, property losses, and casualties in my country from 2009 to 2018

Early detection, timely positioning, and timely extinguishments are essential to reduce forest fire losses and the occurrence of serious forest fires. A lot of work has been focused on forest fire monitoring, in which the common methods are near-ground monitoring, radar monitoring, satellite monitoring, and wireless sensor network monitoring (Yan & Li, 2017). These methods have their own merits, however, they are not that suitable for real-

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time information collection. For near-ground monitoring, the forest rangers cannot patrol all places restricted by terrain and environment. Multi-spectral imagers are limited in field of view and high cost, and also susceptible to interference from forest radiation and reflection. The radar monitoring is vulnerable to interference because the spatial scale of fire radar echo is only a fraction or even a few orders of magnitude of precipitation echo, and mixed in clutter (Huang et al., 2013). Satellite monitoring is easily obscured by clouds and fog, and its operating cycles are too long (Yan et al., 2005). Wireless sensor technology is still in its infancy and cannot guarantee the accuracy of sensors and equipment reliability (Grangeat et al., 2016).

In recent years, with the development of unmanned aerial vehicle (UAV) technology, forest fire monitoring based on UAVs has received more and more attention. UAVs have advantages of high mobility and low cost. The linkage of multiple UAVs can quickly inspect the forest area and return live videos in real-time. Existing research focuses on early forest fire monitoring and cruise path planning by UAVs. For example, ED Wardihani et al. (2018) proposed setting cruise routes for forest fire detection to detect forest fires timely. Na Wei et al. (2019) used UAV cruise planning based on GIS to carry out forest fire prevention. Zhentian Jiao established a forest fire prevention UAV system based on deep learning to monitor forests (Jiao, 2019).

This paper establishes a real-time forest fire display system based on UAV and GIS, in which the image overlay function of Google Earth is used to realize 3D modeling and the image edge extraction technology is used to extract the forest fire boundary. Through several experiments, it has been demonstrated that the system is feasible in real-time display of fire situation. The following of this paper describes the system research background, system design and implementation and the experimental design. Finally, we summarize this paper and give the proposal for later research directions.

SYSTEM DESIGN AND IMPLEMENTATION

The real-time display system for forest fire is composed of three subsystems: data transmission system, image processing system, and display system, as in Figure 2. First, the data transmission system transmits the image data and position data obtained by the UAV and cameras. Then, these data are processed through image processing system. The image processing system processes the visible light image and the thermal imaging image separately to complete the 3D modeling and forest fire boundary extraction. At last, these results are shown in the display system (Nadal-Serrano, 2010).
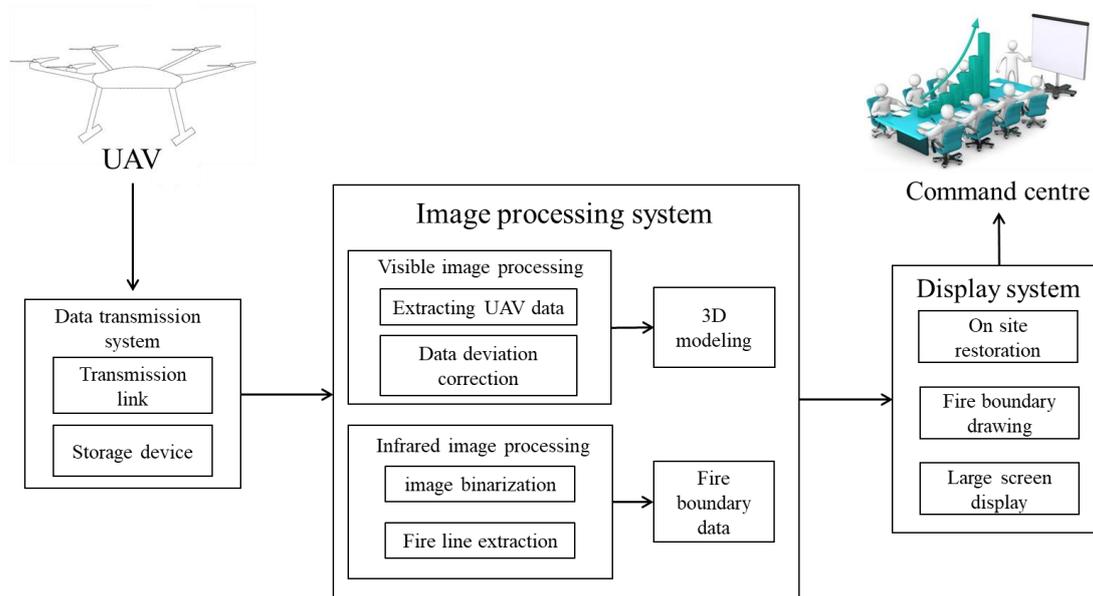

