REVIEW ON FIRE DETECTION TECHNIQUES

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Abstract—Fire is a hazardous environmental issue which can cause serious damage to lives and environment if it is not controlled on time. Every year, fires across the world cause damages beyond description. Therefore development of early fire detection is very crucial to reduce damages. Lots of fire detection methods have been introduced by many researchers. This review will summarize existing fire detection techniques such as various sensor technologies based, image processing based, deep learning network based. Each technique have its own merits and demerits which are also discussed.

Index Terms—Fire detection, Sensor, Image processing, RGB, HSI, YUV, Motion detection, Image classification, CNN

I. INTRODUCTION

Fire is a critical environmental issue. Dreadful consequences of fires are global warming, effects on weather patterns, loss of lives, extinction of rare species. The fire explosion may be due to human actions like smoking, heating or by environmental reasons such as lightning, high temperature. Early fire detection helps in reduction of damages. The objective is to detect the fire early with less false alarming rate and provides an alert to the appropriate authority. With advances in sensor, image processing, information technologies and embedded processing, many new fire detection methods had developed over last years. Advances of fire detection techniques has effectively minimized the losses.

Fire detection technology still faces challenges associated to the reduction of false alarming rate. This paper aims to review existing fire detection techniques.

Conventional multiple sensor based fire detection system have been used in closed compartments such as buildings, ship compartments, aircraft cargo compartments [1]. It takes time to produce alarm because sensor require close proximity of fire, low performance, can't provide detailed information about fire [10,12]. It reacts to changes in gas levels and smoke. In addition, Wireless Sensor Network has been introduced to detect fire in larger areas due to their high flexibility, facility of deployment [9]. It reacts to changes in temperature and CO2 levels.

To enhance the detection of fire, fire detection based on vision sensor is essential. Nowadays CCTV camera is installed all over the world for security applications. Image processing have crucial role in detection of fire [3] and detect fire by extracting fire features such as color, motion, size, shape [3,4]. This technique has high reliability and effectiveness. In addition, due to advances in embedded processing, fire detection system based on Convolutional Neural Network is elaborated. It have fast response and less false alarming rate.

The organization of the paper is as follows: Section II deals with literature review. Comparison is described in section III. Section IV includes conclusion of the paper.

II. REVIEW OF LITERATURE

To detect fire, numerous techniques are available. In forthcoming sections, reviewed some fire detection techniques.

A. Fire Detection Using Smoke and Gas Sensors

The smoke detector alone based fire detection have high false alarming rate. Alarm having no verified smoke is known as false alarming rate. To overcome this problem fire detection based on smoke detector and gas sensors is developed.

The fire detection system (Fig. 1) consists of smoke detector, CO sensor, CO2 sensor, data

processing module, fire alarm algorithm and fire status report module. This fire detection system detect fire by detecting levels of CO, CO2 and smoke by using gas sensors and smoke detector. Generate alarm if rates of increase of these levels exceeds their predefined threshold rate. This system is used in closed areas such as buildings, ship compartments, aircraft cargo compartments. It detect fire like smoldering to combustion.

Smoke concentration is detected by using light scattering method. A photoelectric smoke detector is used here. The light radiated from the LED is passed to the place being detected and received to the photodiode. The obtained light intensity is decreased due to scattering from smoke particles. Generate alarm if the light intensity is below a specified threshold rate. CO and CO2 sensors based on the method of diode laser absorption spectroscopy is utilized for detecting concentrations of CO and CO2. To measure the concentration of gases diode laser absorption spectroscopy is one of the best technique. The wavelength of diode laser is tuned over the absorption line of gases. This causes a reduction of light intensity due to absorption. The light intensity is measured by using photodiode and it then used to detect gas concentration. Wavelength of diode laser is tuned by adjusting its temperature and injection current. Diode laser used here is a distributed feedback (DFB) diode laser. After detecting the levels of CO, CO2 and smoke its output is fed to data processing module.

