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Distance Measurement System Based on Binocular Stereo Vision

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***Abstract*—This system is modeled on the distance perception methods of human eyes. It uses DSP to process the images obtained by two CCD cameras and calculate the distance by the principle of parallax. This paper describes the working principle and hardware platform design. It focuses on the image matching methods based on Canny edge detection and Harris corner detection. The results of the experiment show that the system is efficient and reliable.**

Keywords-binocular stereo vision; image matching; Edge detection; Harris corner detection

I. INTRODUCTION

Binocular stereo vision is one of the hot spots in computer vision research. In recent years, it has been gradually applied to autonomous navigation, engineering surveying and other areas. Distance measurement based on binocular stereo vision is a passive way. Compared with traditional initiative distance measurement methods such as infrared and laser, it has advantages of hidden, safe, simple hardware and so on. However, the software design is more complicated. To obtain the distance information, it needs a series of complex operations to the detected images. Therefore, the focus of the study is on designing a high-performance real-time image processing algorithm.

II. WORKING PRINCIPLE

Computer binocular stereo vision distance measurement is modeled on the distance perception methods of human eyes. Two eyes from two slightly different points of view observe the objective world scene. Due to the optical geometry projection, scenes from different distance image on the retina rather than on the same position. Such position difference on the retina known as binocular parallax, it reflects the objective distance from the scene. Use two or more cameras on the same scene from different locations to obtain stereo images, through a variety of matching algorithms to find out the corresponding point in order to calculate the parallax, and then the distance from the scene can be calculated by triangulation methods [1].

In this paper, the system uses two CCD cameras with the same parameters. Figure 1 is the schematic diagram of the system. The distance of two cameras' optical center is b. The optical axes of the two cameras are parallel. They have the same focal length f. A is the point with the vertical distance from the cameras of L. Its images on the two cameras are A_1 and A_2. $x = x_1 + x_2$ is the parallax.

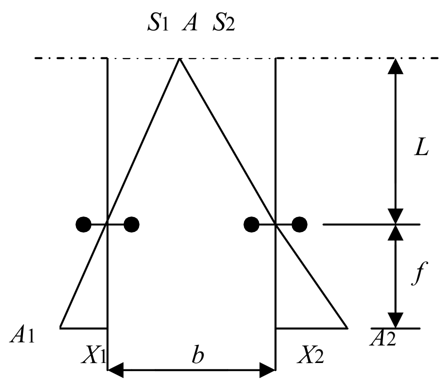

Figure 1. The schematic diagram of the system

According to the principle of similar triangle, we know,

$$\frac{s_1}{x_1} = \frac{L}{f} \tag{1}$$

$$\frac{s_2}{x_2} = \frac{L}{f} \tag{2}$$

$$b = s_1 + s_2 \tag{3}$$

$$L = \frac{bf}{x_1 + x_2} \tag{4}$$

$$x = x_1 + x_2 \tag{5}$$

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$$L = \frac{bf}{x} \tag{6}$$

That is, when the two cameras' optical center distance b and focal length f are determined, the measured distance L is inversely proportional to the parallax x.

III. System Design and Algorithm

A. Hardware Platform

The image processing in this system is based on TMS320 DM642 EVM board. It is a general-purpose hardware platform with high performance-to-price ratio. Due to the strong computing capability of the DSP chip on the board, we can do real-time multi-channel video capture, and realize complex image processing and video compression algorithm [2]. Additionally, we choose two CCD cameras with the same parameters. They are located at the same level with 15cm interval between each other.

After A/D conversion and logic control, images are saved in the system buffer in the form of digital array. At the same time, analog signal parallel access PC video capture card in parallel in order to select the target be tested and issue the instructions. When the DSP processor receive the working instructions from the system, it begin process the digital image data saved in the buffer, and then transport the results to PC to display. Figure 2 is the system block diagram.

