Obstacle Detection Based on Heterogeneous Data Fusion

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Abstract. Obstacle detection is very important for the autonomous movement of robots. Variety of sensors are used in obstacle detection to obtain information about obstacles. Different types of data obtained by sensors cannot be directly analyzed. This paper proposed an obstacle detection method based on heterogeneous data fusion. An image processing method is adopted to process the image of obstacle obtained by monocular vision sensor, and the size and position of the obstacle can be obtained. Then using infrared distance sensors are used to obtain distance of obstacles. Finally the location and distance information of obstacles can be obtained by a specific algorithm. Two experiments are performed for verifying the effect of proposed method. Experiments shown that the proposed method can effectively obtain the position and distance of obstacles.

Introduction

With the development of automation technology, robots are now playing an irreplaceable role in both industrial and civil fields. To realize the autonomous movement of robots, obstacle avoidance system is the key part[1]. Variety of sensors like ultrasonic and infrared sensor are used to fetch different obstacles. In practical application of obstacle avoidance system, single type of sensor cannot detect complex information. Using the heterogeneous data fusion method to process data from variety of sensors could efficiently realizing full range detection[2].

The commonly used technology in obstacle detection is ultrasonic technology. It is easy to calculate the actual distance of obstacle by knowing the time difference between transmitting and receiving ultrasonic wave[3]. Ultrasonic sensor can continuously measure the distance in the approaching process of obstacles, and also has strong anti-jamming ability and directivity[4,5]. For obstacles being too far, the accuracy will also decrease with the attenuation of ultrasonic waves, and ultrasonic waves will not work for objects absorbing sound waves. Infrared sensors are also used in obstacle detection[6,7]. The working process of infrared sensor are affected by the surrounding conditions of the obstacles. Both infrared and ultrasonic technologies require active emission of light and sound waves, and there are restrictions on working conditions. Usage of vision sensors can avoid such problems[8,9,10]. Visual detection systems can usually include one or two cameras[11]. In measuring the distance of obstacles, the accuracy of the visual sensor is not as good as ultrasonic and infrared sensors.

This paper proposed an obstacle detection method based on heterogeneous data fusion. An image processing method is adopted to extract and purify the image of obstacle obtained by monocular vision sensor, and the outline of the obstacle can be clearly located in the image. Then deviding the processed image into several areas, and the area which the obstacle is located can be identified. Using infrared distance sensors for each area to obtain distance, and the location and distance information of obstacles can be obtained. A real experiment were performed for verifying the effect of proposed method.

This paper is organized as follows. Section II introduces the proposed method. The experiments of obstacle avoidance method are presented in Section III. Last but not least, the paper is concluded in Section IV.
Proposed Method

Working efficiency of single camera are usually affected by illumination, resolution and so on. In order to obtain the information accurately, the obtained image must be processed. To identify the obstacle information in the images effectively, the image need to be transferred into a binary image with only foreground obstacles filled with the outline by specific methods. The details of each step are as follows.

First is grayscale transformation[12]. When the image is a RGB model, each pixel in the image is determined by the three components of the RGB tricolor, where the value range of each component is 0 to 255, and when R=G=B, the colorized image becomes a gray image. Therefore the image can use a gray value as a parameter to represent pixel information.

The image taken by moving camera would appearing indistinct because of the motion. Aimed to solve this problem, image data are processed according to the inter-frame difference[13,14]. Inter-frame difference method use the difference of pixel’s gray values of the adjacent frames in the sequence image, and then extracts the moving region of the sequence image by selecting the threshold value. In the two-frame differential method, the variation between the $k$ frame $f_k(x,y)$ and the $k+1$ frame image $f_{k+1}(x,y)$ can be expressed as a binary differential image $D(x,y)$:

$$D(x,y) = \begin{cases} 
1 & \text{if } |F_k(x,y) - F_{k+1}(x,y)| > TH \\
0 & \text{otherwise}
\end{cases}$$

The threshold $TH$ in the above formula is set for processing, when the pixel in the differential image is greater than the threshold, it is a foreground pixel. Otherwise it is a background pixel.

To make the image more clear without losing the important elements, median filter is needed a nonlinear processing method[15,16]. The main function of the median filter is to change the gray value of the pixel which is quite different from the surrounding pixel’s gray value, thus eliminating the noise of the isolated point. The expression of two-dimensional median filter is as follows:

$$y_{j} = \text{Median}_{A}(f_{ij})$$

Here $f_{ij}$ represents the gray value data sequence, and $A$ represents the filtering window.