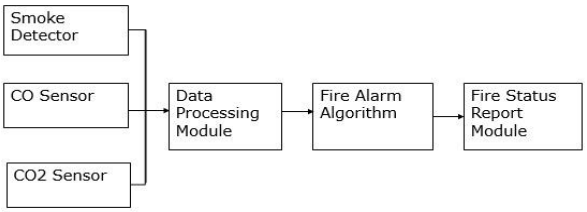

Fig. 1. Fire Detection System [1]

Data processing module consists of data filtering and a method to compute rate of increase of smoke, CO, CO2. Data filtering is used for removing unwanted data based on moving average filter over a specified time window. Compute rates of increase of smoke, CO, CO2 by using linear regression. In this output of the filter over a specified time window is fitted using a straight line and slope of the straight line indicates time derivative of smoke, CO, CO2 and it corresponds to rates of increase of smoke, CO, CO2. Then output of data processing module is fed to fire alarm algorithm.

Fire alarm algorithm using maximum values are sensitive signal offset and needs frequent accurate measurements. To avoid this problem fire alarm algorithm using rates of increase (ROI) is used. If the (ROI) of smoke exceeds its predefined threshold value, then (ROI) of CO and CO2 are examined. In case (ROI) of either CO or CO2 exceeds its predefined threshold value, then fire alarm should be generated. When smoke concentration is not present but concentration of CO and CO2 are present then another fire alarm algorithm is used. In that fire alarm algorithm (ROI) of all fire signatures are simultaneously examined and if any 2 fire signatures exceeds their predefined threshold value then fire alarm should be generated. This fire alarming is resistant to signal offsets due to background changes and aging of sensor.

B. Early Fire Detection System Using Wireless Sensor Networks

This fire detection system detect fire by using a wireless sensor network (WSN). The WSN is have huge amount of sensors which sense environmental measures and transmit the data to a base station using a wireless medium. WSN is used for variety of applications such as remote controlling, target tracking, military, nuclear reactor controlling, environmental monitoring, surveillance because of its deployment facility, high flexibility and high extensibility. The proposed method detect fire in forest by detecting CO2 and temperature based on using WSN.

Properties of WSN:

- Lack of infrastructure: Network is not required infrastructure for connection
- Mobile topology: Because of failure of sensor nodes or mobility of sensor nodes the topology of WSN changes
- Less Physical Security: WSN have possibility of data theft

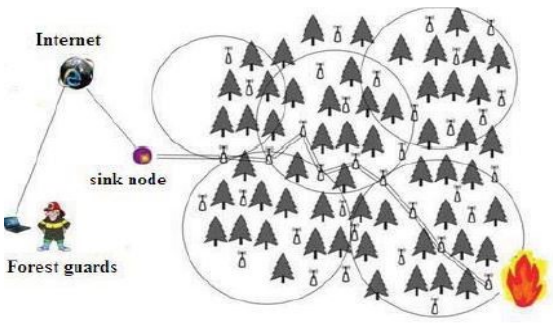

Fig. 2. System Architecture [2]

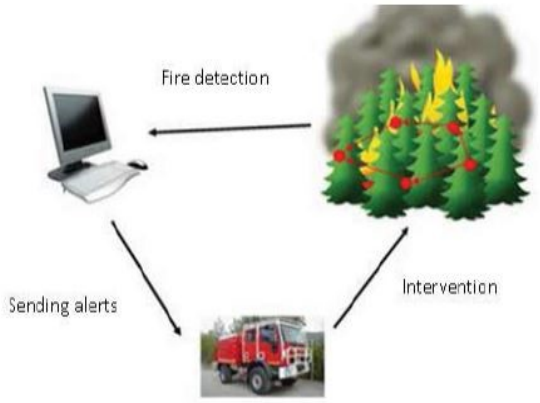

Fig. 3. System Functioning [2]

There are two main WSN architecture:

1. Flat network architecture

In this architecture sensor nodes are deployed in a given space and every node is straightly fed to the destination. Data is send hop by hop until it reaches to the base station via routing protocol such as dynamic source routing protocol [13].

2. Hierarchical network architecture

In this architecture sensor nodes are grouped into clusters. Most powerful sensor is selected as cluster head and remaining sensor nodes are called cluster members. Cluster members transmit the sensed data to the cluster head and which in turn transmit data to the base station. Cluster head is used for maintenance, creation of cluster. This architecture uses data aggregation to reduce number of transmissions by combining datas of all the sensor nodes. Hierarchical architecture is highly efficient and suitable for large areas.

Fig. 2 shows system architecture which consist of tree subsystem which discover fire and forward alert to the forest authority. Early detection of fire reduce damages and control fire. The proposed system have sub systems for each task. Fig. 3 shows system functioning.

