Intelligent Fire Warning System Based On Image-Based Infrared Sensor and Zigbee Technology

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Abstract

Fire is one of the main disasters threatening public safety and social development. The large-scale casualties, property losses and social negative effects caused by fire accidents are particularly serious. Therefore, how to effectively, reliably and timely prevent the occurrence of fire in dangerous places has always been the research hotspots in the field of fire science. This paper proposes an intelligent fire warning system based on a low-cost image-based infrared sensor and Zigbee Internet of things technology, which is a kind of an advanced fire warning system with intelligent networking functions, and mainly uses the emerging method in the field of fire detection---infrared detection technology and the popular Internet of things technology--- short distance and low power wireless network technology based on Zigbee protocol.

Keywords

Early fire warning system, image-based infrared sensor, Zigbee.

1. Introduction

The hazard of fire is large and affects a wide range, especially in dangerous places. The fire will cause the leakage and explosion of dangerous items, which will not only cause property damage and personal injury, but also seriously pollute the environment. At present, smoke detectors are the most widely used detector in fire warning, which has the advantages of high reliability, low cost and convenient control, etc. According to the statistics, the sales and usage of this type of fire detector in the domestic and foreign markets account for 70%-80% of the total number of fire detectors [1]. However, smoke detectors have obvious deficiencies in some aspects, for example, warning is insufficient, and detector sensitivity in large space places is greatly affected by space height, smoke concentration, wind direction, etc., which makes it difficult to achieve early warning of fire [2].

Along with the visual technology of internet developing rapidly, and supported by increasingly powerful hardware, the fire warming system based on image has become gradually one of the research hotspots in the field of fire science. Generally, image-based fire detection can start with visible light images and infrared images, but whatever we take is based on the visual technology or the image technology. In order to achieve high accuracy, good reliability, strong anti-jamming and high real-time ability, the detection effect must be assisted by a high-performance base, which comes high costs and high maintenance costs, so it isn’t widespread for the fire warming based on image.

In this paper we propose an intelligent fire warning system based on image and internet of Things by the theoretical analysis. This system extracts and analyzes the feature information of infrared images of the monitored area, which can predict in time and accurately if the measured area has potential for the fire hazard.

2. System Design

This system includes four layers, the bottom layer is ZE (Zigbee Endpoint) monitoring target which includes the infrared array sensor, STM32， Zigbee module, voltage stabilizing circuit, display screen, and realizes the functions of real-timely acquiring , analyzing and delivering data of monitored target of infrared image. ZE's structure is shown in Fig. 1.

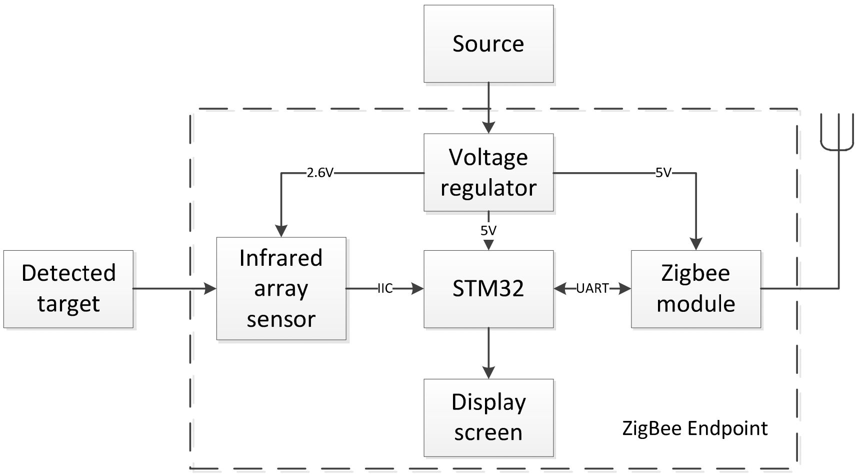


Fig 1. ZE's structure

The second layer is ZR (Zigbee Router) also called Zigbee module whose function is relaying date package transmitting of ZE and forward to the third layer ZC (Zigbee Coordinator), which includes Zigbee module, STM32, voltage stabilizing circuit. ZC realizes the function of network building and data forwarding.

