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Monitoring Temperature Change on a Surface to be Used as an Early Warning System of Fire

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ABSTRACT

Once the temperature of an object reaches its *auto-ignition temperature level*, combustion occurs. If the increase in temperature is prevented before an object reaches this particular temperature level, the object is unable to ignite. In order to achieve the above objective, in this research project, an early warning system of fire has been developed which is capable of monitoring the temperature of objects in a given region continuously. When the possibility of an increase in temperature is detected by the warning system, a warning alarm of fire is activated. A digital camera is used in this warning system to monitor the temperature. The conversion of an ordinary web camera to a temperature monitoring device is the main task of the research project and this report describes how that is accomplished successfully. In this work, the constructed device is tested by capturing photographs of a metal wire while its temperature is increased. Then, the captured photographs are analyzed using software developed especially for the purpose. This device is capable of providing very accurate results when the distance between the camera and the object which is being monitored is less than or equal to 75 cm.

1. INTRODUCTION

The definition of fire has been given as ‘A process involving rapid oxidation at elevated temperatures accompanied by the evolution of heated gaseous products of combustion, and the emission of visible and invisible radiation’ [1]. As the definition says, fire is generated due to an oxidation process. The molecules of materials are chemically bonded with each other and in these chemical bonds there is certain amount of energy. In case of a fire, a material which is going to ignite must react with oxygen atoms, and for this, chemical bonds that exist among molecules of the material must be terminated. For this process, sufficient energy must be provided to the material to terminate the bonds and this particular amount of energy is known as the *activation energy* of the material. When heat is provided to a material, for it to be able to ignite, the amount of heat has to exceed the activation energy [2].

A minimum temperature level for ignition exists for most of the fuels. At this temperature level, a fuel gets sufficient energy for the combustion. There are two types of minimum temperature levels and they are the *flash point* and the *ignition temperature*. The flash point of a fuel is the minimum temperature level at which the fuel ignites due to a free flame, in the presence of air. The ignition temperature or auto-ignition temperature of a fuel is the minimum temperature level at which the fuel ignites in air without a flame or a spark [3].

Most of commercial fire alarm systems have been designed to give a warning in the early stages of a fire and for this, the alarm systems detect heat, smoke or flame. However, when such an alarm system is ready to give a warning signal, it will be too late, because, then the fire has already started and there may be a risk of spreading [4]. The objective of this research work is to prevent an ignition before a flame or an

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oxidation occurs. In order to achieve this situation, an early warning must be provided at a temperature which is much less than the auto-ignition temperature of materials because then, there will be no risk of a fire hazard.

2. EXPERIMENTAL

In this research work an attempt is made to construct a system using a web camera to monitor surface temperature of an object where the initial surface temperature is equal to the room temperature. In digital cameras, there are infrared-block filters installed to block the infrared region of the electromagnetic spectrum. In this research work, for a web camera to be used as a temperature monitoring device, it is necessary to reduce the minimum temperature that can produce a signal in the camera. For this purpose, the infrared-block filter is removed from the web camera to allow the radiation of near-infrared region to reach the image sensor. Necessary computer software is developed for the purpose of analyzing the images captured by the web camera.

In order to test the ability of the web camera to detect and monitor the surface temperature of an object, the following test is carried out. A potential difference is applied between the two ends of a Nichrome wire, through a variac which can be used to vary the potential difference. When the potential difference is varied the input power also varies and power dissipation occurs in the form of thermal energy. Since power dissipation is directly proportional to the square of the voltage, the thermal energy increases rapidly as the voltage increases. Thus, by increasing and decreasing the potential difference across a wire, the temperature of the wire can be increased and decreased respectively. So, the variac acts as a temperature controller for the Nichrome wire. While the temperature was varying, by means of the variac, a series of photographs of the Nichrome wire is taken. In this research work, a non-contact infrared laser gun (DT-320) is used to measure the temperature and the monitoring of the temperature is done via an image processing method. For developing the necessary software, 'C Sharp' is used as the programming language which is employed with .Net framework.

Due to a higher intensity of radiation than that can be detected by an electron well (photo detector) of the image sensor of a camera, that electron wells can get saturated. If there is a higher number of electrons than the maximum number that can be collected by a photo detector, the additional electrons flow to neighboring electron wells. Thus, unexpected light color pixels occur and these pixels are known as *blooming*. Fig. 1 shows a blooming signal which occurs due to the radiation emitted by the Nichrome wire. Since blooming is the only signal required for this research work, measurements are made only using this particular area. Here an attempt is made to contain the initial state of blooming to within a grid area (or a square) and to study how it spreads within this particular area with temperature (this procedure is described in detail below).