Figure 2. The flowchart of system

Data Transmission System

Figure 3 shows the structure of the data transmission system. The system includes the data transmission link and data storage equipment. Data transmission links can choose to use WiFi, 4G, VPN (Virtual Private Network), to build the transmission link according to the network situation around the fire site. Data is transmitted on the link in the form of a stream. Data storage equipment is NVR (Network Video Recorder), which can cache data, realize video storage and support subsequent playback and facilitate the analysis of forest fire and the summary

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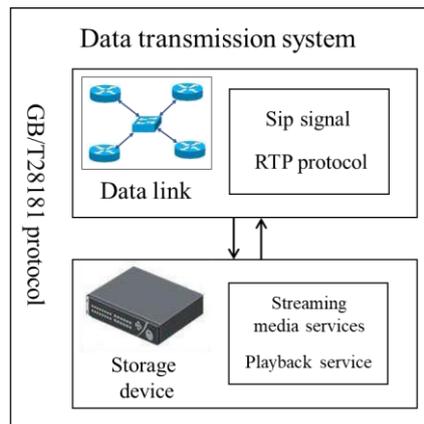of rescue work (Vandecasteele et al., 2015).

Figure 3. Data transmission system architecture

Image Processing System

The image processing system is the core of the rescue command system, which is divided into two parts, visible light image processing and infrared image processing. The former is used to process the data from the UVA and visible light camera to complete 3D modeling. The latter is used to extract the forest fire boundary.

Visible light image processing

The ultimate goal of visible light processing is to achieve 3D modeling. Visible light image processing includes UAV data and visible light camera data processing. The 3D modeling process is shown in Figure 4.
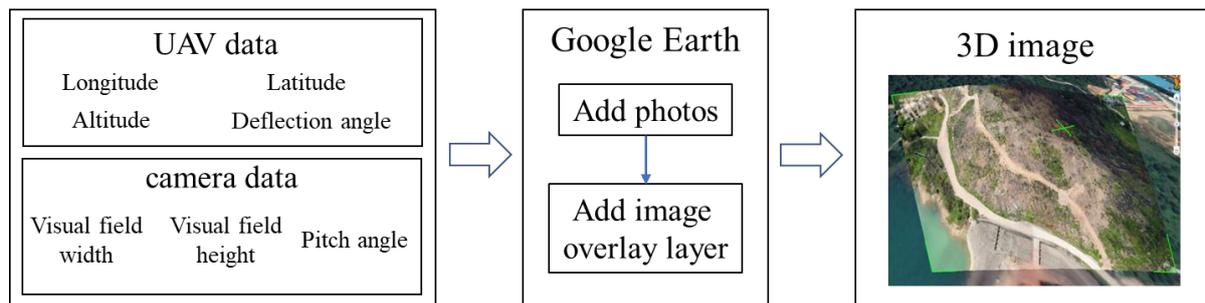

Figure 4. 3D modeling flowchart

Due to the advantages of multiple platforms, high image resolution, and real-time image updates (Liu et al., 2015), this paper uses Google Earth to perform 3D modeling to restore the forest fire scene. In recent years, Rusli et al. (2014) found that the watershed boundaries obtained by Google Earth and SRTM (Space Shuttle Radar Topographic Mapping) were basically the same. Wang et al. (2010) verified the accuracy of Google Earth by comparing satellite images and inversely calculating contours.

3D modeling needs UAV data and visible light camera data. Then, inputting this data into Google Earth in turn as required and the live images taken at that location are loaded into Google Earth by adding photos, too. Next, measuring the latitude and longitude of the four corners of the image in order from left to right and bottom to top. According to the longitude and latitude of the four corners, the image overlay function of Google Earth can complete 3D modeling.

