

**Research Issues in Object Distance Estimation Using a Laser Pointer and a Webcam**

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Abstract—The depth perception of objects in a scene is the primary research objective of the machine vision system. It has many industrial applications, such as robot navigation, scene understanding, metrology, etc. In this paper, some issues of low cost image processing based distance estimation systems are described. The low cost systems use commonly available laser pointer pens and a web camera. These systems are based on the principle of triangulation along with the perspective projection and the fact that light travels in a straight line. The paper presents a prototype system of a laser range estimation system consisting of a laser light pen and a webcam. The main contribution of the paper is a simple procedure for the system calibration and the camera parameter estimation. The system is implemented in the Matlab environment and gives good results.

Keywords—depth; camera calibration; perspective projection; laser spot.

I. INTRODUCTION

Distance estimation of various objects around us is essential for our daily activities, especially for our collision free navigation. There are currently three leading principles used for distance estimation: (1) time of flight, (2) stereo vision, and (3) monocular vision. In the time of flight system, the travel time of a wave from the source to the object and back to the receiver, for example the ultrasonic wave, is used to estimate the distance between the source and the object. This method is sensitive to the surrounding noises. The stereo vision system, which imitates the human vision system, evaluates the distance using the spatial disparity of an object point in two images (captured using a pair of cameras) with the triangulation method. The method is capable to work in any environment, but it is computationally very expensive. Further, the point correspondence problem, i.e. finding the locations of the projections of a scene point in both images, is practically very difficult to solve for real life stereo images in varying lighting conditions [1].

Humans successfully use various clues, such as texture variations, texture gradients, occlusion, known object sizes, haze and defocus, to judge depth from monocular images [2]. However, it is not possible to estimate distances from a single image without additional assumptions and information. For example, in an image of a clear blue sky with a patch, it is difficult to tell if this patch is infinitely far away (sky), or if it is a part of a blue object [2].

Due to ambiguities like these, one needs to look at the overall organization of the image to determine depths [2]. As observed by [2], the further difficulty with the monocular clues is that most of these monocular cues are global properties of an image and cannot be inferred from small image patches. For example, occlusion cannot be determined if we look at just a small portion of an occluded object.

To overcome the above difficulties in estimating depth from a single image, many researchers proposed to use some sort of projections of known structures before capturing the image [3]. These projected structures work as additional clues to estimate the distance of objects in a scene.

The present work extends the work presented in [3] by incorporating a low cost solution to calibration of the system and a simple procedure to calculate camera constant. The work presented in [3] is specific to the underwater distance measurement system, hence uses a sophisticated camera and high power laser rays. In contrast to [3], present work uses a commonly used webcam and a laser pointer pen used in our daily power point presentation.

The remaining part of the paper is organized as follows. Section 2 explains the working principle of the proposed system. Section 3 explains the experimental setup along with the alignment and calibration mechanisms. Section 4 presents results obtained by the setup. The final section presents conclusion followed by the relevant references.

II. WORKING PRINCIPLE

The proposed system is based on two well established facts: (1) the fact that as an object moves away from a camera, it appears smaller in the image captured by the camera and (2) the fact that light (laser) travels in a straight line. The fact one alone cannot be used for estimating objects distances using image processing as sizes of scene objects are not known in priori. As can be seen from figure 1(a), objects of different sizes located at different distances appear of the same size. In figure 1(a), the object AB and object CD are of different heights (sizes) and are placed at different depths, but the images of both the objects are same in size, as shown by EF. Hence, the image size of an object alone cannot be used to estimate depths. However, it is possible to estimate the distance of an object if the size of the object is known. To simulate an object of known size in a scene, a laser ray parallel to the camera axis is projected on the scene object. Since the camera axis and the laser ray are parallel to each other, the distance between the center of the image and the dot created by the

laser ray on the object will be the same irrespective of the distance of the object from the camera. This is shown in figure 1(b) where a laser ray (shown in red) creates two dots (D and B) on two different objects placed at two different depths. It is clear from the figure that the heights of the simulated objects (here AB and CD) are same irrespective of their distances from the camera. However, the images of these two objects are of different sizes and it is clearly shown in the figure 1(b) that as the distance between the object and the camera increases, the size of the image decreases.