1) Fire detection sub system: Each sensor node in the WSN occasionally detect CO2 and temperature values then compare detected values with their predetermined threshold rate. Send message alert to the destination when the temperature and CO2 values exceeds their predetermined threshold rate. Alert message includes values of temperature and CO2, GPS coordinates of sensor nodes.

2) Transport sub system: The alert message is send hop by hop until it reaches to the destination using a routing protocol such as flooding. In flooding when a sensor node sense the data, this data is broadcast to all other neighbouring nodes and this process of broadcasting is continued until the data has reached to the destination. Advantages of flooding are ease of implementation and simplicity. The base station forward the received alert message to the forest guards to take actions for controlling fire.

3) Localization sub system: For localization of fire, cluster head requires its GPS coordinates and the remaining cluster members obtain their GPS coordinates from cluster head's position. Hence when dispersing a cluster head, first secure its GPS coordinates and remaining cluster members obtain their GPS coordinates by taking the distance from cluster head's position.

Operating system used here is a TinyOS. It uses NESC programming language. Sensors used here are mtm-cm5000msp.

C. An Early Fire Detection Method Based on Image Processing

The fire detection is based on using color features of fire. Fire normally shows reddish colors, but the color of fire will varies with fire temperature. When temperature of fire is low, the fire color will be red to yellow range. When temperature of fire is high, the fire color will be white. Also fire color during extra light source or day time have larger saturation when comparing with night time or no light source. Hence these color features of fire is used to detect a real fire.

Fire detection based on RGB color model:

Although of numerous colors of fire, the starting fire usually shows red to yellow color. The related RGB value is indicated as $R \geq G$ and $G>B$. Due to stronger R in fire picture, R should be provides a higher value. So R value should be larger than threshold R_T . Although background lighting conditions may effect fire saturation or produces fire aliases which causes wrong fire detection. Hence fire saturation value should be larger than threshold.

Hence the three RGB based rules for extracting fire pixels from a picture is given below:

$$\text{Rule 1: } R \geq G > B$$
$$\text{Rule 2: } R > R_T$$
$$\text{Rule 3: } S \geq ((255 - R) * \frac{S_T}{R_T})$$

In an image may have fire like portions and these fire like portions are normally extracted as real fire from an image and this causes false fire detection. Here two fire aliases are considered.

Fire colored objects and fire colored illumination sources. Objects with red colors is normally extracted as real fire from an image and this cause false fire detection. The second one, light sources such as solar reflections, artificial illuminations causes false fire detection. Hence to distinguish fire from fire aliases dynamic features of fire is used which comprises variable shape, unexpected movements, growing rate, disorder characteristics. Fire disorder is defined as the difference taken between two consecutive images and fire disorder should be higher than disorder threshold. Growing rate of fire depends up on fuel type and air flow. Let m_i and m_i +1 indicate fire pixel values of current image and next image. If m_i +1 > m_i then there is a growing rate of fire. Hence if these conditions is satisfied, we can say that fire should be real fire not fire aliases.

Fire alarm generation:

The early detection of fire reduces fire damages but wrong fire detection leads to various losses. Hence here using iterative checking on growing rate of fire pixels, an alarm is provides when alarm state is reaches. The basic idea is that if the extracted fire pixels grows with burning time, then fire will be spread out and fire alarm should be issued. m_i +1 > m_i
for repeated times indicate that it is real fire. Let R indicate the times of m_i +1 >m_i , N indicate times of comparing m_i and m_i +1 . When the value of $\frac{R}{N}$ is higher than 0.7, then fire is going to spread out and when the value of $\frac{R}{N}$ is higher than 0.9, then fire must open out.

D. Video Fire Detection Based on Gaussian Mixture Model and Multi Color Features

This fire detection system uses color and motion features of fire. The proposed technique consists of 2 steps.

1. Moving object detection
2. Multi color detection

Finally these two steps are combined to detect accurate fire regions.

1. Moving object detection

Fire and smoke are moving objects and also there are so many fire like moving objects. Here moving object detection is based on using background subtraction. To extract moving objects Gaussian Mixture Model (GMM) [6] based background subtraction is utilized here. In GMM value of every pixel is represented as a mixture of K Gaussian distributions. Every Gaussian distribution that is higher than the threshold is classified as background and other Gaussian distribution is called as foreground. Every pixel is checked with K Gaussian distributions, until a math is found. There are 2 cases.

