Proceedings of the 11th World Congress on Electrical Engineering and Computer Systems and Sciences (EECSS'25)
Paris, France - August, 2025
Paper No. MVML 108
DOI: 10.11159/mvml25.108

Multiple Image-Based Fire Head Detection and Contour-Based Spread Rate of Fire Head Area Estimation

Jeong Kyu Kim[1], Yoseob Heo[2], Jongseok Kang[3], *Tae-Eung Sung[4]
[1]Department of Computer Science, Yonsei University
1, Yeonsedae-gil, Wonju, Gangwon-do, Republic of Korea
hanencia@yonsei.ac.kr
[2]Division of Data Analysis, Busan-Ulsan-Gyeongnam Branch, Korea Institute of Science and Technology Information
41, Centum dong-ro, Haeundae-gu, Busan
joseph87@kisti.re.kr
[3]Division of Data Analysis, Korea Institute of Science and Technology Information
66, Hoegi-ro, Dongdaemun-gu, Seoul, Republic of Korea
kangjs@kisti.re.kr
[4]Division of Software, Yonsei University
1, Yeonsedae-gil, Wonju, Gangwon-do, Republic of Korea
*Corresponding author: tesung@yonsei.ac.kr

***Abstract* -** The purpose of this study is to estimate the area of spread rate of fire head area from multiple images taken at the same location and under the same conditions, but with different times. To achieve it, the study is conducted as follows. First, specify the fire head in the image using deep learning model. Then make each polygon for each fire head by drawing contours and count the number of pixels belonging to the polygons to derive the pixel-based area. Then, convert the unit of area from pixel (px) to area (㎡). to do this we studied how to convert based on an object with a known actual area. Finally, the area of fire head in the two images is compared to calculate the fire head area change and spread rate of fire head area. We expect this research to help provide information in large fires where rapid judgment is required.

***Keywords*:** area estimation, fire head, image segmentation, attention u-net, contour, scale conversion

1. Introduction

When fighting large fires such as forest fires, it is an important process to understand the spread of the fire. In recent years, attempts have been made to use drones to understand the trend of large fires or to extinguish the fire. In this case, it is important to quickly understand the spread of the fire from images or videos taken by drones.

Traditionally, many studies have focused on modelling and predicting the direction of fire spread to understand the tendency of fire spread. With the development of deep learning techniques, methods for calculating the tensor of the fire head from images have also been studied[1]. However, the existing research methods have the following limitations in using images or videos taken by drones. First, it takes a lot of time due to the amount of calculation, which is not suitable for large-scale firefighting where decisions need to be made quickly. In addition, the images taken by drones are shaky, which reduces accuracy when used for real-time analysis.

Therefore, in this study, we aimed to understand the spread of fire through a different approach from previous studies. To do this, we took photos at the same location and conditions with different shooting times and compared them to estimate the spread rate of fire head area.

2. Methodology

This study estimates the spread rate of fire head area through four steps. First, prepare two images to compare the area of fire head and specify the fire head (segmentation mask) through a deep learning model. Using the mask, the fire head is converted into multiple polygons using the contour algorithm. Then, the area of fire head was obtained by counting the number of pixels in the polygon. But it was necessary to convert the unit of area obtained through the above process from pixel (px) to ㎡. To achieve it, we studied the conversion formula using an object with a known area. Finally, the spread rate of fire head area was obtained by comparing the area of each image.

3.1. Making segmentation mask of fire head from initial and last image

To estimate the spread rate of fire head area, two images were prepared to calculate the area change of the fire head. These images were taken under the same conditions of location, shooting angle (horizontal, 0 degrees), shooting distance (100 meters), and resolution (3840x2160), but the shooting time (interval: 3 minutes).

After preparing images, the process of extracting the fire head segmentation mask was performed. This process used the Attention U-Net model (Backbone: VGG-16), one of the deep learning models [2]. However, the U-Net model has a limitation that it can only predict the segmentation mask for images with a size of 256x256. To solve this problem, we divided the images to 256x256 each, perform prediction, and then merge the images again [3].

3.2. Get fire head area using contours from fire head mask

Fig. 2: polygon of fire head made by contour algorithm.

