Distance Estimation using Stereo Vision for Indoor Mobile Robot Applications

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Abstract

Real time and accurate estimation of the distance between the robot and the object or the distance between two different objects is critical for robot applications. Various sensors as laser, sonar or camera have been used for this process. Two sensors as a camera and laser are employed together in some studies in literature. Camera based studies propose different methods using single camera or two cameras. In this study, the distance between the cameras and the colored object (red colored object is accepted in this study) is calculated in pixels and cm using two cameras situated in the same axis. In this proposed study, the images taken from the left and right cameras are preprocessed first. Then, the objects in the environment are determined. The last process is to estimate the required distance. 150 measurements, including distances between 60 cm and 140 cm, are performed in the experimental studies and an accuracy success over %90 is achieved.

1. Introduction

The significance of the studies on robotics is increasing day by day. Especially, obstacle avoidance in dynamic or static environments is an important problem to be solved. Numerous studies related to this subject are encountered in literature. It is fundamental to provide the accurate determination of the distance to the obstacle or the distance between two obstacles. The cameras besides the laser and sonar are also employed to measure the depth or distance. The studies estimating the distance using single or two cameras are present in literature. The cameras are accepted as in the same axes in the studies including two cameras (stereo vision). Stereo camera calibration process is realized to adjust the two cameras in the same axis [1,2]. Intrinsic and extrinsic parameters between two cameras are obtained as the result of the camera calibration process. Rectification process on the image is performed by the use of these parameters. Thus, in the images taken from the cameras, the relations between the same points corresponding to each other are obtained. This process is called epipolar geometry. Image processing techniques are applied after the camera calibration and rectification processes are realized in literature.

Various studies on distant measurement and estimation have been performed. Tran et al. proposed a technique of infrared stereo vision based long distance measurements for ship navigation in 2013 [3]. Zhang et al. suggested a stereo vision based distance measurement technique using correlation method in 2013 [4]. Lai et al. presented a Binocular stereo vision based real time distance measurement system in 2012. After they used Gaussian filter on the images taken from the cameras, they used improved sobel kernel. Besides, they performed real time implementation of their improved algorithm on DSP/BIOS system [5]. Szabo and Gontean proposed a method controlling the robot arms using stereo vision. They used stereo distance calculation for their method [6]. Wahab et al. suggested a method for estimating target distance utilizing monocular vision. They used Hough transformations for image processing techniques in their proposed method [7]. Kordelas et al. combined three kinds of stereo distance estimation methods and proposed a new one [8].

In this study, a system including three stages is proposed. They are image pre-processing, object detection and calculation stages. Camera calibration and image smoothing processes are realized in the image pre-processing stage. The relations between the two cameras are determined and rectification process is provided according to these relations in this stage. The object in the environment is found in the object detection stage. And, in the last calculation stage, the calculations of the related object are realized.

The paper is organized as four sections. In section 2, stereo vision technique is explained, in section 3, the proposed system is presented and in section 4, discussions and proposals are given.

2. Stereo Vision

Stereo vision is defined as to derive a three dimensional image from the two images taken from different points. Stereo vision process is a model which is based on the eye structure of the human being. The humans sense the objects using the information taken from the real world with their two eyes. A similar process as the humans' is required for realizing the robot vision. Stereo vision can be applied for this process. The information of the dynamic or static objects situated in the environment can be obtained using stereo vision. Besides, the depth information can also be provided by utilizing the same technique. The difference between the two locations of the same object, taken by two different cameras, is defined as "stereo disparity" [9]. The process of determining the locations corresponding to the same point in the two images, is called "stereo matching" [9] or "disparity matching".

Obstacle detection and avoidance can be achieved employing stereo vision process. The advantages of the stereo vision based studies in comparison with optical flow, model-based, vision-based and feature extraction based methods realized with robot vision, are listed as; performing the three dimensional definition of the environment, detecting the complex obstacles, having less affect by the change of the environmental aspects, getting more information about the obstacles in the environment. Stereo camera calibration, rectification, determining the stereo distance, stereo matching process requiring high mathematical capacity are the disadvantages of the stereo vision. The two visions taken by the right and the left cameras situated in the same axis are given in Figure 1.