In order to distinguish the foreground from the background more obviously, and eliminating the noise less than the structure element, top hat and bottom hat transformation are used. If $A$ is the input target image, $B$ is the structural element and $G$ is the output image, then the top-hat transform is the figure obtained by subtracting the morphological open operation $A \circ B$ from the original image. The morphological top-hat transformation is defined as follows:

$$G = A - A \circ B$$

The bottom-hat transform is the figure obtained by subtracting the morphological closed operation $(A \cdot B)$ from the original image and it’s defined as follows:

$$G = (A \cdot B) - A$$

Top and bottom hat transform can be used together to enhance the digital image, the combined usage can stretch the foreground and background gray scale and improve image contrast effectively.

To reduce the amount of image data, here using edge detection to process the image[17]. The edge detection algorithm in this paper is based on Sobel operator. The Sobel operator contains two sets of parameters: transverse matrix $T_x$ and longitudinal matrix $T_y$. Used P to represent the image to be processed. The gray values of transverse edge detection $G_x$ and longitudinal edge detection $G_y$ are:
The grayscale of a certain point in the image can be calculated by the following methods:

\[ G = \sqrt{G_x^2 + G_y^2} \]  

(7)

If the gradient is greater than a threshold, the point is considered to be an edge point, and the system gets the outline picture for obstacle avoiding analysis.

Dividing the obtained image into \( N \) vertical equal regions, each region represents a direction from the sensor. Infrared sensors are set to monitor obstacles in each direction. The ultimate goal of image processing is to decide which distance data is an obstacle in these regions. The white part of the previously processed binary image consists of the outline of the obstacle and its surface. After the binary image is obtained, the binary pixel statistical ratio \( X \) of the above \( N \) regions is calculated. Following is the definition of \( X \):

\[ X = \frac{P_w}{P} \]  

(8)

Where \( P \) represents the total number of pixels in a single region and \( P_w \) represents the number of white pixels in this region. Threshold \( T \) is used to determine which areas are the main volume of obstacles and which are negligible. If \( X > T \), the infrared distance sensor should return the distance data in this direction, and the location and distance of the obstacle can be determined.

**Experiments**

An experiment is explained in this section to verify the effect of proposed method. Using gray scale transformation and frame difference method for the color image, then using the top and bottom hat transform to enhance the contrast of the image. Finally using edge detection to mark the contour of the obstacle more obviously. In order to test the effectiveness of obstacle detection in a more complicated case, two images of obstacles with different numbers and sizes were collected. “Figure 1(a)” shows the processing procedure of our image processing method. Two samples which are shown in the left part of “Figure 1(b)” are processed separately to obtain the edge detection, morphological processing and binary filling map, it shows that the method have the same effect under multi-obstacle case.

To determine the location of obstacle, further processing of the image should be taken. Taking a single obstacle sample as an example image which shows in “Figure 2(a)” the actual distance of obstacle measured manually is 42.15 cm. Then process the image by the method proposed method, the processed image shows “Figure 2(b)”. Dividing the image into 7 vertical regions, meanwhile setting 7 infrared distance sensors to measure the obstacle’s distance for each region. The white part of the binary image is composed of the outline of the obstacle and its surface. As mentioned in last section, setting 0.2 as a threshold \( X \), which means that when \( X \) greater than 0.2, the volume of the white area in this area can no longer be ignored, and the infrared distance sensor of the region will be enabled to return distance data in this direction. If there are barely white areas in a given region, such as region1/2/3/7, the values of \( X \) are close to 0 and far less than 0.2, the distance ensors in these direction are wait for the enabling state, and the obstacle avoidance system only needs to receive the distance information of the 4/5/6 regions. And by comparing the distance information between the 4/5/6 regions, it can be seen that region 5 has the largest \( X \) while region 4 and 6 are slightly smaller,
which shows that region 5 is the main product of the obstacle. In this case, the location and distance of
the obstacle can be determined only by returning the distance data of the region 5.

The final result of distance data is 41.246, which means the distance between the obstacle located
in the region 5 and the camera is about 41.246 cm. So far, obstacle position and distance detection of
obstacle avoidance system has been completed. Comparing to actual distance of obstacle, the error
percentage of measurement is 2.14% and basically accords with the requirement range.

![Multi-obstacles](image1.png)

**Figure 1.** Multi-obstacles (a) Two obstacles (b) Three obstacles.

![Multi-obstacles](image2.png)

**Figure 2.** Multi-obstacles.

**Conclusion**

In this paper, a method that can acquire the position and distance of obstacles based on heterogeneous
data fusion were proposed. The proposed method has the following advantages: Firstly, the accuracy
and efficiency of obstacle detection are increased by the usage of heterogeneous data fusion method.
Secondly, using the monocular vision, system processing speed can be greatly increased. Thirdly, by
the design of measuring distance in different regions with range sensors, the directivity and real-time
of ranging are improved. Therefore, the proposed method can acquire the distance and position of
obstacles well.

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