Distance Measurement Using Dual Laser Source and Image Processing Techniques

Omar Y. Abdulqadir

omarkorjia@yahoo.com

Al-Mamon university college - Electrical Engineering Dept.

Wameedh R. Abduladheem

wam_alqudsi@yahoo.com

Al-Mamon university college - Electrical Engineering Dept.

Abstract: *Camera based systems are gaining popularity in automotive driver assistance systems. They are used to detect obstacles, road signs, road markings and other road users. Today, even low cost camera technology enables obtaining a very good image resolution. The proposed system presented in this paper can be used to measure the distance or the displacement of an object, by applying laser optics and trigonometry.*

The vision-based system was developed using a dual laser source and a CCD camera for recording images which are processed to obtain the distance from an object. The image processing techniques used in this paper consists of two main improved processes which are, the detection of a laser spot using image processing and the calculation of the *distance based on laser spot position on the image and the relationship between pixel number and distance. It is shown that the proposed system is able to measure distances in a quick and accurate fashion.*

Keywords: Image Segmentation, Morphological Operations, Geometric Moments

1. Introduction

Distance measurement of an object in front or by the side of a moving entity is required in a large number of devices. These devices may be small or large and also quite simple or complicated. Such distance measurement systems are available. These use various kinds of sensors and systems. Low cost and accuracy as well as speed are important in most of the applications.

Lasers can be used in various ways to measure distances or displacements without physical contact. In fact they allow for the most sensitive and precise length measurements, for extremely fast recordings (sometimes with a bandwidth of many megahertz), and for the large measurement ranges, even though these features are usually not combined by a single technique. Some of the most important techniques used for laser distance measurement are as follows:

- *Triangulation* is a geometric method, useful for distances in the range of approximately 1 millimeter to many kilometers.
- *Time-of-flight measurements (or pulse measurements)* are based on measuring the time of flight of a laser pulse from the measuring device to some target and back again. Such methods are typically used for large distances such as hundreds of meters or many kilometers. Using advanced techniques, it is possible to measure the distance between

Earth and the Moon with an accuracy of a few centimeters [1]. Typical accuracies of simple devices for short distances are a few millimeters or centimeters.

- The *phase shift method* uses an intensity-modulated laser beam. Compared with interferometric techniques, its accuracy is lower, but it allows unambiguous measurements over larger distances and is more suitable for targets with diffuse reflection. Note that the phase shift technique is sometimes also called a *time-of-flight technique*, as the phase shift is proportional to the time of flight, but the term is more suitable for methods as described above where the time of flight of a light pulse is measured [2].
- For small distances, one sometimes uses *ultrasonic time-of-flight* methods, and the device may contain a laser pointer just for getting the right direction, but not for the distance measurement itself [3,4].
- *Frequency modulation methods* involve frequency-modulated laser beams, for example with a repetitive linear frequency ramp. The distance to be measured can be translated into a frequency offset, which may be measured via a beat note of the sent-out and received beam [5,6].
- *Interferometers* allow for distance measurements with an accuracy which is far better than the wavelength of the light used [7].

Depending on the specific demands, very different technical approaches can be appropriate. They find a wide range of applications, for example in architecture, inspection of fabrication halls, criminal scene investigation (CSI), and in the military.

2. Image Processing Techniques

Several image processing techniques are used in this paper for detection of laser spot and calculating its location. The details of these techniques and the required mathematical models are listed in the following sections.

2.1 Image Segmentation

Segmentation means partitioning an image into distinct regions containing each pixel with similar attributes. To be meaningful and useful for image analysis and interpretation, the regions should strongly relate to depicted objects or features of interest. Meaningful segmentation is the first step from low-level image processing transforming a gray scale or color image into one or more other images to high-level image description in terms of features, objects, and scenes. Segmentation techniques are either contextual or non-contextual. The latter take no account of spatial relationships between features in an image and group pixels together on the basis of some global attribute, e.g. gray level or color. Contextual techniques additionally exploit these relationships, e.g. group together pixels with similar grey levels and close spatial locations [8].

Thresholding is the simplest non-contextual segmentation technique. With a single threshold, it transforms a grayscale or color image into a binary image considered as a binary region map. The binary map contains two possibly disjoint regions, one of them containing pixels with input data values smaller than a threshold and another relating to the input values that are at or above the threshold. The former and latter regions are usually labelled with zero (0) and non-zero (1) labels, respectively.