UAV data contains UAV's longitude, latitude, altitude and yaw angle in flight. Visible light camera data contains the camera's visual field width and height, focal length and pitch angle. Among them, altitude, yaw angle and pitch angle should be corrected, and the visual field width and height need to be calculated through camera's focal length.

The height correction is the UAV's height value minus the height deviation value of the forest fire place. The calculation of the height deviation value is: select a number of points, each point is 10 meters apart, then use the UAV to measure the height value of each point. Next, the former height value minus the same point's height value on Google Earth. At last, calculate the average value $\bar{x}$. The $\bar{x}$ is the height deviation value. For the correction of the UAV's yaw angle and the camera's pitch angle, first determine the value of the positive or negative value. If it is non-negative, no processing will be performed. Or, the UAV's deflection angle value will be added by 360. The

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camera's pitch angle value adds 90.

On the basis of visible camera data, the width and height of the camera's field of view can be calculated. The calculation formula is shown in formula (2-1).

$$\theta = 2 \times arctan(\frac{Length\ of\ the\ sensor\ edge}{2}/L) \tag{2-1}$$

L is the focal length used by the mounted camera during shooting, and θ is the field of view.

Thermal Imaging Image Processing

The color space of the original thermal imaging image is RGB, the fire area under this color space has the characteristics of discontinuity and incompleteness, which is not suitable for segmentation. Besides, the correlation between R (red), G (green), and B (blue) in the RGB color space is very high. A single parameter is difficult to segment the fire area too (Zhang et al., 2015). To solve this problem, we convert the thermal imaging image into the grayscale image and then into the binary image (as shown in Figure 5). The binary image has only two colors, pure black and pure white, with obvious contrast, and it is very suitable for image segmentation and edge collection.
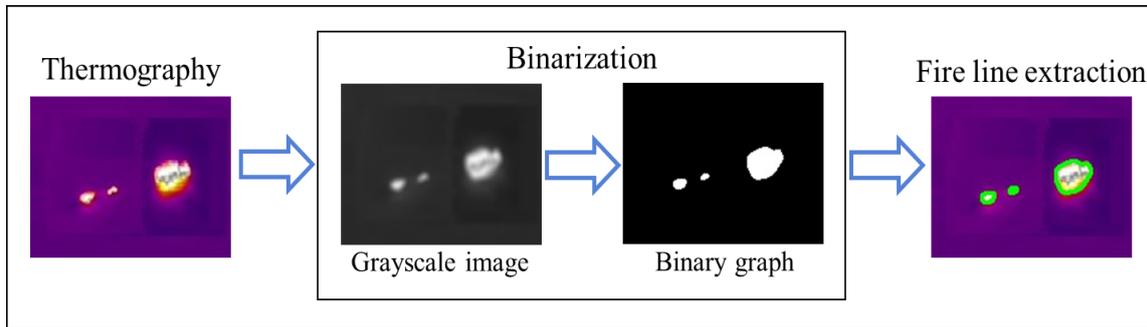

Figure 5. Thermal imaging image processing flowchart

The specific image binary conversion steps are as follows:

a)   Gray conversion

The commonly used way to convert RGB model to grayscale is:

$$GRAY = 0.3R + 0.59G + 0.11B \tag{2}$$

b)   Binary conversion

First, a threshold is selected. Then, according to the threshold, the part of the grayscale image becomes black or white, and the other part becomes the corresponding color. In this paper, in order to suit the large temperature range and multiple colors in the thermal imaging camera, the OTSU algorithm is selected.

The basic idea of the Otsu algorithm is: mark T as the segmentation threshold between the foreground and the background, the proportion of front sights in the image is W0, and the average gray scale is U0; the proportion of background points in the image is W1, and the average gray scale is U1. The total average gray level of the image is:

$$U = W_0 \times U_0 + W_1 \times U_1 \tag{3}$$

Traverse T from the minimum gray value to the maximum gray value, when T makes:

$$G = W_0 \times (U_0 - U) \times 2 + W_1 \times (U_1 - U)^2 \tag{4}$$

When the maximum is selected, T is the optimal threshold for segmentation [14].

