Design and Realization of Fire Detection Using Computer Vision Technology

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Abstract: Recently, vision-based target positioning technology has received considerable attention in the field of computer vision. The positioning technology has many advantages such as faster speed, higher accuracy and more stable and reliable positioning results. Therefore, it plays an important role in the fields of robot technology, military reconnaissance, geographic survey and field measurement. Based on the positioning technology, the paper designs an embedded vision system with DM816x microprocessor (the processing module) and CCD camera equipped with an infrared filter (the acquisition module), which realizes the recognition and positioning of the fire. Moreover, with 200 groups of experiments in a warehouses, the fire detection system has an alarm accuracy rate over 98%, and positioning accuracy of fire is far higher than the national standard of China. In addition, an automatic fire protection system is proposed, which consists of the fire detector and the water cannon, then it can automatically extinguish the fire when a fire is detected.

Key Words: Computer Vision, Target Recognition and Position, Visual Fire Detector, Automatic Fire Protection System

1. INTRODUCTION

Fire has made a great contribution to the civilization development of human society. However, once the fire is out of control, it would cause huge losses to human life and property safety. In 2000, the Luoyang Dongdu Mall fire caused a lot of economic losses, and 309 people had lost their precious life at the same time. Four years later, the fire in Jilin Zhongbai Mall also turned a lot of property into ashes. What's worse, a fire in China Central Television's new building in 2009 caused damage worth about 150 million yuan [1]. Hence, it is very necessary to prevent human life and property from being damaged by fire. Fire would be accompanied by different physical characteristics in the process of combustion. In response to these different characteristics, researchers and engineers design different fire detectors including flame sensitive fire detector, solid sensitive fire detector, gas sensitive fire detector, image fire detector, temperature sensitive fire detector and sound sensitive detector [2]. The detailed classification of fire detectors is shown in Figure 1. Among various fire detectors, the image fire detector is a special kind of fire detector, which is a non-contact fire detector. The image fire detector can judge the fire in a distance according to the flame information of the fire or shape information of the fire's smoke. Therefore, the image fire detector has a good advantage to detect the fire in large space such as warehouses, shopping malls, forests and so on. In recent years, some scholars have done a lot of research about image fire detector.

Ordinary video camera was used to detect smoke in the visible range, and this technology combined with gas or temperature sensor technology to realize the indoor fire detection [3]. In [4], a method of detecting fire by visual technology was proposed, in which the characteristic information of flame and smoke in the video was extracted to determine whether fire occurred in the video region. Apart from that, the fuzzy c-means(FCM) method using the technique of background subtraction played a significant role in the early stage of fire smoke detection [5]. Then, another fire detection was realized in three steps: utilizing optical flow to find suspicious fire areas, taking chromatic detection based on Lab color space and judging fire through fire upward motion information [6]. In addition, a fire position system used two new infrared sensors to obtain images of the fire on two sets of thermopile arrays, and the images were processed to obtain the location of the fire in closed spaces, such as rooms or tunnels [7].

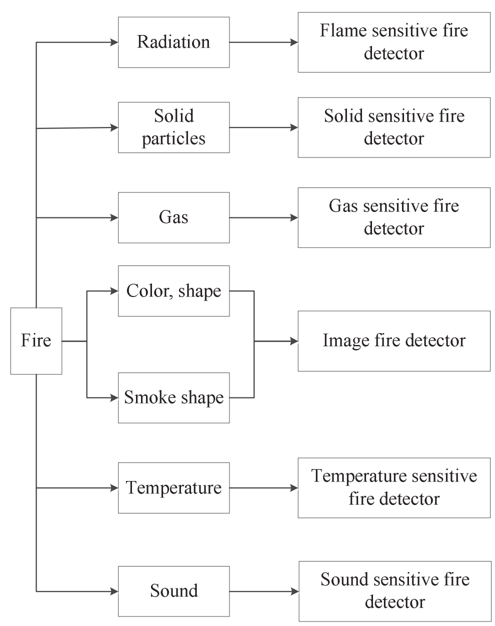

Fig 1. Fire detector classification.

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However, smoke from the early stages of the fire is difficult to capture by the camera, so it is difficult to achieve accurate fire alarm in real-time. Moreover, the fire detectors based on the color images are vulnerable to the environmental interference and may make false fire alarms. In order to avoid the problems, a new fire detector is designed and proposed. This paper mainly introduces the fire identification process and fire position process, then proves the practicability and superiority of the fire detector through a mass of experiments. In the end, the new fire detector of this paper has three advantages and novelties as follows.

(1) The fire detector uses the infrared filtering technology to filter out visible light, which can obtain the gray image of the fire. This technology is used to not only avoid the impact of ambient light on fire identification, but also can get the central point of fire easily, thus improving the positioning accuracy to fire.