The top layer is PC (upper-computer) software which realizes the functions of monitoring and displaying real-timely for the whole system including the monitoring state of ZE and the state of communication network. The system is shown in Fig. 2.

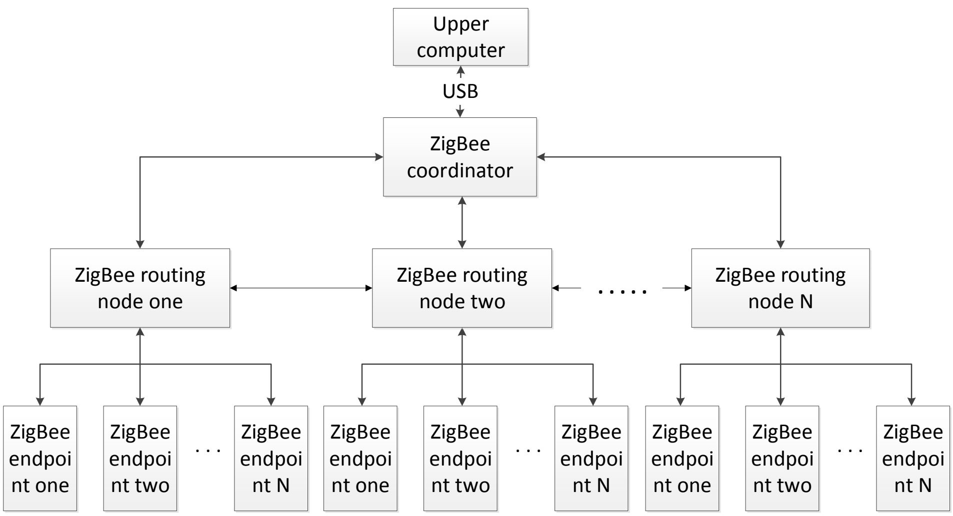


Fig 2. The structure of the system

3. Thermal Infrared Image Capture System Design

Thermal infrared image capture is the process which STM32 sets and reads storage of MLX90621 by IIC protocol. The program flow chart of MLX90621 is shown in Fig. 3.

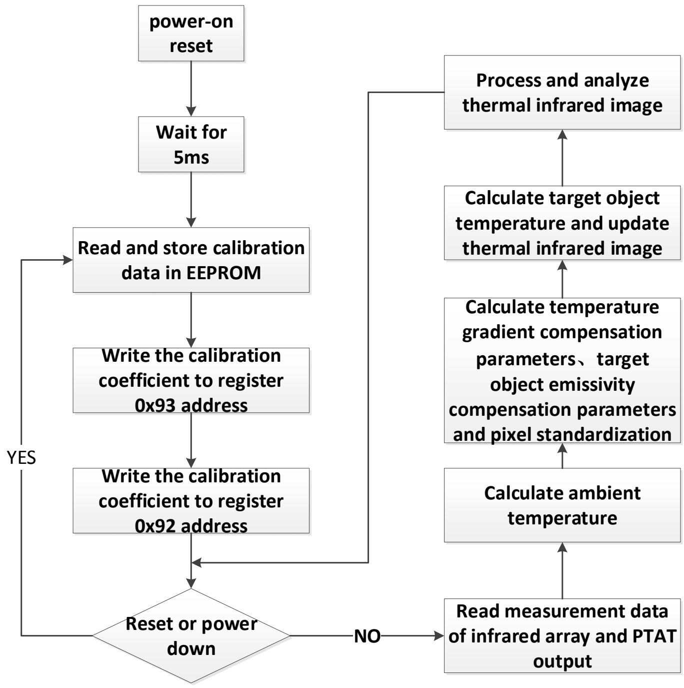


Fig 3. The program flow chart of MLX90621

Use the formula (4-1) to calculate the temperature around MLX90621 (Ta) :

$$T_a = \frac{-K_{T1} + \sqrt{K_{T1}^2 - 4K_{T2}\left[V_{TH}(25) - PTAT\_data\right]}}{2K_{T2}} + 25,\left[°C\right] \tag{1}$$