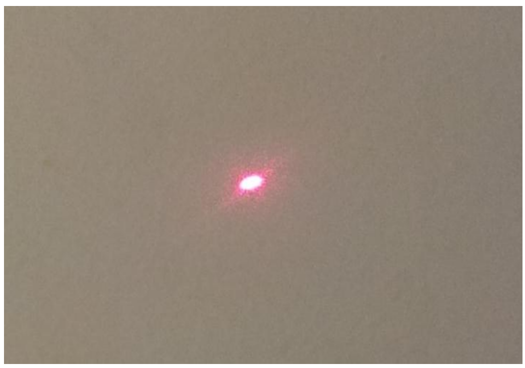
Segmentation of color images involve a partitioning of the color space, i.e. RGB or HSI space. One simple approach is based on some reference (or dominant) color (Red, Green, and Blue) and thresholding of Cartesian distances to it from every pixel color. In this work, a simple red segmentation with no value setting. That algorithm [9] converts RGB color space into single component color space represents the degree of red. Let Ri, Gi, Bi be the Red, Green, Blue values of a pixel. Let DRi be degree of red of a pixel. For all pixels then:

$$Ri = Ri - (Gi + Bi) \quad (1)$$

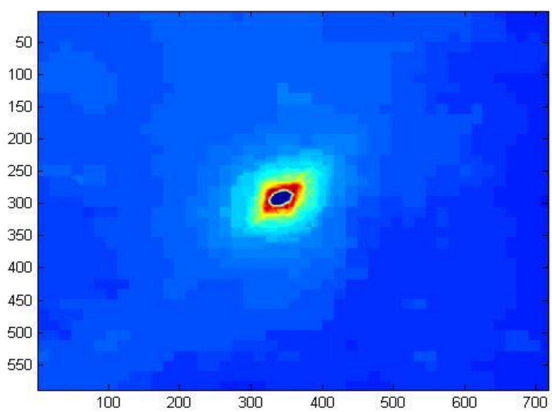
$$Gi = Ri - Gi \quad (2)$$

Bi = Ri - Bi (3)
If (Ri < 0) Ri = 0 (4)
If (Gi < 0) Gi = 0 (5)
If (Bi < 0) Gi = 0 (6)
DRi = Ri + Gi + Bi (7)

These formulae try to measure the degree of red compared with other colors. The red degree of each RGB component is calculated as presented by the formula. Finally, the degrees are totalized to obtain degree of red of a pixel.



(a) Original picture



(b) After applied RGB-Red conversion

Figure 1: RGB to Degree of red conversion

Figure 1, is an example of the algorithm implementation applied on a laser spot.

After RGB to degree of red converting has been presented a thresholding process is to convert it into black and white image, where every converted pixel with intensity greater than 45% of the maximum is regarded as a white otherwise its black, as shown in figure 2.

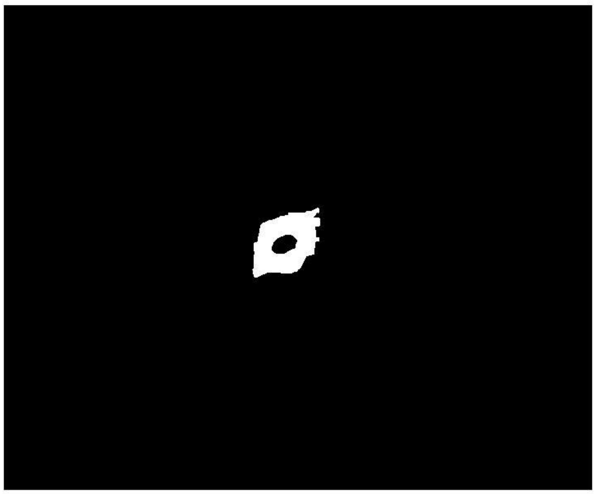


Figure 2: The result of the thresholding process

2.2 Morphological Operations

Morphology is a broad set of image processing operations that process images based on shapes. Morphological operations apply a structuring element to an input image, creating an output image of the same size. In a morphological operation, the value of each pixel in the output image is based on a comparison of the corresponding pixel in the input image with its neighbors. By choosing the size and shape of the neighborhood, you can construct a morphological operation that is sensitive to specific shapes in the input image [10]. The most basic morphological operations are dilation and erosion. Dilation adds pixels to the boundaries of objects in an image, while erosion removes pixels on object boundaries. The number of pixels added or removed from the objects in an image depends on the size and shape of the structuring element used to process the image. In the morphological dilation and erosion operations, the state of any given pixel in the output image is determined by applying a rule to the corresponding pixel and its neighbors in the input image. The rule used to process the pixels defines the operation as dilation or erosion. Dilation and erosion are often used in combination to implement image processing operations. For example, the definition of a morphological opening of an image is erosion followed by dilation, using the same structuring element for both operations. The related operation, morphological closing of an image, is the reverse: it consists of dilation followed by erosion with the same structuring element. The figure 3 below shows the thresholded image after applying the closing morphological operation.