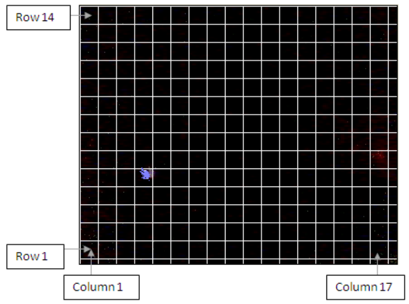

Fig. 1: The blooming signal is at the grid area where the row = 5 and column = 4.

It is known that all colors are produced by a combination of the three primary colours, red, green and blue. The blooming signal is also produced with these three component colours. Therefore, it is useful to study how these components vary with the temperature within the grid area. For this purpose, a special method is introduced in this research work. To study the spreading of the blooming, an average pixel value of each colour component is calculated by choosing the width of the grid area to be 20 pixels. For example, to obtain an average pixel value for the red colour, the red components of each and every pixel in the grid area are added and the sum is divided by the number of pixels in the grid area.

Number of pixels in a grid area with 20 pixel width = $20 \times 20 = 400$

Pixel value of the red component at the i^{th} raw and j^{th} column of a grid area= $r_{i,j}$

Average pixel value of the red component of the grid area = $\frac{1}{400}\sum_{i=1}^{20}\sum_{j=1}^{20} r_{i,j}$ .... (1)

Here, the row and column numbers of Figure 1 should not be mistaken with i and j of $r_{i,j}$ of Equation (1). The row and column numbers of Figure 1 are for selecting a grid area from the figure. Then, the pixel is selected from the i^{th} raw of pixels and the j^{th} column of pixels of the selected grid area.

Following the same procedure with Equation 1, average pixel values were calculated for green and blue components. Light colour pixel values are found to be much greater than dark color pixel values. It is a standard method for a computer software to assign 0 for each component of black colour and 225 for each component of white colour [5]. As the pixel values of the blooming area are higher than the pixel values of the rest of the grid area, the average pixel values go up while the blooming grows. Hence, the average pixel value indicates the spreading of the blooming.

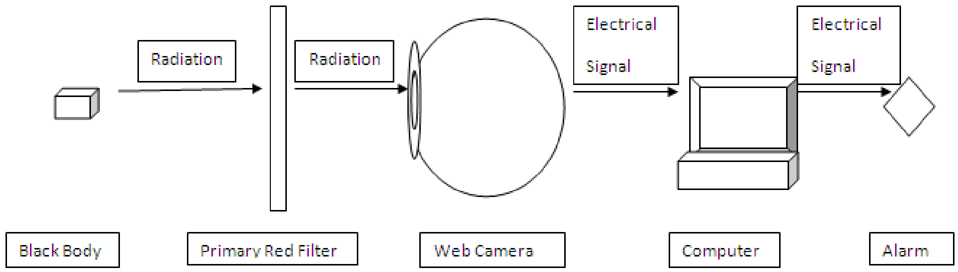

Fig. 2: A schematic diagram of the experimental arrangement

After identifying the blooming of the image sensors, this research work required to employ the blooming as a warning signal. It has been identified that there are some other sources which produce the same kind of signals at the image sensor. These sources are

1. White color objects
2. Shining objects

It becomes extremely difficult to produce a warning when those objects are present. In order to prevent those signals from entering, a primary red filter is installed at the front face of the camera (see Fig. 2).

3. RESULTS AND DISCUSSION

3.1 Photographs taken with a nichrome wire in a lighted room (without the primary red filter)

Photographs presented here were taken when the room was lighted, without installing a primary red filter in the web cam. Fig. 3(a) shows a picture of a shining metal which produced a signal much similar to that of the blooming moment. Fig. 3(b) is a picture of a white color paper and, such an object can produce a picture that is very much similar to the one obtained for a blooming moment (shown in Fig. 3(c)). If the temperature is rising near these two objects, the user of this early warning system is unable to recognize the fire risk. With this system, an electronic alarm is coupled to provide the warning. But, if there is an error in the electronic alarm, the user must be able to recognize the blooming moment using the naked eye. Therefore, shining metals and white color objects are considered as noises for the early warning system of fire.

The primary red color filter is used to pass only the red color. This is a band pass filter but the data sheet provided by the manufacturer does not show what the exact pass band is [6]. Approximately, it may be from 600 nm to 1000 nm. Therefore, radiation in this wavelength range causes blooming to occur in the image sensor, when the particular filter is employed. Through this filter, the wavelengths outside the human sensitive range can be transmitted. This is an advantage in detecting lower temperatures.

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Fig. 3 (a): Shining metal is shown by the arrow.

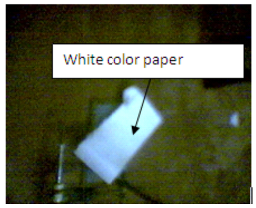

Fig. 3(b): White color paper is shown by the arrow.

Fig. 3(c): Blooming moment

3.2 Photographs Taken with a Nichrome Wire in a Lighted Room (with the primary red filter)

Fig. 4 (a): A photograph of a shining metal when the primary red filter is used.