●   Forest fire boundary extraction

The boundary is the edge where the attribute of the area changes suddenly, which is essentially the sudden change of the signal (Jiang et al., 2009; Zhang & Shi, 2000). The existing image edge extraction methods can be divided into three categories, one is based on a certain fixed local operation method, such as differentiation method, fitting method and so on, which belong to the classic edge extraction method. The second type is energy Minimization, which is the criterion for global extraction methods. The third category is represented by high-tech developed in recent years, such as wavelet transformation, mathematical morphology, and fractal theory. After the binarization, the thermal imaging image has a clear distinction between black and white and obvious grayscale changes (Cui et al., 2009). Considering, the real-time display system has high requirements for timeliness, edge extraction adopts

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a differential operator method.

The edge detection in the differential operator method can be realized by using the Robert cross operator. Establish the gray value function $f(x, y)$, for row pixels and column pixels in the binary image, then the edge in the image is the place where the gray value function's value changes suddenly. Derivation of the gray value function $\left(\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right)$, known from the nature of the derivative, when the function value changes suddenly, the absolute value of the corresponding derivative value is the largest, at the position (x, y) The maximum value of the derivative is:

$$G = \left[\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2\right]^{1/2} \tag{5}$$

Correspondingly, the direction to obtain the maximum value is:

$$\alpha = arctan\left[\frac{\frac{\partial f}{\partial y}}{\frac{\partial f}{\partial x}}\right] \tag{6}$$

Based on this, the expression of Robert's operator is derived as:

$$|G| = MAX(|f(i,j) - f(i+1, j+1)|, |f(i+1, j) - f(i, j+1)|) \tag{7}$$

Based on this theory, the edge extraction of the image can be achieved with the help of the OpenCV open source library.

Display System

After the display system receives the 3D modeling data and the wildfire boundary data, it first performs on-site restoration based on the 3D modeling data, and then uses the drawing function in the OpenCV to draw the boundary on the live image based on the forest fire boundary data. The final image after processing is displayed on a screen. In addition, the fire location, fire area, wind direction, wind speed and other related data are displayed on the screen according to the requirements of the on-site commanders, what they need most is the wind direction and the location of the fire area. The final effect is shown in Figure 6.

Figure 6. Display system

EXPERIMENT TESTING

3D Modeling Using Visible Light Image

We choose an open area in a mountainous area as the experimental site, and the DJI MATRICE 300 RTK UAV and H20T multi-function mounted camera to shoot. Before the experiment, we placed a number of 1m*1m red square cloths on the ground as simulated fire points. To ensure accuracy, the distance between each cloth was about ten meters. The drone uses 45° tilt photography when shooting, and uses laser ranging to measure the longitude and latitude of each point. After acquiring the image data, mark the simulated fire position on Google Earth, numbered 1-5, and use the image overlay function for 3D modeling. After modeling, mark the simulated fire points in the three-dimensional image, numbered A-E, and the effect is shown in Figure 7.

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Figure 7. 3D modeling diagram

Using the distance ruler in Google Earth to measure the distance between the corresponding simulated fire points to estimate the error in the 3D modeling. The maximum distance in the figure above is 12.1 meters, the minimum is 3.81 meters, and the average is 7.328 meters. According to the regulations, from the discovery of fire to the fire alarm should be within one minute. Considering the limit case, the maximum distance of forest fire spread in one minute can be used as the upper limit of error. Crown fire spreads at a speed of about 83m/min ~ 133m/min without obstruction along the wind (Xu et al., 2012), which is one of the most harmful forest fires. So, the error should not exceed 133m, and the above differences are all within the allowable range of error. Subsequently, UAV was used for multi-directional and multi angle shooting. Considering the camera deviation angle and pitch angle, 28 points were selected for 3D modeling and error distance measurement. The detailed results are shown in Table 1. Among the 28 points, the maximum distance error is 26.85 meters, the minimum is 1.37 meters, and the average value is 13.59, which is also within the allowable range of error. It can be seen that the results of using Google Earth to perform 3D modeling to restore the forest fire scene are reliable.

