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Stereo vision with laser diode distance measurement

Manaf A. Mahammed[1]

1 Department of Physics, College of Science, University of Duhok, Duhok, Kurdistan Region of Iraq, Iraq, manaf.zivingy@uod.ac

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Abstract

An efficient technique is used to measure the distance of a target from the camera. A laser diode emitter is used to illuminate the desired portion of the target with bright laser spot and a 3D web camera is used to image the target. Image processing together with stereo vsion basic equations were used to calculate the distance from the measuring of disparity between the two images of the bright laser spot on the target. The results were compared with tests made using digital laser range finder and showed good agreement. The percentage error ranged from 0.025 % to 1.757 %.

Introduction

Obtaining the distance of obstacles and objects plays essential role in many important fields like robotics, traffics, military surveying. Different methods are used to measure target distance of an object, an obstacle, or a target from a camera position. The methods may be active or passive [1]. A passive stereo vision method was used by the author [2] to measure the distance of an object from a 3D camera using template matching technique. An active method was used by [3] who used a laser emitter with a single camera to find the distance of an obstacle from a robot. In a work [4], a webcam with laser diode is used to estimate distance from real video images sequences. And in another work, a system of near distance measurement that uses 5 mw laser diode with web camera to measure the distance from the camera is used. They measured the distance up to 218 cm with error of ±3cm [**5**]. Also, in another work, a vision based system, is designed to measure the distance between unmanned underwater vehicle and wall in front of vehicle using a camera and single laser pointer [**6**]. Authors in the last three works used the laser emitter with one camera and laser emitter fixed at specified distance from the camera and the laser beam hitting the target must be parallel to the optical axis of the camera. This implies that there must be an accurate alignment of the laser beam with the optical axis of the camera and any small deviation may cause a large error in measured distance. Hsu and Wang, proposed an improved stereo vision system to accurately measure the distance of object in real world. Their results showed that their system was capable of providing distance measurement with less than 5% of measurement error [7]. Ivanov, et al. [8**],** used a simple method of fast background subtraction based on disparity verification that is invariant to change in illumination. In that method, the segmentation is performed by checking background image to each of the additional auxiliary color intensity values at corresponding pixels. Shojaeipour, et al., presented a method to measure distance of obstacle in order for robot to transverse to its target location using laser pointer and a webcam, making use of image processing [9]. In order to avoid this problem and keeping the laser emitter in this work, a 3D webcam is used with the laser emitter. The laser emitter is not fixed at specified distance, however, the main job of the laser emitter is to make a bright spot on the target and its position and beam alignment are not important.

Basic Stereo Vision Equations

Fig.1. shows the basic diagram of a 3D webcam that consists of two webcams, the left webcam and right webcam. They have equal angle of view θ_0 and equal focal length f. They are put together such that their optical axes are parallel to each other and separated by a distance b. The shaded area can be seen by both webcams at the same time. Illuminating a target T within the shaded area by a red laser emitter will cause a bright red spot on the target which can be seen by both webcams at the same time. The target plane is at a distance D from the lenses of both webcams. The spot image in the left camera will be at a distance x_1 pixels to the left of the camera center while in the right webcam the spot image situates at distance x_2 pixels to the right of the camera center. θ_1 and θ_2 are the angles made by the reflected laser beams from the target T with the optical axes of the left and right webcams respectively. Making use of triangle similarity from figure, it is easy to write that, $b = b_1 + b_2$, and that:

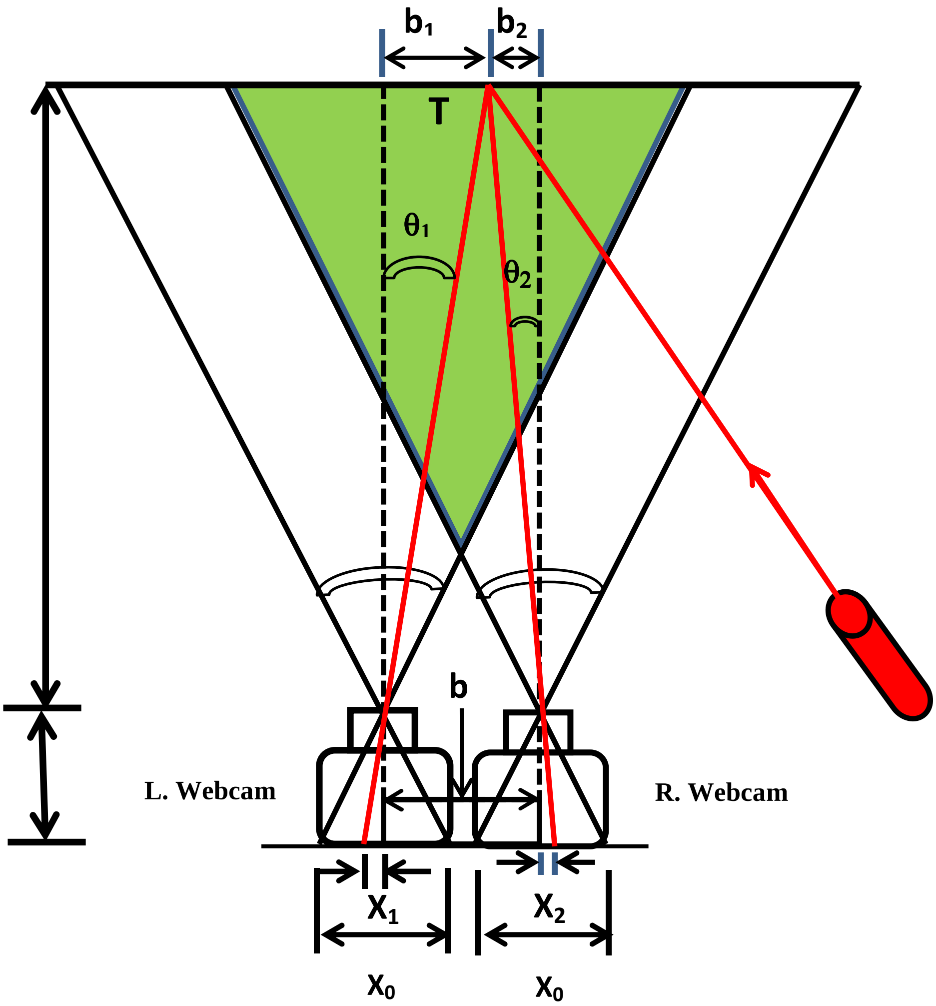

Fig.1: basic diagram of a 3D webcam

$$b_1 = (D/f)(-x_1)$$

and that

$$b_2 = (D/f)(x_2)$$

from which

$$b=(D/f)(x_2-x_1).$$

Solving for D we get:

$$D=\frac{bf}{x_2-x_1} \tag{1}$$

From equation (1) above it seems that the range which is the distance of the target from the two webcams, is inversely proportional to the difference in the positions of target images imaged by both cameras, x_2-x_1, which is called disparity. This horizontal distance X_0 represents the horizontal width of the image for each camera in pixels. This horizontal distance X_0 can be related to the angle of view θ_0 and the focal length of the lens as follows:

$$f=\frac{X_0/2}{\tan(\frac{\theta_0}{2})} \tag{2}$$

From equations (1) and (2), the range D will be given by:

$$D=\frac{X_0 b}{2\tan(\frac{\theta_0}{2})(x_2-x_1)} \tag{3}$$

Equation (3) shows that the distance to the target D is given in terms of easily measurable quantities X_0, b, θ_0, and (x_2-x_1). In order to compensate for misalignment error and optical distortion in camera lens, some modifications must be done in equation (3). A correction factor δ will be added to the angle of view $\theta_0/2$ in order to account for the actual angle of view and also the disparity will be raised to exponent n in equation (3) to account for the probability of the inverse proportionality between the distance and the disparity. Thus equation (3) can be written as:

$$D=\frac{x_0 b}{2\tan(\frac{\theta_0}{2}+\delta)(x_2-x_1)^n} \tag{4}$$

This equation can be written as:

$$D = k.x^{-n} \tag{5}$$

$$k = \frac{x_0 b}{2\tan(\theta_{effective})}$$

k must has a constant value since it depends upon the optical and geometrical properties of the camera. $\theta_{effective}$(= $\frac{\theta_0}{2}+\delta$) is the effective angle of view for each camera. The k and n must be determined practically by measuring real distances and correlating them with disparity values obtained by image processing method.