Figure 3: The closing morphological operation

2.3 Geometric Moments

The two-dimensional geometric moment of order (p + q) of a function f(x, y) is defined as [8]:

$$M_{pq} = \int_{a1}^{a2}\int_{b1}^{b2} x^p y^q f(x,y)dxdy \qquad (8)$$

Where p, $q = 0, 1, 2, \ldots, \infty$. Note that the monomial product $x^p y^p$ is the basis function for this moment definition.

The definition of the zeroth order moment M_{00} of the function f(x,y):

$$M_{00} = \int_{a1}^{a2}\int_{b1}^{b2} f(x,y)\, dxdy \qquad (9)$$

This represents the total mass of the given function or image f(x,y) when computed for a binary image; the zeroth moment represents the total area of the image. The two first order moments are

$$M_{10} = \int_{a1}^{a2}\int_{b1}^{b2} x\, f(x,y)dxdy \qquad (10)$$

and

$$M_{01} = \int_{a1}^{a2}\int_{b1}^{b2} y\, f(x,y)dxdy \qquad (11)$$

Which represent the centre of mass of the image f(x, y). The centre of mass is the point where all the mass of the image could be concentrated without changing the first moment of the image about any axis. In the two-dimensional case, in terms of moment values, the coordinates of the centre of mass are

$$\bar{x} = \frac{M_{10}}{M_{00}}, \qquad \bar{y} = \frac{M_{01}}{M_{00}}. \qquad (12)$$

As a usual practice, the centre of mass is chosen to represent the position of an image in the field of view. The equations (12) define a unique location of the image f(x, y) that can be used as a reference point to describe the position of the image.

3. Proposed System for Distance Measurements

Based on triangulation [11], the distance between both laser sources in one side and the detected wall on the other side is shown in figures 4 and 5, for before and after the crossing of both laser beams.
The related equations for both cases are:

- ***Before crossing***

$$D = \left(\frac{w_s - w_m}{2}\right) \tan\theta \qquad (13)$$

Where

w_s the distance between both laser sources
w_m the distance between both laser spots
D the distance between laser sources and detected wall

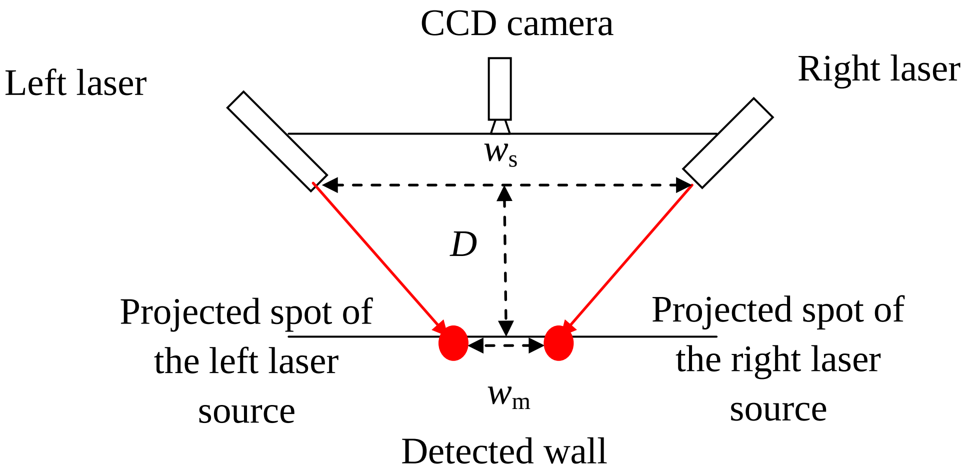


Figure 4: Geometric analysis before the crossing of both left and right laser beams