(2) DM816x-based fire detector is more suitable to process video applications, which has greatly accelerated the speed of the fire identification algorithm and reduced the time it takes for the fire to be identified.

(3) The fire detector can be connected with the water cannon to realize the automatic fire protection system, which can automatically extinguish the fire in a fixed position.

2. REALIZATION OF FIRE DETECTION BY USING THE COMPUTER VISION TECHNOLOGY

2.1 Fire Recognition

In case of fire, computer vision technology can identify the fire according to the fire's static and dynamic characteristics. It is easier to identify the flame based on the gray image captured by the camera. Therefore, the foreground and background of the gray image are separated to get a binary image. Then, the fire can be detected by the connected-component labeling technology, the flame roundness analysis technology, the corner detection technology and the difference image technology. The algorithm for fire recognition is shown in Figure 2.

2.2 Camera Model and Coordinate Systems Transformation Matrix

The core component of computer vision technology is the camera. The process of capturing an image from a camera is actually an optical imaging process, which maps a point in a space to a specific position on an image by a conversion relationship between different coordinate systems [8-10]. The four coordinate systems are as follows.

Pixel coordinate system: the origin is at the left vertex position in the image. Points in the coordinate system are represented by (u_i, v_i), and axes of the coordinate system are respectively to the right (*U* axis) and down (*V* axis).

Image coordinate system: the origin is at the center of the CCD image plane, and the *X*-axis and the *Y*-axis of the image coordinate system are parallel to the *U*-axis and the *V*-axis of the pixel coordinate system, respectively. By the relationship between the pixel coordinate system and the image coordinate system, the correspondence between the pixel and the physical size of the object in the image can be gained.

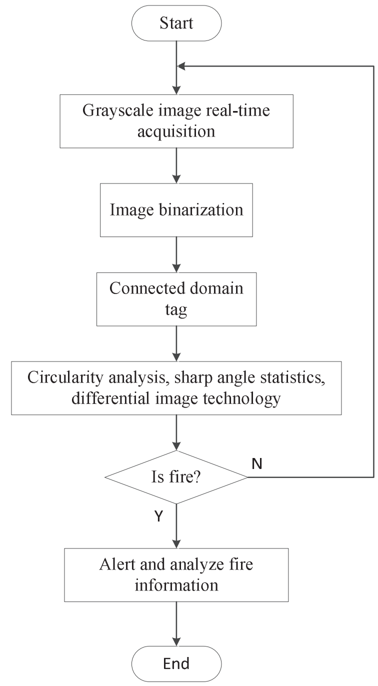


Fig 2. Flame recognition algorithm.

Camera coordinate system: the origin is at the position of the optical center of the camera. The points of the coordinate system are represented by (X_c, Y_c, Z_c). The camera optical axis is the Z_c axis, and the X_c and Y_c axes are parallel to the *X* and *Y* axis of the image coordinate system.

World coordinate system: the origin of the coordinate system can be arbitrarily selected, and the points of the coordinate system are represented by (X_w, Y_w, Z_w).

The homogeneous conversion relationship between the pixel coordinate system and the image coordinate system is shown in the formula (1). In the formula (1), u_0 is the horizontal distance of the center point of the image from the origin of the pixel coordinate system, and v_0 is the vertical distance of the center point of the image from the origin of the pixel coordinate system. In addition, dx and dy are the size of the pixels of the image.

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{dx} & 0 & u_0 \\ 0 & \frac{1}{dy} & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{1}$$

The homogeneous conversion relationship between the camera coordinate system and the world coordinate system is shown in formula (2). In the formula (2), R is a 3×3 orthogonal matrix, $\vec{0}$ is a 1×3 vector and T is a 3×1 vector. R and T represent rotation and translation transformations from the world coordinate system to the camera coordinate system, respectively.

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = \begin{bmatrix} R & T \\ \vec{0} & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} \tag{2}$$

The conversion relationship between the camera coordinate system and the image coordinate system is shown in the formula (3). The f represents the focal length of the camera. Z_c represents the distance of the object from the optical center.

$$Z_c \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} \tag{3}$$

Finally, the formula (4) represents the transformation relationship between the pixel coordinate points and the world coordinate points.

$$Z_c \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{dx} & 0 & u_0 \\ 0 & \frac{1}{dy} & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} R & T \\ \vec{0} & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} \tag{4}$$

2.3 Fire Positioning

The most common vision location systems are monocular and binocular vision systems. A constraint that allows the target to move in a fixed plane needs to be determined so that the monocular vision system can uniquely determine the world coordinates of the target. The binocular vision positioning system needs to match the image feature points of the two camera images, and then calculate the coordinates of the target according to the parallax principle. No matter what type of vision system, the process of achieving the positioning of the fire is same, as in Figure 3.