Materials and Method

The stereo vision setup used in this work for determining the target distance consists essentially of two similar web cameras (webcams) integrated into one device as a 3D webcam. The angle of view of each camera is 40^o. Both cameras have the same optical properties, i.e. the same focal length and the lens aperture. The optical axes of both cameras are parallel to each other and at 6 cm distance from each other. Both cameras are connected to the Laptop via a common USB cable. An inexpensive laser diode pointer emitter that emits a red laser light at wavelength 650 nm and maximum output power of less than 5 mW is used to illuminate the target creating a small bright red spot. The laser diode is powered by a simple electronic circuit which is triggered by an analog output pulse generated within the Matlab code and sent through one of the sound card output channels.

Result and Discussion

1-Image Processing

In order to find the distance of the target using the stereo vision system mentioned above, a Matlab code is written to control the two webcams of the 3D RGB colored web camera. The program acts to run both

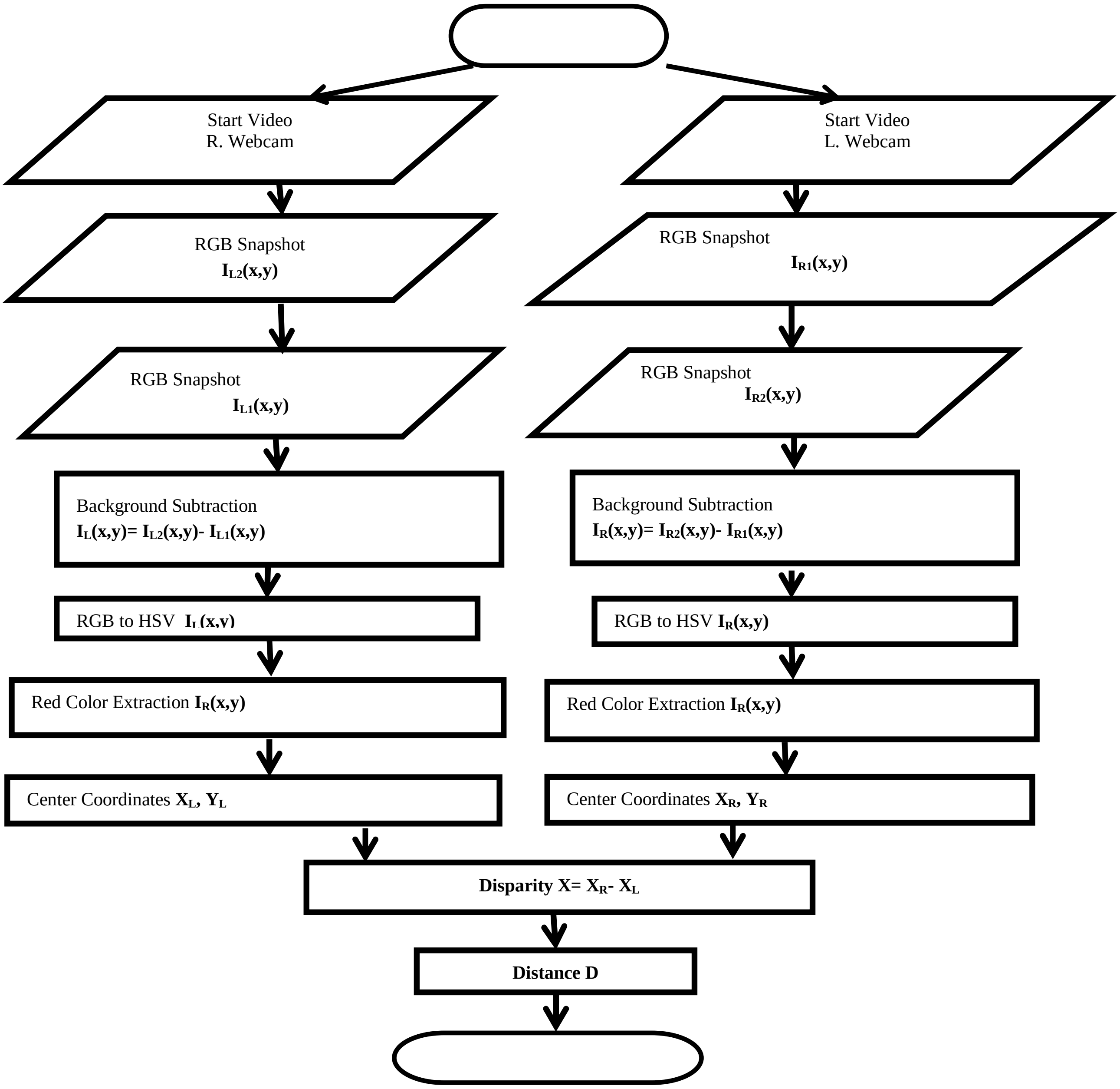

Fig. 2: Image acquisition and processing flow chart.

webcams (Left and Right) almost simultaneously. At the beginning, each of the two cameras will start imaging the target with no laser spot, and then each camera will make only one snapshot for the target image $I_{L1}(x,y)$ and $I_{R1}(x,y)$. Both of the images will be referred as background images. Immediately after the snapshots, the program will create a trigger audio pulse and send it as an analog output via the sound card of the laptop. This pulse is detected and amplified and used to trigger a monostable multivibrator circuit. The multivibrator circuit when triggered generates a square pulse of 4 second duration used to operate the semiconductor laser diode. When the laser light begins to hit the target, each webcam within the 4 seconds of the laser pulse duration time will take a second snapshot for the target, while the target is illuminated by laser. The new two snapshots $I_{L2}(x,y)$ and $I_{R2}(x,y)$ will include the image of the laser spot as well as the background. The background image for each of the left and right cameras is then subtracted from the next ones that include the laser spot images resulting of two images with the same dimensions [I_L (x,y) and I_R (x,y)]. The last two images are for the laser spot only as can be seen by both cameras with background subtracted. In order to get the coordinates of the laser spot in both images I_L (x,y) and I_R (x,y), the color space is changed from RGB(red, green, blue) color space to HSV (hue, saturation, value) color space. For the sake of removing colors other than red laser color, the red component is extracted from the last two images and finally the coordinates of maximum pixel value is found for the extracted red laser spot images in the left and right webcams. To know the coordinates of the center of the bright red spot image the median value of coordinates is found. The disparity is calculated from the difference of the x-coordinates of the spot in both images. Image acquisition and processing steps are shown by the flowchart in figure (2).

2- Experimental tests

In order to find the amount of the correction term □□added in equation (4), a series of tests were made to measure the distance D to a target. In each test the target is put in front of the 3D webcam, the program runs, the target is illuminated by the red laser light. The disparity is calculated for each case. The format used for the webcam was (640 pixel*480 pixel). The distance D to the target is measured by using a digital laser rangefinder. The tests are repeated for different target distances. The distances D(cm) are plotted against the disparity x(px) for each case as shown in Fig. 3 using Excel program and the following empirical power formula is deduced:

$$D(cm)=13847[x(px)]^{-1.18} \qquad (6)$$

where D(cm) is the distance of the target in centimeters and x(px) is the amount of disparity in pixels. Comparing both equations (5) and (6), it can be found that k= 13847 and n=1.18. These values will be included within the Matlab code to find the distance.