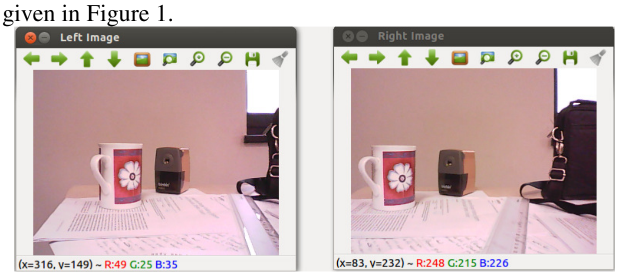


Fig. 1. The images of the left and the right camera situating in the same axis

3. Proposed System

In this study, the distance between the cameras and the colored object is estimated using stereo vision technique. This process includes three stages as image pre-processing, object detection and calculation. This study can also be used to obtain the distance between the object and the robot in mobile robot applications. Besides, the study is applicable for the single board computers commonly used among embedded systems, too. Ubuntu operating system, OpenCV library and C programming language are used in this study. A general block diagram of the proposed system is shown in Fig. 2.

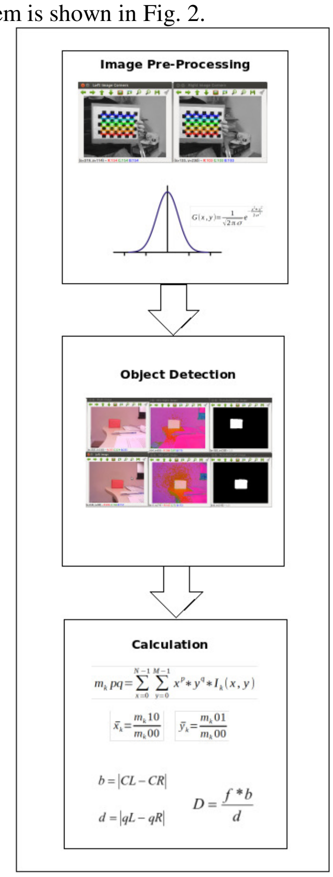
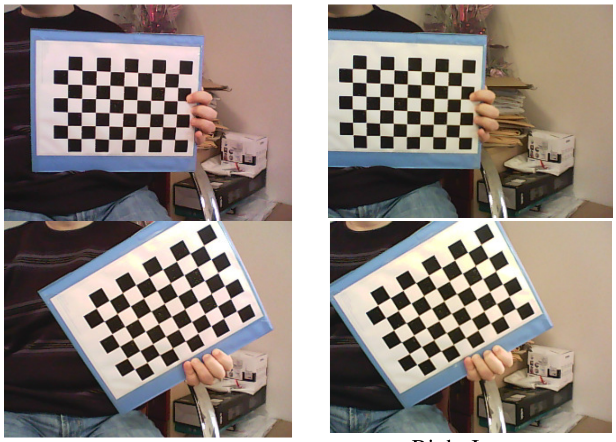


Fig. 2. The block diagram of the proposed system

3.1. Image Pre-Processing Technique

The first step of the proposed system is image pre-processing stage. This block includes the processes of stereo camera calibration, image rectification and filtering the obtained image. Stereo camera calibration is a process getting the intrinsic parameters and extrinsic parameters. The intrinsic parameters result from lens distortion while the extrinsic parameters depend on modeling the geometric relation between the two cameras. To be able to provide a proper stereo vision, the intrinsic and extrinsic parameters should be obtained by calibration process. The rectification process is realized according to these obtained parameters.

In camera calibration process, the images are taken from the two cameras. Different images of a model (Tsai) like a chess board taken from different angles and distances are utilized to calibrate the cameras. Sample image pairs used for calibration process are seen in Fig. 3.



Left Image　　　Right Image

Fig. 3. Sample image pairs used for calibration

In camera calibration process, finding all of the edges of Tsai grid in the images taken by left and right cameras at once means these images are a successful stereo vision pair. The values for these successful image pairs are recorded. In this proposed algorithm, when 15 successful pairs are captured, it is accepted that the calibration process is completed. Then, image rectification process is realized using these values. All of the corners are found successfully in Fig. 4.

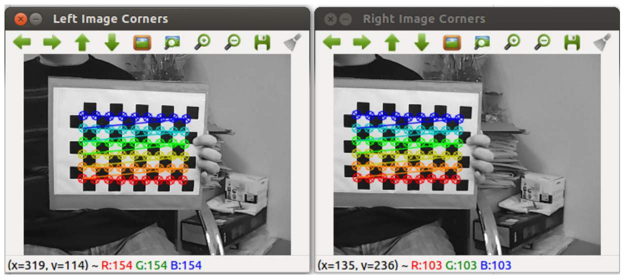


Fig. 4. A successful stereo image pair

After the calibration and rectification processes are performed, filtering process is applied for getting rid of unnecessary details. In this proposed system, Gauss filter, commonly used in image processing, is utilized. Two dimensional mathematical form of Gaussian distribution according to x and y axis is given in Equation 1 [5,10,11,12].

$$G(x,y)=\frac{1}{\sqrt{2\pi\sigma}}e^{-\frac{x^2+y^2}{2\sigma^2}} \tag{1}$$

3.2. Object Detection

Wave length of the light, the eyes of the human being can see, is between 400 nm and 700 nm. This range corresponds to the range between infrared and ultraviolet. The basic colors of the light are red, green and blue and other colors comprise of the mixture of their different rates. If these three colors are mixed with a rate of 100%, the white color occurs. The color, black arises when there is no light. One of the common processes for the image processing is color conversion process. The ranges of three main colors can be listed as 450-490 nm for blue, 490-560 nm for green and 635-700 nm for red [13].