To estimate the area of fire head, we made each polygon for each fire head by drawing contours from segmentation mask derived in advance using contour algorithm[4]. Contour algorithm is to join all continuous points along the boundary which has same color or intensity[5]. it is used to determine the presence of boundaries in given image through local measurements[6]. Then, we calculated the area of the fire head by counting the number of pixels belonging to this polygon.

3.3. Convert pixel(px) to real metrics(㎡)

The unit of area derived from the above process is pixel (px). However, the unit of pixel (px) is not intuitive because it is not actually used by humans, and the size of pixel can vary depending on the resolution of the image even taken of the same object. Therefore, it is necessary to convert the area consisting of pixel (px) to ㎡. To achieve it, we studied a separate formula to get ㎡ per unit pixel (px).

To make the formula, we arbitrarily set several conditions. First, the number of pixels can vary depending on the camera's resolution, shooting distance, and angle, even for the same object. Therefore, the resolution of the camera was fixed at 3840x2160 (4k), and the angle from which the camera captured the fire head was 0 degrees, i.e. horizontal. The object of photography was a Korean 100 won coin (area: $0.0125^2\pi\ m^2$), which was repeatedly photographed at 10 cm intervals to derive the number of pixels per 10 cm.

Exponential regression was used to derive the equation. The equation was found to be statistically significant ($p<0.05$), derived as follows:

$$area(m^2) = \frac{0.0125^2 * \pi}{\left[\left(dist(m) * 100\right)^{-2.08832 * e^{1780182}}\right]} * px \quad (1)$$

The measured area (px) of the Korean 100 won coin photographed by distance and the area (px) estimated by the above formula are shown in Table 1.

Table 1: Measured area by distance for a 100-won coin in South Korea and area estimated from the formula.

Distance (cm)	Area (px)	Estimated Area (px)
10	439389	439448.6926
20	103376	103337.9572
30	44302	44312.28933

3.4. Calculating spread rate of fire head area

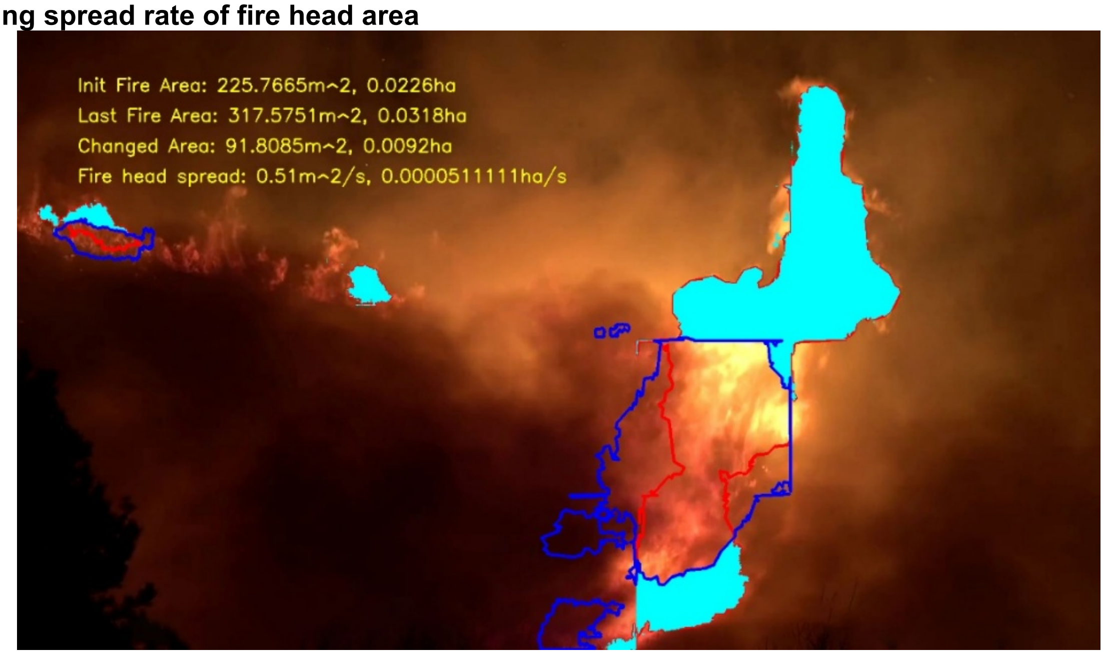

Fig. 3: Result of spread rate of fire head area

Spread rate of fire head area means the change in area per unit time. It's calculated by difference between the fire head area derived from the last image and the initial image. In this study, the area change was calculated as the difference between the areas of all the fire heads detected in the images taken, calculate as follows:

$$Fire\ head\ spread(m^2 / s) = \frac{\text{area of fire head of last image} - \text{area of fire head of initial image}}{interval(s)} \quad (2)$$