In the formula, K_{T1}, K_{T2}, $V_{TH}(25)$ are the calibration parameters of EEPROM, whose storage mode is showed in Table 1:

$$V_{TH}(25) = 256 * V_{TH}\_H + V_{TH}\_L \tag{2}$$

$$IF\ V_{TH}(25) > 32767 \rightarrow V_{TH}(25) = V_{TH}(25) - 65536 \tag{3}$$

$$K_{T1} = \frac{256 * K_{T1}\_H + K_{T1}\_L}{2^8} \quad if\ K_{T1} > 32767 \rightarrow K_{T1} = K_{T1} - 65536 \tag{4}$$

$$K_{T2} = \frac{256 * K_{T2}\_H + K_{T2}\_L}{2^{21}} \quad if\ K_{T2} > 32767 \rightarrow K_{T2} = K_{T2} - 65536 \tag{5}$$

Table 1. Part storage mode of EEPROM parameters

EEPROM address	Parameter name	Storage mode	Parameter
0xDA	V_{TH_L}	Complement of two's	V_{TH} used to calculate thermodynamic ambient temperature
0xDB	V_{TH_H}	Complement of two's	
0xDC	K_{T1_L}	Complement of two's	K_{T1} used to calculate thermodynamic ambient temperature
0xDD	K_{T1_H}	Complement of two's	
0xDE	K_{T2_L}	Complement of two's	K_{T2} used to calculate thermodynamic ambient temperature
0xDF	K_{T2_L}	Complement of two's	
0xD2	K_{T_scale}	Unsigned int	K_{T_scale} used to calculate K_{T1} , K_{T2}

Concretely, the calculation of K_{T1}, K_{T2}, $V_{TH}(25)$ are showed in following formula:

The temperature of the target of MLX90621 (To) can use formula (6) to calculate:

$$T_{O(i,j)} = \sqrt[4]{\frac{V_{IR(i,j)_{COMPENSATED}}}{\alpha_{comp(i,j)} * (1 - K_{S4} * 273.15) + S_{x(i,j)}} + \left(T_a + 273.15\right)^4} - 273.15, [^\circ C] \tag{6}$$

In the formula, $V_{IR(i,j)_{COMPENSATED}}$ is the compensation signal gotten after a pixel experiences thermal gradient compensation, emissivity compensation and migration calculation in infrared array. $\alpha_{comp(i,j)}$ is the parameter of every pixel for compensating sensitivity. K_{S4} is sensitivity compensation factor in different conditions. $S_{x(i,j)}$ is an operator for above three parameters and Ta. Because the calculation of $T_{O(i,j)}$ is complex relatively and the calculation idea is the same as Ta, which is obtained after relevant parameters of EEPROM calibrates in real time the output of infrared array, and the process is not described here.

In order to display directly the temperature information of the target and the monitoring states of the endpoint, this system associates the temperature with the chroma based on HSV color space which can divide temperature by colors. The model of HSV color space composed by hue, saturation and value is shown in Fig 4. As the model shown, when saturation and value are constant, hue is variable continuously, so the temperature gradient image is obtained after temperature has relation to hue. Because the seven inches screen displays based on RGB, HSV pixel format related to temperature is converted into RGB format by the conversion algorithm.

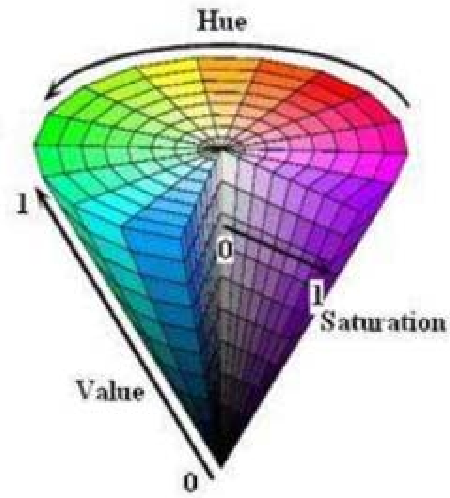


Fig 4. The model of HSV color space

Finally, thermal infrared image can be obtained by above the process of thermal infrared image collection and the algorithm of temperature gradient image.