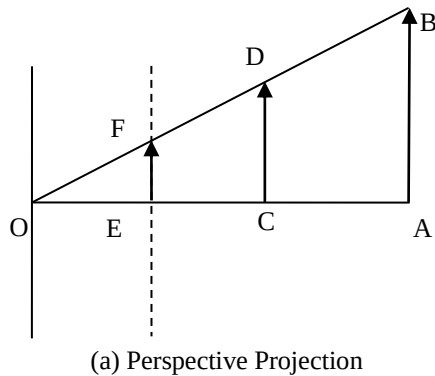
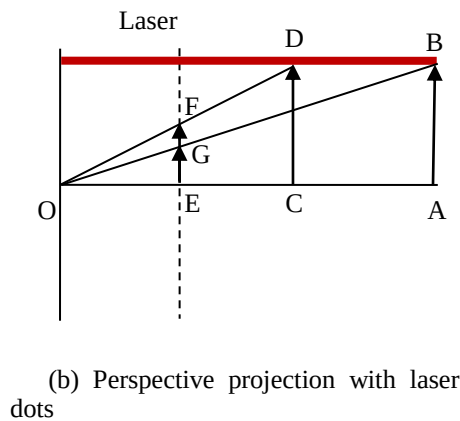


Figure 1. Working principle

Once we get an image of a scene with a projected laser spot, the distance of the object can be estimated by just locating the dot in the image and finding its distance from the center of the image. There are many well known algorithms available in image processing to accurately locate the dot, for more detail kindly refer [4]. The distance of the object is calculated using the principle of similar triangle as described below.

Consider $\triangle OAB$ and $\triangle OEG$. These two triangles are similar, hence

$$\frac{OA}{AB} = \frac{OE}{EG} \quad (1)$$

Where, OA is the distance of the object AB from the focus of the camera (to be estimated). AB is the distance between the camera axis and the laser ray (known). OE is the focal length of the camera (constant for a camera). EG is the image size that is equal to the distance between the image center and the laser spot. Hence, equation 1 can be rearranged as given in equation 2.

$$OA = \frac{AB * OE}{EG} = \frac{k}{EG} \quad (2)$$

Where, k is known as camera constant whose value is determined during the calibration process, as explained in the next section.

III. THE PROTOTYPE SYSTEM

Based on the working principle as explained in the previous section, an experimental system is developed as shown in figure 2. The system consists of a webcam and a laser pointer pen. The webcam and the laser pointer are mounted on a wooden stand. The wooden stand has a groove to keep the laser pen parallel to the camera axis. The webcam and the laser

pen are fixed on the wooden base. The webcam has the facilities to tilt and rotate its head in various directions so that webcam axis can be aligned with the laser ray direction.

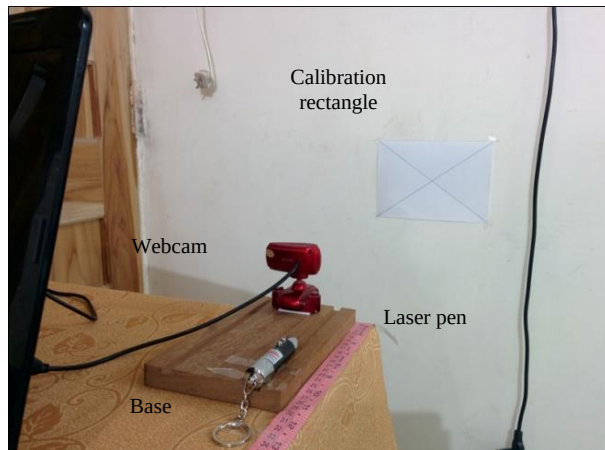


Figure 2. Experimental setup

IV. THE CALIBRATION PROCESS

Before using the experimental setup for distance estimation, it must be properly calibrated so that the axis of the camera and the laser ray must be parallel to each other. For this purpose, the following steps are used:

1. Place the experimental setup on a horizontal surface facing a vertical wall, for example top



Figure 3. Alignment process of the camera axis and the laser ray

surface of a table. A simple spirit level can be used to check the horizontalness of the surface (Figure 2).