3. AUTOMATIC FIRE PROTECTION SYSTEM

When a fire breaks out in the fire protection area, the automatic fire protection system can warn people of a fire and automatically take measures to extinguish the fire. The automatic fire protection system could be realized by a fire detector based on computer vision and a water cannon system. The fire detector could identify and locate the fire, then through the network, the fire detector could send the location information of the fire to the water cannon system. The water cannon system adjusts the cannon angle to extinguish the fire according to the coordinate information of the fire source. This automatic fire protection system could quickly and accurately identify and extinguish fire. The schematic diagram of the automatic fire protection system is shown in Figure 4. In the Figure 4, the left half is the workflow of the vision-based fire detector, and the right half is the workflow of the water cannon system. They are interconnected by network to realize the automatic fire protection system.

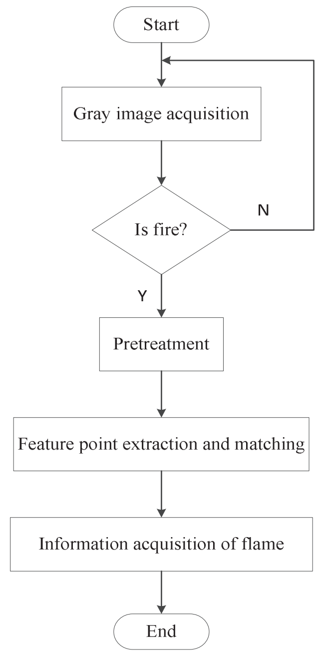


Fig 3. Computer vision based fire location algorithm.

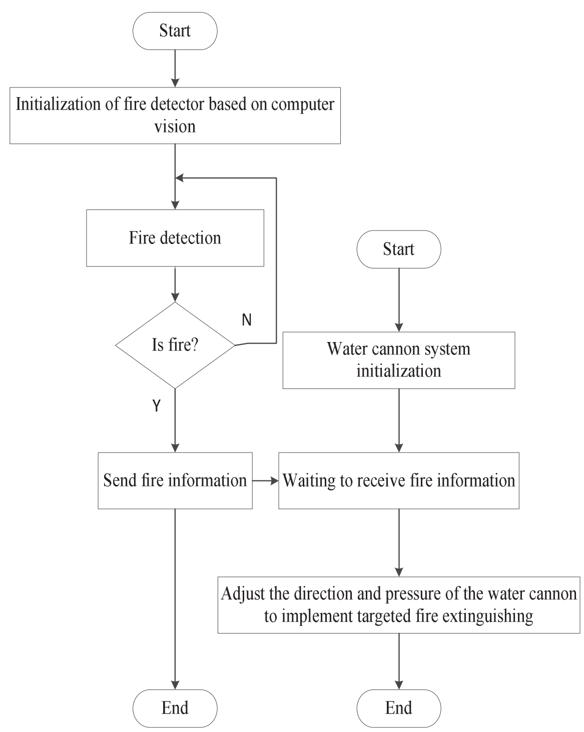


Fig 4. Automatic fire protection system.

4. EXPERIMENTS AND APPLICATION

4.1 System Configuration

The picture of the embedded fire detection system based on DM816x is shown in Figure 5. In Figure 5, the top part is the power module, the middle part is the main control module, and the bottom part is the image acquisition module, which contains two cameras.

The DM816x has excellent clock configuration, high precious, fast response and low circuit complexity, and it is more suitable for audio and video processing. In addition, the camera on the left side of the Figure 5 adds filters to capture gray image required for real-time fire monitoring, while camera on the right side of the Figure 5 is used for real-time color image acquisition for staff to view the target area.

Fig 5. The picture of the fire detector system.

Furthermore, in this paper, the site of the experiments is a warehouse. The specific target monitoring area is: X-axis direction (-2000mm, 2000mm), Y-axis direction (23000mm, 27000mm). The seven chessboard images, which are symmetrically distributed on both sides of the camera's optical axis, are the image source to calibrate the camera. From the perspective of the camera, the checkerboard position can cover the monitoring area as much as possible. The chessboard placement is shown in Figure 6 and Figure 7, where the first checkerboard image is located (0mm, 25000mm).

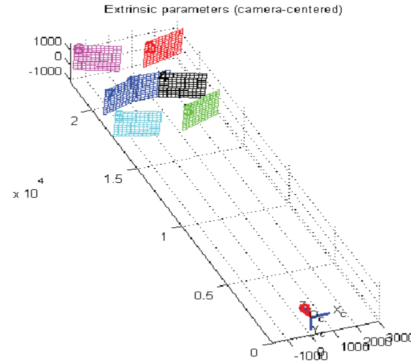


Fig 6. 3D rendering of the position of the checkerboard.

