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Determining the burnt area based on digital processing and image analysis

Abstract

The paper presents the evaluation of the possibility to apply the Normalized Difference Vegetation Index (NDVI) to determine the burned area using the machine vision method. Digital analysis to determine the NDVI has been based on images obtained by transducers in visible light and near infrared (NIR). Under appropriate conditions, the described method offers an alternative to the existing methods of observation and manual measurement. As great progress has been made in the field of unmanned aerial vehicle data acquisition, the method described constitutes a possible solution especially in cases when evaluation of loss assessment caused by external fires is supposed to be prepared.

Keywords: burnt area analysis, external fire, NDVI.

1. Problem definition

Data on fire development and information concerning surface burned in external fires are nowadays obtained from people taking part in rescue and firefighting actions as well as from other sources. Those include pictures taken from the ground level and aerial photographs taken in visible light. Images from thermal imaging cameras are also used to detect and evaluate the development of fire. However, it is not possible to clearly identify the area of the burned area on the received thermograms. Limitations encountered in these methods could be caused by several reasons.

First of all, it is difficult to find reference points in thermograms, and as a result, it cannot be determined which area has been captured. Secondly - the rapid cooling of the area where the combustible material is stored may lead to some misinterpretation. The recorded area that has been burnt may be marked differently due to already low temperature.

Other possibility includes satellite pictures. An image of a large burnt area can also be obtained from satellite data. In such case, this kind of area can be determined based on the selected spectral ranges. However, such ranges cannot be used to study the dynamics of fire. The images are taken at precisely defined times and the size of a single pixel in the image - depending on the satellite - can even represent 900 m^2. Such low precision rules out the prospect of conducting researches on the fire development.

There is a possibility to estimate the burned area on the basis of ordinary aerial photographs. It must be remembered that there are no tools to automate this process and identifying an area as the burned one is a matter of subjective assessment of the person estimating the loss. Taking photos in visible light and near infrared makes it possible to determine the shape of the burnt area. On the other hand, using this method to estimate the increments of surface covered with fire during combustion seems to encounter a number of issues.

It can therefore be stated that the use of thermal imaging cameras and the Normalized Difference Vegetation Index (NDVI) for assessment of burnt area can be treated as mutually complementary.

2. Solutions applied

At present, most of the conducted researches on the development of external fires are based on images from spectrophotometers mounted on orbital satellites. Full range of spectral ranges allows you to determine various remote sensing indicators. However, these photos can be taken in a strictly defined time frame.

The basic assumption of this experiment was to determine the burned area based on images recorded from low-height. There was an extra assumption that concerned minimal hardware usage and no remote sensing satellite data due to their time limitations.

It was decided that in this experiment, two spectral ranges (red and near infrared) would be used. This solution was dictated by the applicability of the CMOS detector. The spectral ranges of 680 nm and 865 nm enabled to specify the NDVI index, which is used in remote sensing techniques to determine the degree of vegetation vigor. This index is a representation of the contrast between reflection in near-infrared and red-band absorption [1]. The index can take a value from the range −1..1.

Table 1 shows the values depending on the observed material.

Tab. 1. NDVI values for individual materials

No.	NDVI value	Description of the material
1	< 0.105	No Vegetation
2	0.105 - 0.256	Less Vegetation
3	0.256 - 0.320	Moderate Vegetation
4	0.320 - 0.382	Dense Vegetation
5	> 0.382	Highly Dense Vegetation

Source: Data computed by author using NASA – GLCF LandsatTM Imagery (2010), ERDAS Imagine 10 & ArcGIS 10)

NDVI is the basic index of vegetative behavior and it is determined by equation 1, based on two values:

$$NDVI = \frac{NIR-VIS}{NIR+VIS} \tag{1}$$

where: *NIR* - the amount of light reflected in the near infrared band; *VIS* - the amount of light reflected in the red band [2, 5].

The method of determining the index has been chosen due to the fact that photosyntheticly active objects under observation absorb radiation at wavelengths in the range of 0.4–0.7 μm. On the other hand, radiation in the range of 0.7–1.1 μm is absorbed to a small extent. The remote sensing technics also uses other derivative indicators such as Dry or Senescent Carbon, which is used to estimate the amount of carbon in dry matter [3].The indicator has been engaged in fire risk estimations.

In the years 2000-2005 some researches were conducted to evaluate the fire risk using the NDVI indicator [6]. These works included comparison of the NDVI index and the Fire Potential Index (FPI). The Fire Potential Index is a moisture-based vegetation flammability indicator. It is a function of current living vegetation greenness as a proportion of maximum greenness, and current 10-h dead fuel moisture as a proportion of the moisture of extinction. Thus the FPI is high when the living vegetation is mostly or completely cured and the 10-h dead fuel moisture is low. The FPI is low when the living vegetation is near fully green and the 10-h moisture is high i.e., near the extinction moisture. In any case, if the 10-h moisture is equal to or greater than the extinction moisture, the FPI will be zero.