In this study, after the image with RGB format is obtained from the stereo image pair passed through the image pre-processing stage, it is converted to the HSV color space [14]. In the experimental study, the only red colored object is used. Using the threshold value for the color desired to be left alone in the environment, only the related color values of the stereo image pair are allowed.

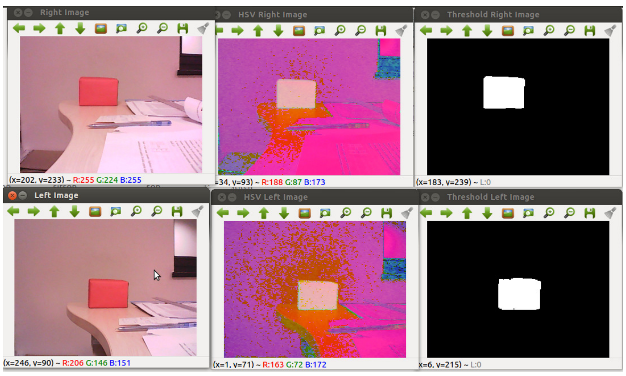


Fig. 5. The stereo image pair in HSV color space and the images which the morphological process is applied

After the threshold process is applied, disconnections on the parts of the obtained black and white image of the object occur. For combining the disconnected parts and having a clear object image, the erosion and dilation morphological processes are applied respectively [10,15]. The stereo image pairs in HSV color space and the images which the morphological process is applied are seen in Fig. 5.

3.3. Calculation Technique

Commonly used technique, moment operation is applied in the calculation stage. Mathematical equation for moment operation is shown in Equation (2) [10,16].

$$m_k pq=\int_x\int_y x^p * y^q * I_k(x,y)d_y d_x \tag{2}$$

Formulas given in Equation (3) are used for finding the center points of the objects.

$$\bar{x}_k=\frac{m_k 10}{m_k 00} \qquad \bar{y}_k=\frac{m_k 01}{m_k 00} \tag{3}$$

The difference of the center points of the image pair, the difference between the coordinates of innermost and outmost points of the object are found. The depth information of the each point is calculated using the Equation (4). D is the depth information, f is the focal length, b is the distance between the two cameras and d is the pixel difference of the same points between the pixels of the left and right images of the object in Equation (4).

$$D=\frac{f*b}{d} \tag{4}$$

The distance estimation process is realized employing the Equation (5). D_{EST} is the estimated distance of the object, N is the number of points taken for calculation of the distance, D_i is the distance of each point.

$$D_{EST}=\frac{1}{N}\sum_{i=1}^{N}Di \tag{5}$$

3.4. Application Results

In this study, 150 measurements are performed for the different objects having distances between 60 and 140 cm. The accuracy values of the measured distances are verified by measuring the same distances with a laser distance meter and a ruler. The accuracy of the measurements is found over 90%. And the graphical view of the measured values and the accuracy percentage is depicted in Fig. 6.

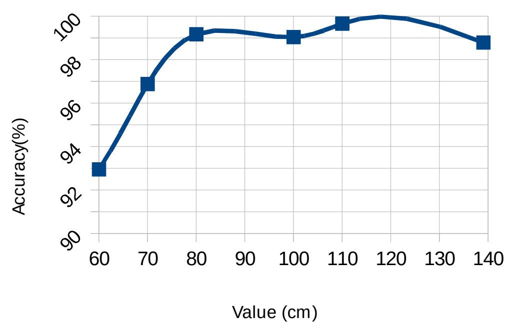


Fig. 6. Graph of the measured distance values and the accuracy

4. Conclusions

Distance estimation with stereo vision for mobile robot applications is realized, in this study. Since the open source software tools are utilized, a low-coast system is proposed. The system is designed in a manner which can be operated in embedded systems such as single board computers, BeagleBoard-xM, PandaBoard ES. It can perform real-time distance estimation. Therefore, it can be employed in mobile robot applications. High accuracy values are obtained for the objects 60-140 cm far from the cameras.

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