In case of calculate the area change with some fire head area, not all of in image, two scenarios are considered. First, for simple spreading, where the initial fire head and the spreading fire head overlap, calculate as follows:

$$Area\ change(m^2) = area(last\ mask) - \Sigma(area(initial\ mask\ that\ overlap\ with\ last\ mask)) \quad (3)$$

On the other hand, there are cases where the fire head has spread but has disappeared from the initial point, which is calculated as follows:

$$Area\ change(m^2) = area(last\ mask) - area(initial\ mask\ that\ bijection\ with\ last\ mask) \quad (4)$$

3. Result

Using the above methodology to calculate the spread rate of fire head area, the result is as follows. First, in the initial image, the area of fire head estimated 109810.0px, which is converted to 225.7665㎡. And in the last image(3 minutes later), it was 154464.5px and 317.5751㎡, respectively. The changed area was estimated to 91.8085㎡, and the spread rate of fire head area was finally estimated to 0.51㎡/s.

4. Conclusions and further studies

In this study, we proposed a method to calculate the area of fire images taken at different times in the same environment and calculate the difference between them to obtain the area change and spread rate of fire head area. The results of this study are expected to help provide relevant information to quickly extinguish large fires such as forest fires.

This study has the following limitations. First, the procedure to verify the error between the estimated area and the actual area is missing in this study. Therefore, we will continue to research on the verification process. Lastly, the process of converting the area derived from pixels to ㎡. The same object may have different number of pixels depending on various conditions. In this study, the formula was created assuming that the center point of the fire head and the shooting angle are horizontal (0 degrees) and the resolution is 3840x2160(4K). In future research, we will study the conversion formula in a form that can be used in various shooting conditions.

Acknowledgements

This work was supported by the Korea Planning & Evaluation Institute of Industrial Technology and funded by the Korean government (Ministry of Trade, Industry, and Energy, Ministry of Science and ICT, Ministry of the Interior and Safety, National Fire Agency, Project Title: Development of gas hydrate extinguishing agent and fire suppression technology for inaccessible fires, Project Number: 1761002860).

References

[1] Y. Xu, D. Li, H. Ma, R. Lin, and F. Zhang, "Modeling Forest Fire Spread Using Machine Learning-Based Cellular Automata in a GIS Environment" Forests, vol. 13, no. 12, 2022

[2] A. Huang, L. Jiang, J. Zhang and Q. Wang, "Attention-VGG16-UNet: a novel deep learning approach for automatic segmentation of the median nerve in ultrasound images", *Quantitative imaging in medicine and surgery*, vol. 12 no. 6, pp. 3138-3150, 2021

[3] Y. Liu, Q. Ren, J. Geng, M. Ding and J. Li, "Efficient patch-wise semantic segmentation for large-scale remote sensing images", *Sensors*, vol. 18, no. 10, 2018, 3232.

[4] X. Y. Gong, H. Su, D. Xu, Z. T. Zhang, F. Shen, and H. Yang, "An Overview of Contour Detection Approaches" *International Journal of Automation and Computing*, Vol. 15 no. 6, pp. 656–672, 2018

[5] R. Khamdamov, K. Rakhmanov, E. Saliev and Z. Karshiyev, "Advantages using of the contour analysis method for detecting fire from video images," *in proceedings of the 2021 International Conference on Information Science and Communications Technologies (ICISCT)*, Tashkent, Uzbekistan, 2021, pp. 1-4

[6] Z. Zhang, J. Zhao, D. Zhang, C. Qu, Y. Ke and B. Cai, "Contour Based Forest Fire Detection Using FFT and Wavelet," *in Proceedings of the 2008 International Conference on Computer Science and Software Engineering*, Wuhan, China, 2008, pp. 760-763