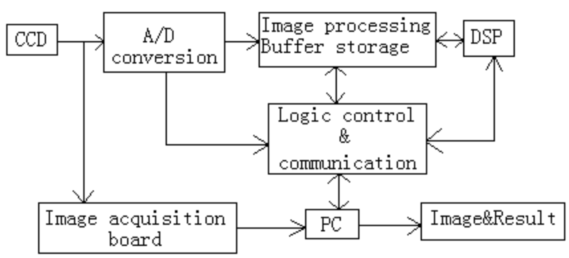

Figure 2. The system block diagram

B. Algorithm Study

For the positioning technology of binocular stereo vision, the key technology of calculating the coordinates is to accurately extract the binocular parallax. It requires high-precision image matching technology. Therefore, solving the image matching problem is the main target of this system's software design.

Area-based and feature-based the two methods of image matching. Area-based matching is to choose the neighborhood of a certain point in the image as a template, search a corresponding point neighborhood with the similar distribution of gray value in another image according to a similarity measure sequence, and then achieve the image matching. Area-based matching is a method that using image pixel gray value directly. Therefore, it is very sensitive to the change of noise, light and contrasts [3]. Feature-based matching is not using gray value directly, but through the gray-derived features to achieve the match. So it is not so sensitive to the change of light and contrast.

In practice, because of the inherent differences between the two CCD, the sensors' defect and image noise, when using gray-related based matching algorithm, some related functions are lack of sharpness, and often false match, poor reproducibility and it is difficult to obtain accurate results of the image matching. To solve these problems, this paper put forward a method that combine area-based and feature-based matching, combine edge features and corner features. That is, filter, edge detection and Harris corner feature detection based image matching algorithm.

1) *Image filter.*

In order to reduce the noise influence to the image matching results, smooth filter is done to the images on the first. We have studied the neighborhood average filter and median filter. With the effects of edge detection, we find that the neighborhood average filter is more effective than the median filter. Furthermore, the choice of window size is also very important when using neighborhood average filter. On one hand, too big window makes the edge fuzzy and the computing time longer. On the other hand, too small window makes the filter results poor. According to the results of the experiment, we choose the Gauss filter with 3×3 template. Figure 3 is the results of the experiment.

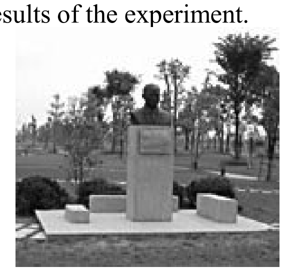

Figure 3. The original image

Figure 4. Median filter

Figure 5. Gauss filter

2) Edge detection.

In experiment, we have studied and compared a variety of edge detection algorithm commonly used. Canny edge detection proves to be more applicative to Harris corner detection than others. Figure 4 shows the effects of some kinds of edge detection algorithm

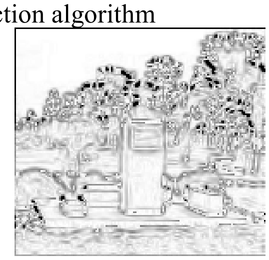

Figure 6. Prewitt edge detection

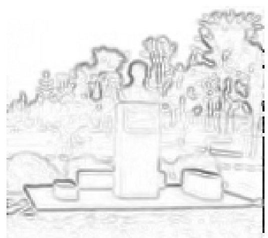

Figure 7. Robert edge detection

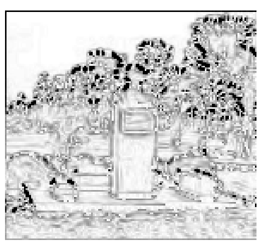

Figure 8. Sobel edge detection

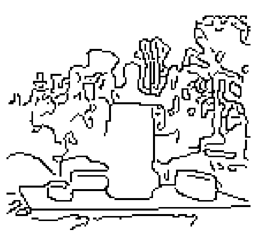

Figure 9. Canny edge detection

3) Image matching based on Harris corner detection.