- ***After crossing:***

$$d1 = \left(\frac{w_s}{2}\right)\tan\theta \qquad (14)$$

$$d2 = \left(\frac{w_m}{2}\right)\tan\theta \qquad (15)$$

Since,

$$D = d1 + d2 \qquad (16)$$

Then,

$$D = \left(\frac{w_s + w_m}{2}\right)\tan\theta \qquad (17)$$

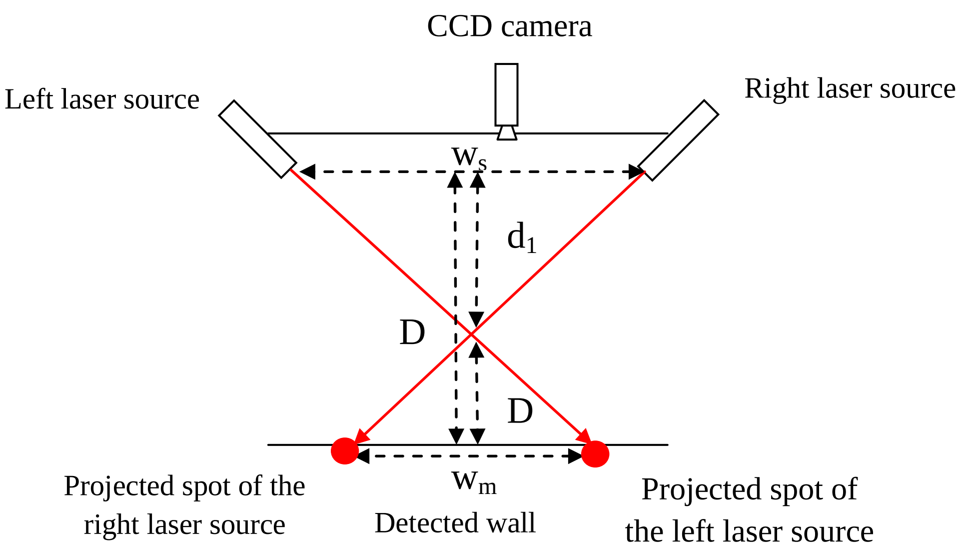


Figure 5: Geometric analysis after the crossing of both left and right laser beams

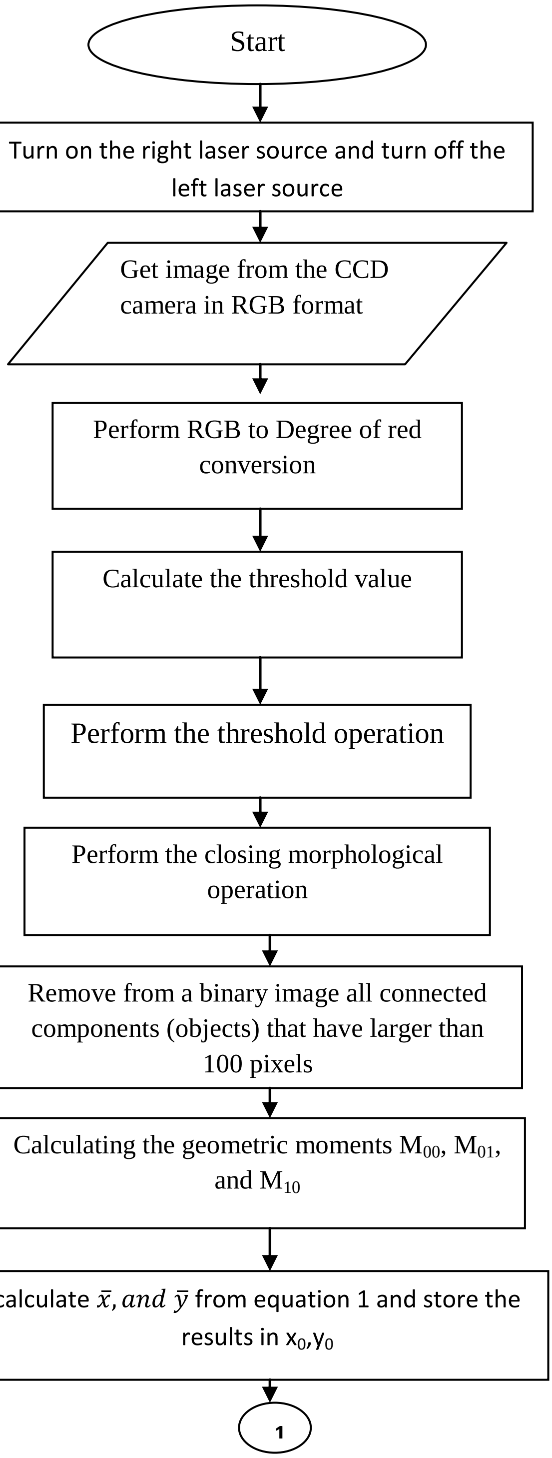
After setting the appropriate distance calculations (equations 13 and 17), a set of image processing techniques are chosen. The image segmentation using thresholding technique after converting the