In addition, the chessboard template uses 13×13 square, and the edges of the checkerboard are 110mm. After processing the seven checkerboard images, the parameters of the camera can be obtained, as shown in Table1. Focal length represents the distance between the center of the lens and the imaging plane. Principal point represents the imaging center point. Skew represents the tilt rate, and distortion represents the radial and tangential distortion parameters.

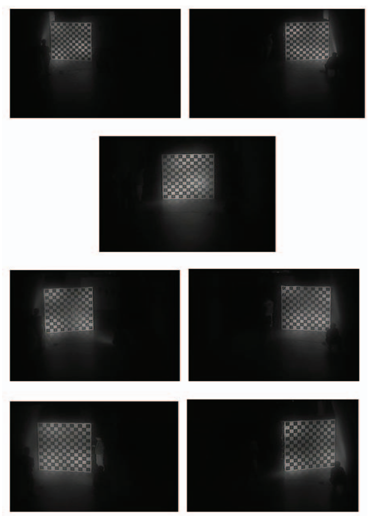


Fig 7. Physical map of the placement of checkerboard.

Table1. Camera Parameter

Focal Length	[1880.86943 2002.92594]
Principal point	[437.20314 464.01360]
Skew	[0.00000]
Distortion	[-0.30361 -0.24184 -0.00601 0.00124 0.00000]

4.2 Results

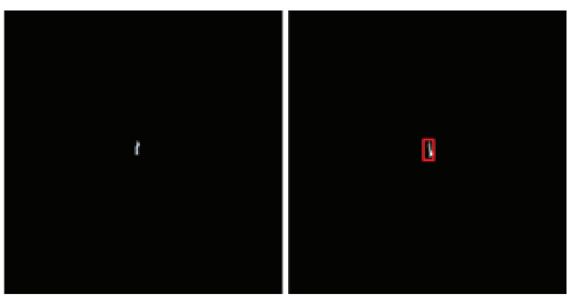
As the camera has been initialized, the fire test can be conducted in the flame monitoring area of a warehouse. The experimental results are listed in Table2, where real represents the true position of the fire, calculation represents the fire position displayed by the fire detector, error represents the difference between the true fire position and the predicted fire, and time indicates the running time of the fire detector.

Table2. Actual and Theoretical Coordinates of the Fire

Fire	Real/mm (X_w, Y_w, Z_w)	Cal/mm (X_w, Y_w)	Error/mm	Time/s
P1	(-805,25066,110)	(-800,25100)	(-5,-34)	7
P2	(235,25066,110)	(225,25100)	(10,-34)	8
P3	(695,25066,110)	(700,25100)	(-5,-34)	8
P4	(0,23986,110)	(0,24000)	(0,-14)	7
P5	(-400,23580,110)	(-400,23600)	(0,-20)	9
P6	(-285,25066,110)	(-275,25100)	(-10,-34)	7
P7	(695,23986,110)	(700,24000)	(-5, -14)	8

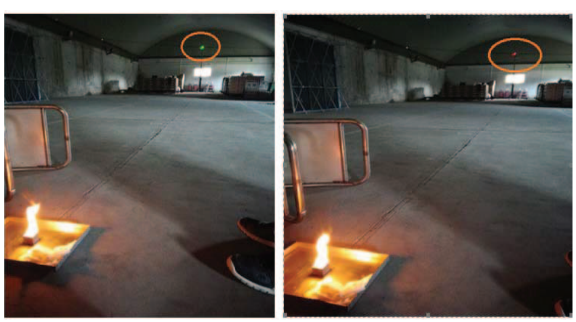
The white spot in the Figure 8(a) is a fire, and the fire detector is in the orange circle of the Figure 8. At this time, the fire detector has not detected the fire, and its green indicator light is always on, as shown in the Figure 9(a). About 8 seconds after the fire started, the fire detector detects the fire and issues a fire alarm. At this point, the green indicator of the fire detector is off and the red indicator light is always on, as shown in the Figure 9(b). At the same time, the fire area on the touch screen is marked by a red rectangle, as shown in the Figure 8(b).

In addition, this method of detecting and positioning fire based on gray image has passed the certification of the China National Supervision And Test Centre For Fire Electronic Product Quality, and now the detector has been applied in a paper mill in Hunan.



(a) (b)

Fig 8. Video monitor screen displayed on the touch screen.



(a) (b)

Fig 9. The state of the fire detector.

5. CONCLUSION

The experiment results show that the fire detector based on computer vision technology can recognize and locate the fire quickly and accurately. At a distance of about 25 meters from the fire detector, a flame about 1.5 inches high can be detected in 9 seconds. Besides, this paper conceives an automatic fire protection system, which is realized by combining fire detector with water cannon. The system can finish automatic directional fire extinguishing and reduce the unnecessary loss caused by the traditional large-area water spray. At present, the automatic fire protection system has been in the testing stage of a company. The automatic fire protection system will effectively promote the development of the automatic fire protection industry and has broad market prospects.

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