First case: A pixel is matches with K Gaussian distribution. In this situation, if the Gaussian distribution is categorised as background then the pixel is categorised as background else pixel is categorised as foreground.

Second case: A pixel is not matches with K Gaussian distribution then pixel is categorised as foreground.

2. Multi color detection

The next phase of proposed method is multi color detection using RGB, HSI and YUV color models.

1. Fire detection based on RGB color model

Although of numerous colors of fire, the starting fire usually shows red to yellow color. The related RGB value is indicated as $R \geq G$ and $G>B$. Due to stronger R in the fire picture, R should be provides a higher value. So R value should be larger than threshold R_T . Although background lighting conditions may effect fire saturation or produces fire aliases which causes

Fig. 4. Original Image [4]

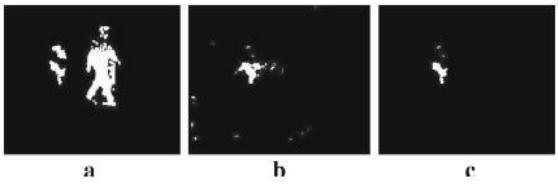

Fig. 5. (a) Output of moving object detection. (b) Output of multi color detection. (c) Output of combination [4]

wrong fire detection. Hence saturation value of fire should be larger than threshold.

Hence the three RGB based rules for extracting fire pixels from an image is given below:

Rule 1: $R \geq G > B$
Rule 2: $R > R_T$
Rule 3: $S \geq ((255 - R) * \frac{S_T}{R_T})$

2. Fire detection based on HSI color model

HSI color model represent color using hue, saturation and intensity. Red-to-yellow color fire's hue value is range from 0 to 60. Background lighting may affect the saturation of fire. Brighter regions have higher saturation than dark regions. This is due to the fact that fire is the vital and only lighting if there no other lighting. Hence hue have more white for fire. To provide sufficient illumination in image processing, intensity value should be higher than threshold. Hence the three HSI based rules for extracting fire pixels from an image is given below:

Rule 1: $0 \leq H \leq 60$

Rule 2: $20 \leq S \leq 100$

Rule 3: $100 \leq I \leq 255$

3. Fire detection based on YUV color model

YUV color model represent color with 1 luminance component (y) and 2 chrominance components (u), (v). This color model is resistant to lighting conditions and decreases the affect of lighting changes. The luminance should be large and chrominance should be less. Hence the three YUV based rules for extracting fire pixels from an image is given below:

Rule 1: $Y \geq Y_T$

Rule 2: $|U - 128| \leq U_T$

Rule 3: $|V - 128| \leq V_T$

Y_T, U_T and V_T are thresholds values of Y, U and V.

Lastly, the 3 rules of RGB, HSI and YUV color models are combined using union operation to create multi color model, which is then used on an image to extract fire pixels, denoted as $R_{color}(i, j, n)$.

Fig. 6. System Overview [7]

$R_{color} = R_{RGB} \cup R_{HSI} \cup R_{YUV}$

Utilizing moving object detection or multi color detection only to detect fire should cause wrong fire alarming. Hence we incorporates the results of GMM and multi color detection to get correct fire pixels from an image, denoted as $R_{fire}(i, j, n)$.

$R_{fire}(i, j, n) = R_{moving}(i, j, n) \cap R_{color}(i, j, n)$

Fig. 4 shows input image and fig. 5 shows outputs.

E. Convolutional Neural Networks Based Fire Detection in Surveillance Videos

This fire detection system detect fire by using convolutional Neural Network (CNN). The traditional methods still have false alarming rate. Hence used CNN for fire detection which will reduce false alarming rate. The proposed method balances the computational complexity and accuracy of fire detection.

Fig. 6 shows overview of the system. The image captured by the camera is classified based on using CNN. If the image is categorised as fire, then an alert will send to appropriate authority.