4. Thermal Infrared Image Capture System Design

MLX90621 infrared array sensor taken by this system can only extract temperature information of target monitored. In order to extract the information of the object temperature regions, the raw image data for thermal infrared should be pretreated.

This system studies the pretreatment algorithm of detecting fire, which starts from threshold segmentation and edge detection and also combines with the characteristics of thermal infrared image, but in fact, they have some limitations, as follows:

Based on threshold segmentation. When there is overlap caused by the small difference between two pixels value, the global threshold is not accurate. In addition, this way considers only the pixel value but the space feature of image, so it is sensitive to noise.

Based on edge segmentation. There is contradiction between high noise resistance and high detection accuracy, when detecting edge.

According to above analysis and experimental validation, the threshold segmentation of image search is proposed in the paper based on the change trend of temperature. Besides, fire can be predicted by the expanding trend of high temperature area and the average temperature of future area, the flow chart of this algorithm is shown in Fig.5:

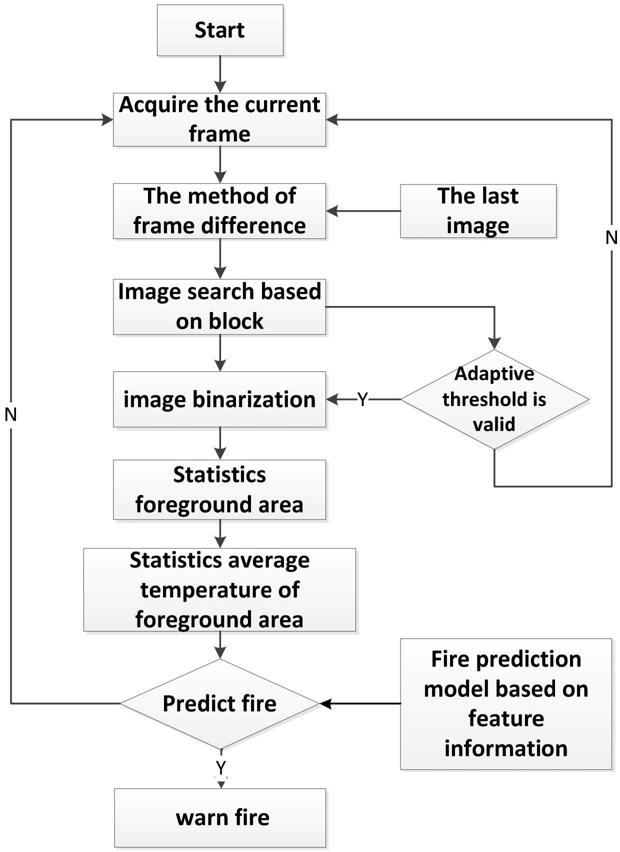
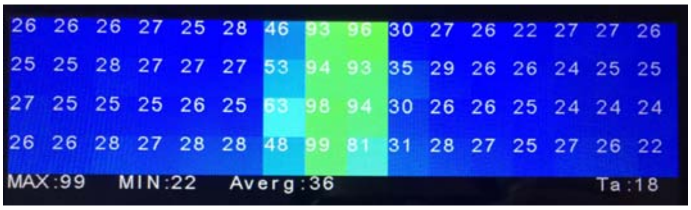
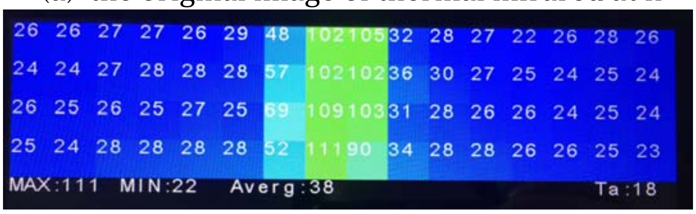


Fig 5. algorithm for fire warning based on thermal infrared image

Temperature increment of every pixel, the change trend of the temperature, in the detection cycle can be acquired by the inter-frame method for adjacent two frames of thermal infrared image, as shown in Fig. 6.