Fig. 4 (b): A photograph of a white color paper when the primary red filter is used.

Only the red color components of radiation from shining metals and white color objects pass through the filter (See Fig. 4(a) and (b)). There is a significant difference between the blooming moment and the signals produced by the above objects (see Fig. 3). Therefore, the naked eye is able to recognize the blooming moment even though the room is lighted. The primary red filter has solved the problem which was considered in Section 3.1.

Fig. 5 shows that there is an increasing trend in the average pixel values of red beyond the surface temperature of 242 °C. This is common for blue and green components too. When the web camera detects this signal at this temperature, it could not be seen with the naked eye. So, the data of Table 1 is a proof for silicon's capability of detecting colors in the infrared region. However, it was not possible to find the minimum intensity required for the blooming. From the findings of this research project, it was possible to prove that around 242 °C, a grey body is also able to emit radiation which causes blooming.

Table 1: Average red, green and blue pixel values of the specific grid area when the width of the grid area is 20 pixels.

Number	Temperature (°C)	Red	Blue	Green
1	94	9	0	0
2	117	6	0	0
3	193	0	0	0
4	242	14	3	3
5	263	15	5	3
6	268	15	12	9
7	278	19	22	15
8	281	34	45	29

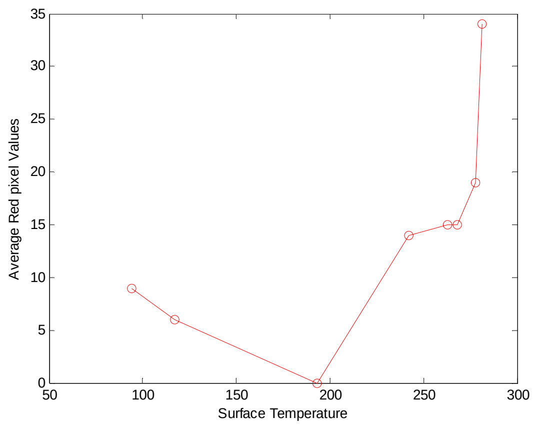

Fig. 5: Average pixel values of red color vs. Surface temperature (°C)

3.3 Photographs taken with a piece of graphite (with the primary red filter inserted)

Tenma 72-820 digital IR-thermometer was employed to measure the temperature of a piece of graphite that was heated with an oxygen flame to a high temperature. Here graphite was used because it was needed to prove that blooming could be obtained at temperatures below 300 ^{o}C for non-metallic materials (see Fig. 6).

Fig. 6(a): A photograph taken at 288 ^{o}C (Average of red = 16, blue = 8, green = 14 in a grid area in the middle of the blooming region)

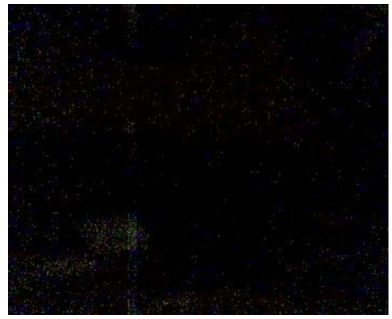

Fig. 6(b): A photograph taken at 292 ^{o}C (Average of red = 17, blue = 10, green = 15 in the same grid area marked in Figure 6(a))

3.4 Noise

The main source of the noise is the sun. It generates a much higher intensity of radiation and emits a wide range of wavelengths. Even though the whole the range of wavelengths cannot reach at the surface of the earth, the visible region, near-infrared region, microwaves and radio waves are able to incident on the earth [7]. Other waves are absorbed by distinct layers of the atmosphere. The visible and near-infrared regions are the main causes for generating noise in the web camera. Due to the high intensity of these radiations, blooming occurs.

3.5 Recognizing the blooming programmatically

At about 243 ^{o}C, the blooming is so weak and the signal is shown as a light colored continuous area. After analyzing the picture by means of software developed especially for this purpose, it could be realized that most of the pixels of the blooming area contains red, blue and green values greater than 100. But, there are so many noises in the photographs which appear as light color random dots. Therefore, it is necessary to be able to differentiate the blooming area from the noises. Since the blooming area is continuous and noises are discontinuous, when the software finds pixels with three color component values greater than 100, it checks whether those values of the neighboring pixels are greater than 100. Likewise, a continuous blooming area can be detected and once a blooming area is detected, the software transmits a signal to the alarm. This serves as the warning signal for fire.

4. CONCLUSION

The system described in this report is capable of giving a warning signal for fire when the surface temperature reaches a value close to 268 ^{o}C. Since the auto-ignition temperature must be much higher than the surface temperature of the objects for the warning signal to appear, the warning system is recommended to be used for materials whose auto-ignition temperature is higher than 300 ^{o}C. This system is more suitable for

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monitoring temperature inside of buildings at night time because then there is no noise disturbance due to sunshine.

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