The cases mentioned earlier concern fire risks. Burning intensity indexes (Burn Area Index) and NBR (Normalized Burn Ratio) were also estimated [4]. The last of the two uses the SWIR range 2.08–2.35 μm besides the red band. The correlation between BAI and NBR burning intensity and a pre-fire NDVI indicator was also studied, but the results showed no significant correlation [7].

In the studies, it was decided to use the NDVI indicator to determine the area of burnt soil cover because the low value of this coefficient indicates the absence of chlorophyll. Lack of this element is characteristic for the observed area after burning against the background of the healthy soil cover.

3. Description of the experiment

No ordinary camera can be used to receive images in both spectral ranges (680 nm and 865 nm), although some matrix CMOS detectors can cover the tested measuring range. It is due to the fact that RGB filters overlay the standard matrix, so downloading images only in the IR band seems to be not possible. In our case, monochrome cameras equipped with CMOS detectors with extended detection range for near infrared were used to capture the images.

Table 2 lists the most important camera's parameters.

Tab. 2. Summary of the most important parameters of the Basler camera

Parameter	Value
Resolution (H×V pixels)	1280×1024
Sensor's size	1/1,8"
Type of sensor	CMOS with a shift register
Pixel's size (μm)	5.3 ×5.3
Max. numer of frames	60
Transducer's resolution	12 bit
Sensor	EV76C661

Two Basler cameras were used to capture the images. Filters Schneider Filter IFG BP-680 100 HT and a polarizing Schneider Filter IF AUS SN2 025.5 Linear Pol were mounted on the lens of the first camera. The second camera was equipped with a band-pass filter Schneider Filter IFG BP-865 100 HT and a polarizing filter as well. The use of a polarizing filter allows to absorb the polarized light reflected from the glossy surfaces of plants. The light polarization effect on non-metals is greatest at Brewster's angle. Lack of a filter causes distortions in the light spectrum captured by the detector. Lack of a filter causes distortions in the light spectrum captured by the detector.

The width of the transmitted band in both cameras' color filters equals 100 nm. The system of mounting the cameras was designed in order to minimize the parallax between two recorded images. Camera's outputs were connected to the laptop via a Router with two Gigabit Ethernet cables. The software provided by the camera manufacturer "Pylon5 for Windows" was used for image acquisition. The manufacturer's software provides detailed settings for parameters such as: electronic shutter speed, sensitivity, trigger mode, etc. Cameras had the ability to synchronously trigger electronic shutters so that both images were taken exactly at the same time. Figure 1 shows the sensitivity of the camera detectors that were used and the ranges of applied band-pass filters.

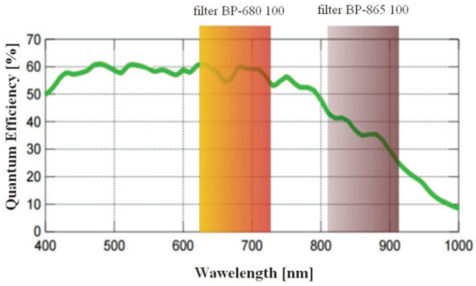

Fig. 1. Ranges of applied band-pass filters

The sensitivity of the detectors that were used in both cameras is lower for the range of 815..915 nm (NIR) comparing to the range of 630..730 nm. (R). The average sensitivity difference was determined based on the quantum yield curve of the CMOS detector (Fig.1). For the range of 815..915 nm the difference equals 58% comparing to the range of 630..730. The difference in sensitivity was compensated by extending electronic shutter speed of camera with NIR filter. The electronic shutter time was extended by 73% to match the sensitivity to the camera with the 630..730 nm filter. Since the sensitivity levels were aligned at the stage when pictures were being captured, there was no need to multiply the results in NIR range by the coefficient. Therefore, the measurement resolution of the system was not reduced.

An experiment was prepared to conduct the study. The work was carried out on August 25, 2016 between 2 pm and 5 pm. The activities involved a controlled fire of the soil cover. The purpose of the study was to collect data on the soil cover fire, which would allow to determine the burnt area. The controlled fire was carried out under the supervision of the State Fire Service. A Fire Service Unit was securing the site of the study. The fire was recorded using ordinary cameras, a measuring infrared camera and monochrome cameras equipped with the filters described earlier. The cameras were mounted in a basket of a mechanical ladder (Fig. 2, 3).

After the measurement stand had been set up, a fire was started. During the experiment, the image was recorded with a thermal camera and monochrome cameras. After the experiment was completed, the images in two spectral bands were analyzed.

A PC software for Delphi environment was developed in order to determine the coefficient distribution. This software is called "NDVI Generator". The input data consisted of two images taken in the ranges of 680 nm and 865 nm.