(a) the original image of thermal infrared at k



(b) the original image of thermal infrared at k+1

Fig 6. the compared image of thermal infrared at adjacent moments

There are following matters if dividing by the fixed threshold. One is that noise appears with the change of background temperature. Two is that the environment is targeted highly, so the threshold value should be changed with the change of the target monitored. Three is that the split range would expend for certain heat source with high thermal radiation, which affects segmentation accuracy.

According to above matters, image search method based on block is proposed in the paper which can search for thresholds that can adapt to local or global temperature changes, as follows:

Set the rectangular window of the 2*2 size, search for the temperature change image obtained by inter-frame difference method, and set the step length to 1.

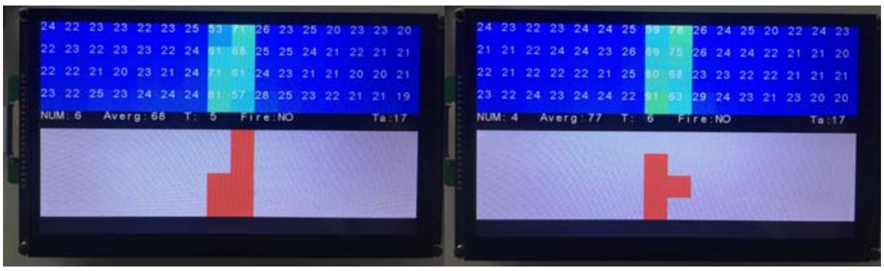
Acquire the maximum (the maximum of change) and the minimum (the minimum of change) in the rectangular window, and set differential threshold of the local window to t. If maximum - minimum >t, record the maximum.

Move step length, and repeat (b) until all the images are complete.

Count the maximum of all the records, and choose the smallest maximum as the binarization threshold of split thermal infrared images. If the maximum is invalid, do not split the image and exit fire prediction process.

Above process is about the setting of t, which need to detect target and the cycle according to the actual condition. In this simulation experiment, the detection cycle is 1.5s, and t is 5. When the temperature increment is negative, differential result is forced to zero, and ignore the change trend of temperature instability. In addition, reduce the upper limit of the difference between maximum and minimum and monitor instantly the change trend of temperature for avoiding the external interference factors.

In this system, after counting the average temperature and the area of the foreground area, track the change trend of temperature, so a fire prediction model which regards the foreground area, average temperature and the duration of temperature rise as the reference standard is produced. When all the conditions are met, it is regarded as the early characteristics of fire and the system starts to warn. The detection effect pictures that the foreground pixel is 3, the foreground average temperature pixel is 140 and the duration of temperature rise is 5s are shown in the Fig. 7. When time equals to k, k+1 and k+2, adaptive threshold T changes with temperature rising. Extracting the foreground area with the greatest temperature change, when the values of the foreground area (with the number of binary pixels said), the foreground average temperature (average) and the duration of temperature rise reach defaults, the flag of the alert status will be placed.



(a) at k momemt (b) at k+1 momemt

(c) at k+2 moment (d) fire alarm

Fig 7. the process of fire detection

5. Conclusion

This paper introduces a fire warning system based on thermal infrared array sensor and Zigbee technology. The system uses a low-cost infrared array sensor to collect the ambient temperature, and generates a temperature gradient image through the HSV color space. Finally, fire can be detected through the threshold segmentation method of image search based on the change trend of temperature, the high temperature region expansion trend and the foreground region average temperature. Verified by experiments, the fire prediction model can reliably predict the fire. In addition, the network through Zigbee wireless communication technology improves the flexibility and feasibility of the system, and makes the system have greater practical significance and application value.

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