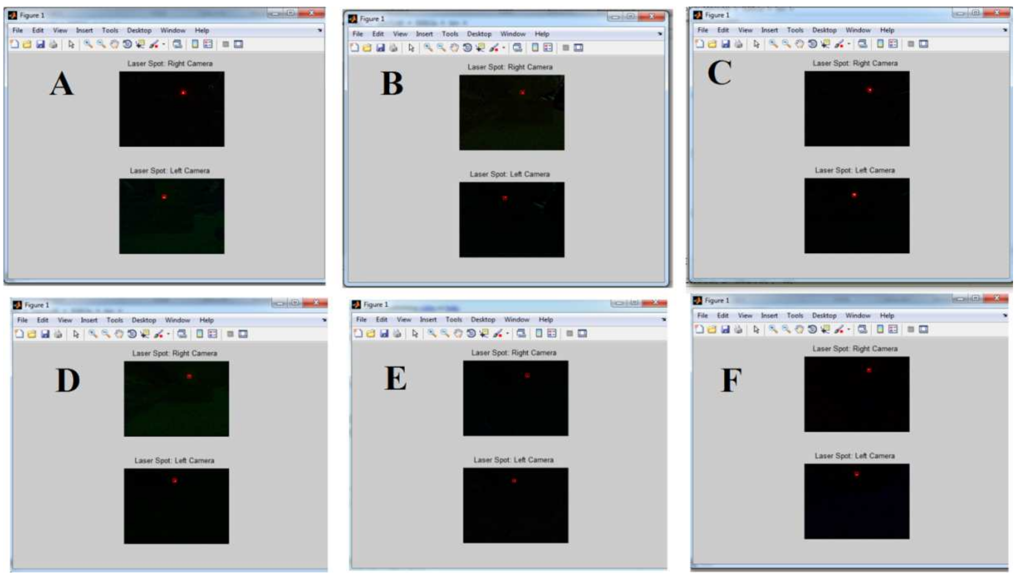

Fig.4: Images of six tests showing the bright red laser spots with black background due to subtraction

3- Final Tests

In order to test the final corrected distance equation, six extra tests were executed. In each test, the disparity between the images of left and right webcams is calculated and the distance D to the illuminated target is calculated. Also for comparison, the distance is measured by using a digital laser range finder of 1 cm resolution. The results are tabulated in table (1). Relative percentage errors are calculated and also tabulated in table (1). The absolute percentage errors ranged from 0.025 % to 1.757 % for the distance values mentioned in table (1). Images of the above tests showing the bright laser spots with background subtracted are shown in figure (4).

Table-1: Disparities and distances for six tests

Test No.	**Disparity x(px)**	**Distance**		**Err.%**
		Calculated D(cm)	**Measured D(cm)**	
A	119 px	49.46 cm	49 cm	0.938
B	108 px	55.46 cm	55 cm	0.836
C	98 px	62.19 cm	62 cm	0.306
D	90 px	68.77 cm	70 cm	1.757
E	80 px	79.02 cm	79 cm	0.025
F	76 px	83.95 cm	85 cm	1.235

Conclusion

An active method is used to select a point on the target to which the distance is to be found. Stereo vision method is used with triangulation to determine the distance of a selected point of the target from the camera. The triangulation method is used to drive the stereo vision equations and the correction factor due to camera misalignment error and optical distortion in camera lens was added. An empirical formula was deduced between the distance and disparity. Many successful tests were made to find the distance of a target. Results were compared with measurements done by using digital laser range finder of 1cm resolution. There was good agreement between them with percentage error ranged from 0.025 % to 1.757 %. In this research a laser diode emitter is used with two webcams (3D web camera) to determine the required distance instead of using the laser source with only one webcam as done with some previous works [10]. This can be justified by the fact that the laser source in this work is not fixed with the two webcams and it can be put at any distance from the webcams and that the laser source position will not be included in calculations. Thus the laser beam alignment problems were avoided. This will serve for future works if the laser spot is to be replaced with an object of certain color and it will be easy to track the motion of the object by finding its position coordinates every time. The distance between the two webcams cannot be varied since both webcams are integrated in one device forming 3D web camera.

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