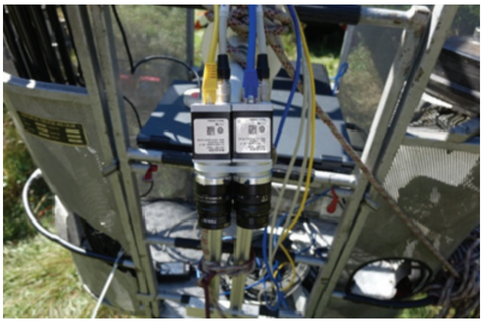

Fig. 2. Basler acA1300 monochrome cameras mounted in a mobile elevated work platform (MEWP)

Fig. 3. The area after burning seen by the set of cameras

The rules which influence the software's operating are quite simple. The program has been developed to determine a corresponding pixel value in the output picture for each pair of pixels from two input images. The program performs operations on all pixels:

```
// instructions in pseudocode
NDVI:= ((IR-R)/(IR+R));
NDVI:=(NDVI+1)/2; //normalization from -1..1 to 0..1
Output pixel:= round(NDVI * 256);
```

The coloring of the resulting image was introduced in order to visualize the results of the program in a more efficient way. The red color (Figure 4) indicates areas which values do not exceed the accepted threshold.

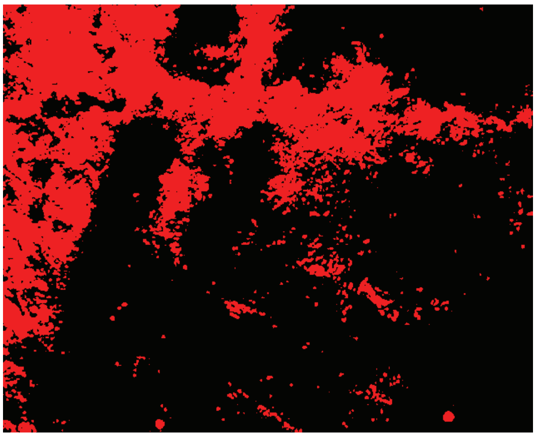

Fig. 4. View of the spatial distribution of NDVI with the threshold -0.2

The optimum NDVI = – 0.2 was determined based on experimental selections of the threshold levels. According to Table 1, the value of –0.2 corresponds to the coefficients of dead plants, roads and buildings, and soil.

Figure 4 shows the infrared thermogram during combustion of the area under study.

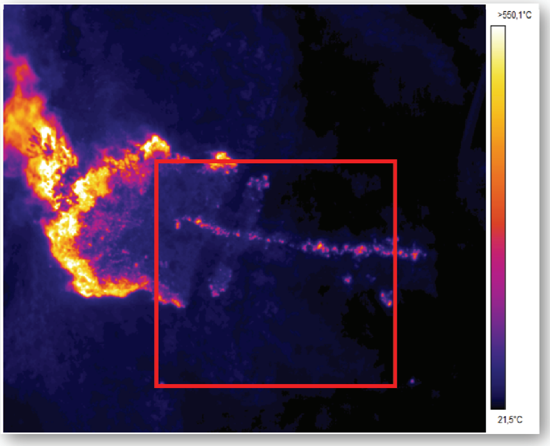

Fig. 5. Infrared view captured by the Flir SC-640 camera in the final stage of combustion

During the course of the experiment, an attempt was made to determine the dynamics of the fire. It specifically considered the dynamics of the fire front movements and was based on subsequent sequences of the NDVI distribution. However, since the rising smoke obscured the area under observation, these places were falsely interpreted as burnt areas. Correct interpretation is possible only without the presence of smoke.

Another fact that needs to be mentioned is that in case of a higher threshold (level 0) the presence of shadows causes artificial NDVI underestimation. The elements of dead vegetation may also coincide with the range that accompanies the burned area.

4. Conclusions

The method that has been described is relatively simple and does not require expensive equipment. However it must be remembered that its effectiveness is determined by conditions described below:

- Tested area cover must be homogeneous in order to determine the losses.
- Tested area cannot be shaded.
- Tested area must be free of dead vegetation, roads, buildings and objects.
- The surroundings cannot be in smoke.

Recommendations:

- For correct interpretation of the burned area, the NDVI threshold can be assumed at –0.2 or determined experimentally.
- The area should be well lit by sunlight, preferably at noon. That would help to shorten any possible shadows.

Despite many conditions that limit the applicability of this method, it can be said that it has an undoubted advantage over the use of images from the thermal imaging camera. Indisputably, its strong point is the ability to be applied long time after the soil cover is burned. On the other hand, the advantage over satellite image analysis lies in the much higher image resolution and the lack of time regimes associated with long intervals between subsequent satellite passes. The small size of the detectors and their relatively low price, predestine the method described for use in unmanned aerial vehicles during the evaluation of the fire losses.

5. References

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