Table 1. Simulation fire point statistics table

Simulated fire point	Distance difference(m)	Simulated fire point	Distance difference(m)	Simulated fire point	Distance difference(m)	Simulated fire point	Distance difference(m)
1	3.91	8	12.03	15	15.71	22	3.77
2	5.19	9	3.83	16	12.73	23	1.37
3	4.88	10	5.23	17	22.00	24	10.10
4	14.29	11	20.69	18	23.06	25	13.28
5	25.15	12	26.85	19	15.84	26	12.92
6	6.57	13	19.92	20	15.89	27	17.19
7	8.48	14	15.60	21	20.98	28	23.01

Maximum value:26.85

minimum value:1.37

average value:13.59

Fire Boundary Extraction Using Thermal Imaging Image

We use the UAV images of the forest fire that occurred in Foshan City, Guangdong Provenience in December 2019 as our experimental data. Two typical images are selected, one is an image of a small fire when the forest fire just happened, the other is an image of relatively a large fire after it spread for some time.

From Figure 8, it can be seen that as long as there is a forest fire in the UAV shooting screen, the fire boundary can be extracted clearly.
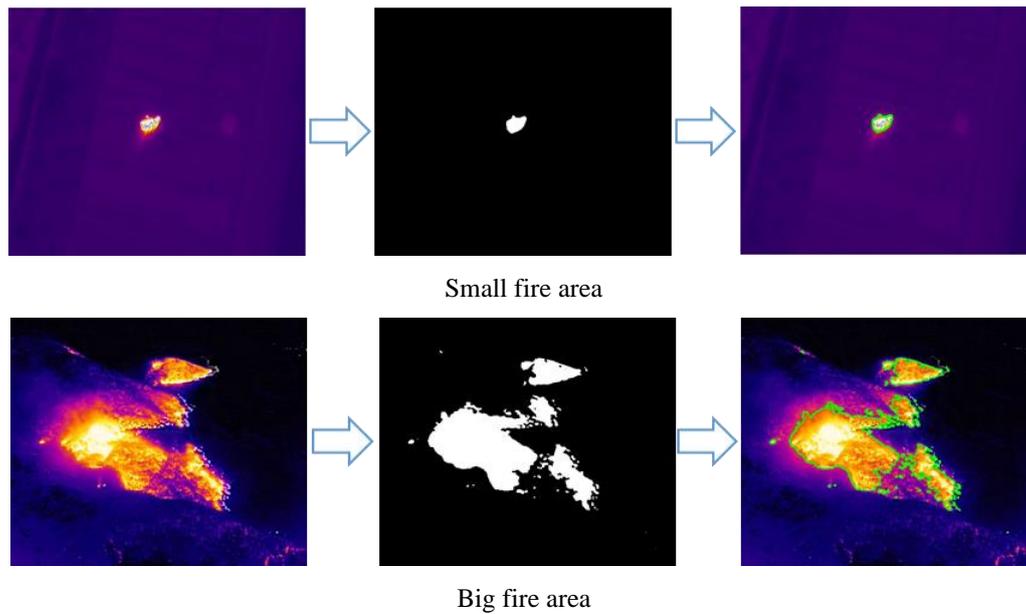
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Small fire area

Big fire area

Figure 8. Firewire extraction display

Real-Time Display Test

We also test the real-time performance of our system. We ignited a few piles of wood in an open field to simulate the fire, as shown in Figure9(a). At the same time, we use drones to shoot live scenes and display them on the large screen of the system through algorithm processing, as shown in figure9(b). In the middle of the large screen is the result of 3D modeling and visible light image superposition. The red point is the location of the fire point calculated by the system's algorithm. It can be seen that there is a certain error, but it is not more than 10 metres, which is acceptable. The top right is the fire location extracted from the thermal imaging image, and the bottom right is the live video streaming. After experimental testing, the entire system has a delay of about 2s, which can meet the requirements of real-time display.

Figure 9(a). On-site fire display

Figure 9(b). Real-time display

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CONCLUSION

The realization of the system gives a solution to the lack of on-site information, which is very significant during forest fire rescue. This system is based on UVA and GIS. Through visible light cameras and infrared cameras and Google Earth, the system completes the three-dimensional modeling and the restoration of the forest fire, forest fire boundary extraction and some other functions. With the help of this system, the commander can formulate a scientific and reasonable rescue plan based on the actual situation of the forest fire. The system has a playback function, which is also a great help to the review and summary. There are still some improvements that can be done in the future. The current method is only suitable for small-scale forest fires. When faced with a complex fire environment such as smoke, fire tornados, wind, and so on, the system may be disturbed. In the future, we will conduct large-scale fire experiments to explore these issues.

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