CNN is mainly used for image classification. CNN architecture is shown in Fig. 7. It works by extracting features from images and it automatically learn features from images. During training process of CNN, already known input image and several filters are convolved to obtain feature maps. After, applies ReLU function to each of the feature maps to increase the non linearity, then applies pooling layer to each of the feature maps to reduce the size. After, flattens the feature maps in to one long vector and which is then fed to the fully connected layer (FC). FC layer processes the features through it and classify image in to various classes using an activation function. Here two classes are considered, fire class and non fire class. All the layers are organized in a hierarchical architecture. During training weights are adjusted using back propagation algorithm. Once the network has been trained, a new image is passed to the network and image will pass through all the layers and FC layer uses the features of input image for classifying input image in to various classes based on using features of trained image.

In this fire detection system a cost effective CNN model is used such as a model alike Google Net [16]. It have several advantages such as high accuracy, small size, suitable for implementing on FPGAs. The model have 100 layers accompanied by 2 convolution layers, 4 max pooling layers, 1 average pooling layer and 8 inception layers as given in Fig 8.

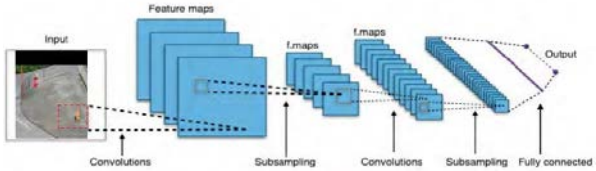

Fig. 7. Classical CNN Architecture [5]

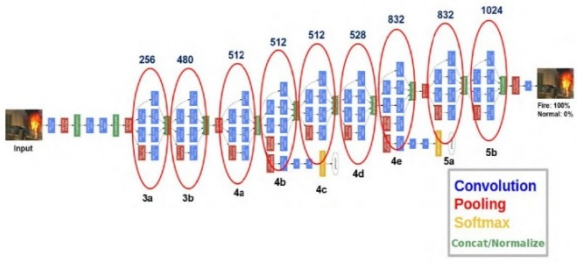

Fig. 8. Architecture of Proposed Model [5]

Input image of size 224 × 224 × 3 pixels and 64 filters having size 7 × 7 pixels and stride 2 are convolved to obtain 64 feature maps having size 112 × 112 pixels. After, max pooling layer having size 3 × 3 with stride 2 is applied to reduce the size of feature maps. Then, result of the pooling layer is again convolved with 192 filters of size 3 × 3 with stride 1 to obtain 192 feature maps having size 56×56 pixels. Next, applies max pooling layer having size 3×3 with stride 2. Then, applies 2 inception layers (3a) and (3b). Inception layer is used for reducing computational complexity which uses 1×1 covolutions for decreasing the dimensions. After, applies max pooling layer having size 3 × 3 and stride 2, then applies 4 inception layers 4 (a-e). Then, max pooling layer layer having size 3 × 3 and stride 2 is applied, next 2 inception layers (5a and 5b) is applied. Next, average pooling layer having size 7 × 7 and stride 1 is applied. After, a dropout layer is used to avoid overfitting. Next, flattens the outputs in to one long vector and which is then fed to fully connected layer. Fully connected layer classify image in to fire class or non fire class.

III. COMPARISON

Fire detection based on smoke and gas sensors are resistant to background changes and noises, reduce false alarm generated by smoke detector operating alone and disadvantages are it take time to produce alarm, not suitable for outdoor spaces, low performance, can't provide information about location of fire, fire size.

Fire detection based on WSN can be used for large areas, high flexibility, facility of deployment, high extensibility and disadvantages are high coordination is required between sensor nodes, more complex to configure than wired network, possibility of data theft.

Fire detection based on image processing is cost effective, provide information about whether the fire will spread out or not, reduced detection time and disadvantages are it fails to distinguish real fire from fire like moving objects, high false alarming rate.

Fire detection based on GMM and multi color models have better effectiveness, robustness, adaptability, can differentiate fire from fire colored objects and fire like moving objects and disadvantages is it have false alarming rate.

Fire detection based on CNN have less false alarming, high accuracy, less human interference, fast response and disadvantages are it require high memory and long training time.

IV. CONCLUSION

In this review paper variety of fire detection techniques are discussed and analyzed. Fires can potentially result in a great losses to lives and environment. To protect environment and human lives different fire detection techniques are required. The main goal of fire detection system is to detect fire early with low wrong alarming rate. From the comparative study we can conclude that, fire detection using CNN model is fast and accurate method. All the methods in the literature are compared and demonstrates higher performance in terms of high fire detection rate and low wrong alarming rate.

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