With its advantage of simple calculation and stability, Harris is an operator based on signal point characteristics extraction. In addition, it can extract point characteristics quantitatively and reasonably [4]. The process that follows,

$$M = G(\tilde{s}) \otimes \begin{bmatrix} g_x^2 & g_x g_y \\ g_x g_y & g_y^2 \end{bmatrix} \qquad (7)$$

$$I = \det(M) - k \cdot tr^2(M), k = 0.04 \qquad (8)$$

In the formulas above, g_x is the gradient on direction x. g_y is the gradient on direction y. $G(\tilde{s})$ is the Gauss template. $\det$ is the determinant of the matrix. tr is the matrix straight track. k is a default constant. Each point's element value in matrix I matches to the interest value of the corresponding point.

In order to improve the stability of the matching algorithm, we use normalized correlation coefficient as similarity measure of two characteristic points. Considering two images f_1 and f_2, suppose the parallax of the matched characteristic points is (d_x, d_y), the similarity measure between the regions with the center of the characteristic point can be defined by normalized correlation coefficient $r(d_x, d_y)$ as

$$r(d_x, d_y) = \frac{\sum\limits_{(x,y)\in S}\left[f_1(x,y) - \overline{f_1}\right]\left[f_2(x+d_x, y+d_y) - \overline{f_2}\right]}{\left\{\sum\limits_{(x,y)\in S}\left[f_1(x,y) - \overline{f_1}\right]^2 \sum\limits_{(x,y)\in S}\left[f_2(x+d_x, y+d_y) - \overline{f_2}\right]^2\right\}^{\frac{1}{2}}} \quad .(9)$$

$\overline{f_1}$ and $\overline{f_2}$ are the average gray values of all the pixel matched in the two regions. The and-sign is executed on all the pixels in the small window functions with the centre of the characteristic point.

After smooth filter, the left and right images acquired from binocular cameras are processed by Canny edge extraction and Harris corner points extraction. With restraint based on the relative location (if the characteristic points in the right image p_r and in the left image p_l are the correct match points couple, p_r in the right image should locate in a sub-region with the centre of the p_l coordinate) and polar line restraint, the initial candidate match relations are set up. Then based on regional match, gray values' similarities are measured in the characteristic point neighborhood, as well as symmetry test. The final corresponding points are judged as the correct match characteristic points.

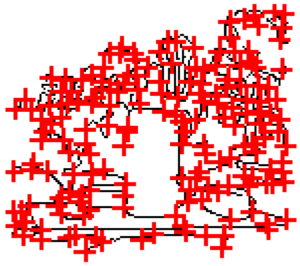

Figure 10. Harris corner detection

IV. RESULT ANALYSIS

A. The Experiment Results

The programs of this system are all developed in Microsoft Visual C++ 6.0 environment. Then the programs are transplanted to the DSP. After data Processing, the results are displayed on the PC screen.

At last, we do measurement to the same object from different points of view and different distance. Table 1 gives the specific experimental data.

TABLE I. THE RESULTS OF BINOCULAR STEREO VISION DISTANCE MEASUREMENT

The actual distance (m)	The measured distance (m)	The error (%)
0.7	0.661	5.57
1.0	0.988	1.20
1.5	1.513	0.87
3.0	2.966	1.13
5.0	5.062	1.24
6.0	6.078	1.30
7.5	7.784	3.79

The measuring range of binocular stereo vision distance measurement system is related with the cameras' focal length and resolution. According to the results of this experiment, the system has high measurement accuracy in an appropriate range.

B. Error Analysis

Measurement error of the system is mainly from image match error and optical sensor error. Image match error is the problem of programs. To reduce the error, we should find a more efficient way of image match. Optical sensor error comes from the unparallel of optical axis, cameras' focal length error, baseline error, and so on [5]. To reduce the optical sensor error, it is necessary to select high-quality optical equipments, adjust carefully in experiment process, and fixed the equipments firmly after adjusting.

V. CONCLUSION AND FUTURE WORK

In this paper, we have studied the binocular stereo vision distance measurement system based on parallax principle, introduce and analyzed the key algorithm, brought out the image match method based on Harris corner characteristic detection, obtained the ideal results. In the following system optimization process, we can use assembly language to write some of the programs to make the entire system more efficient and reliable. It is expected that the system will be widely applied in engineering measurement and automatic control.

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