2. With the help of a water filled tube, mark two horizontal points on the vertical wall to draw a horizontal line.
3. Place the calibration rectangle, a rectangular piece of paper with diagonal marked, on the vertical wall so that one side of the calibration rectangle aligns with the horizontal line drawn in step 2. The center of the calibration rectangle should be approximately at the height of the webcam head.
4. Now start the webcam in video mode. Looking at the computer screen connected with the webcam, tilt the webcam head till the horizontal sides of the calibration rectangle become horizontal and the opposite sides of the rectangle are of equal length in the video. This ensures that the camera axis is perpendicular to the vertical wall. With this step, the camera axis and the laser ray are parallel to each other. Figure 3 shows this process. The more accurate the alignment, more accurate the result.
5. After the alignment, take two images of the wall along with the laser spot from two locations of known distance from the wall.
6. Using the following formula, calculate the camera constant for both the images

$$k = AO * EG$$

If both values are equal, the calibration process is over and the setup is ready for use. Otherwise, repeat the above steps to ensure alignment of the camera axis and the laser ray. The camera constant for the prototype system obtained by the above process is 2720.

V. IMPLEMENTATION AND RESULTS

The image processing toolbox of Matlab is used to process the captured images to locate the laser spots and to calculate the center distance between the image center and the laser spot. In most of cases, laser spots are the brightest spots in the captured images. To efficiently detect the group of the brightest pixels in an image, the RGB image captured by the webcam is converted into an HSV image. The HSV color space is quite similar to the way in which humans perceive color. In the HSV format, the brightest pixels will have the highest value of V. In the most cases, laser spot pixels have the

values of V is generally 1. Now, the required pixels are found by just finding the pixels with the highest value of V in the HSV image. The center of the laser spot is calculated by taking average of all the pixels of one spot or by finding the centroid of the spot pixels. The center of the image is the center of camera axis, which is equal to $(r/2, c/2)$, where r is the number of rows and c is the number of columns in the image. The size of the simulated object image is the Euclidian distance between the image center and the laser spot center. The image center is found to be at (120,180). The above procedure is implemented in Matlab code and few sample results are shown in figure 4. Table 1 shows the estimated distances along with the corresponding actual distances. It can be seen from the result that the prototype is quite accurate in estimating the distance. Figure 5 is showing the estimated distance by the prototype system for a randomly placed object.

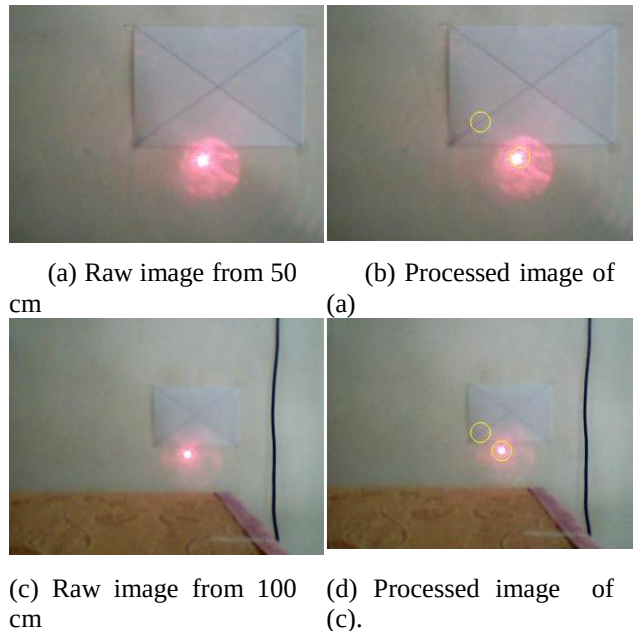


Figure 4. Images used during calibration

TABLE I. TABLE SHOWING THE ACTUAL DISTANCE AND THE ESTIMATED DISTANCE.

S. No.	Estimated distance (cm)	Actual distance (cm)
1.	49.8417	50
2.	59.5343	60
3.	71.1515	70
4.	79.9181	80
5.	88.4395	90
6.	98.0030	100
7.	111.4408	110



Figure 5. The estimated distance of a randomly placed object is 46.4251 cm.

VI. CONCLUSION

In this paper, a low cost distance estimation system has been described that uses a laser pointer pen and a webcam. The system uses the concept of the perspective projection and the fact that light travels in a straight line. The paper also describes a simple procedure for system calibration. It is found that the system performance is good for closer objects but it deteriorates as distance increases. This is due to the error in manual alignment of the camera axis and the laser ray. Theoretically, it can be calibrated to estimate any distance accurately till the laser spot can be located in the image. To further improve the performance, high resolution camera and more accurate alignment procedure should be used.

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