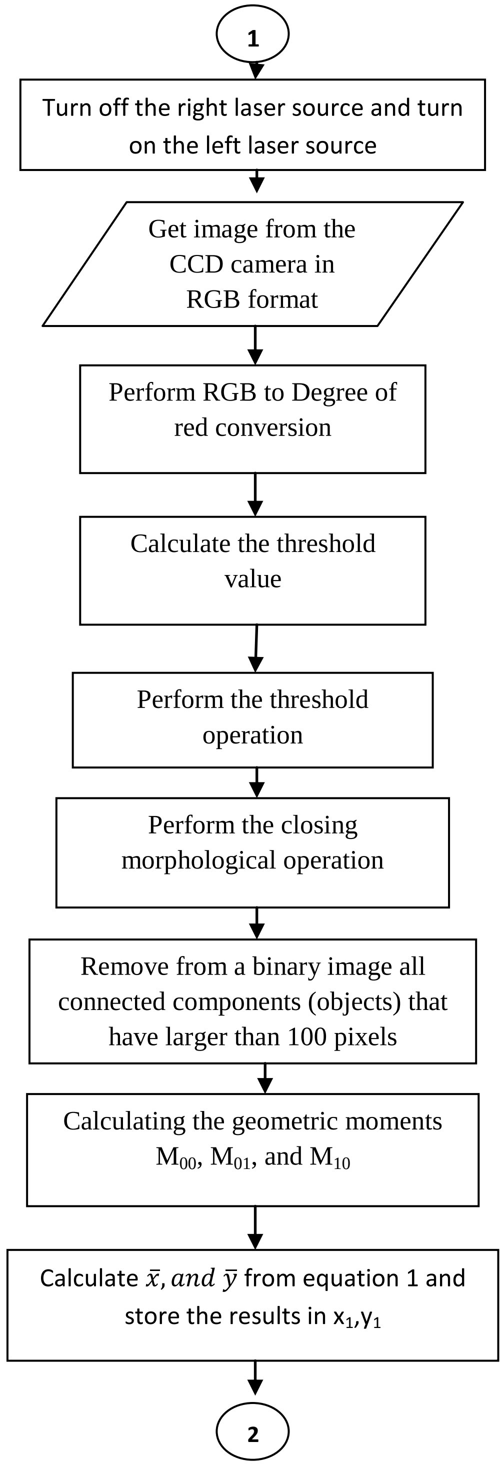
RGB image to degree of red format is necessary for extracting the red laser dot projected on the obstacle. Next, the closing morphological operation is applied to close the red dot to one image object and remove other objects that have size more than 100 pixels. Finally, the center of the object (red dot) is localized by calculating the geometric moments (equations 9-12).

The image acquisition operation, the previous set of techniques and the distance calculation are implemented using built-in MATLAB® functions.

The use of image processing technologies in the proposed system needs to get images with reasonable resolution (640X480 pixels), a CCD camera is used for the purpose. This camera mounted in the middle between two laser sources, both mounted as shown in figures 4, and 5, each with 5mw power and the wavelength of the emitted laser is 635nm. For practical considerations, ϴ=60o and Ws=33 cm.

Figure 6 summarize the process of measurement using the proposed system:


Start
Turn on the right laser source and turn off the left laser source
Get image from the CCD camera in RGB format
Perform RGB to Degree of red conversion
Calculate the threshold value
Perform the threshold operation
Perform the closing morphological operation
Remove from a binary image all connected components (objects) that have larger than 100 pixels
Calculating the geometric moments M_{00}, M_{01}, and M_{10}
calculate $\bar{x}, and\ \bar{y}$ from equation 1 and store the results in x_0,y_0
1


1
Turn off the right laser source and turn on the left laser source
Get image from the CCD camera in RGB format
Perform RGB to Degree of red conversion
Calculate the threshold value
Perform the threshold operation
Perform the closing morphological operation
Remove from a binary image all connected components (objects) that have larger than 100 pixels
Calculating the geometric moments M_{00}, M_{01}, and M_{10}
Calculate $\bar{x}, and\ \bar{y}$ from equation 1 and store the results in x_1,y_1
2

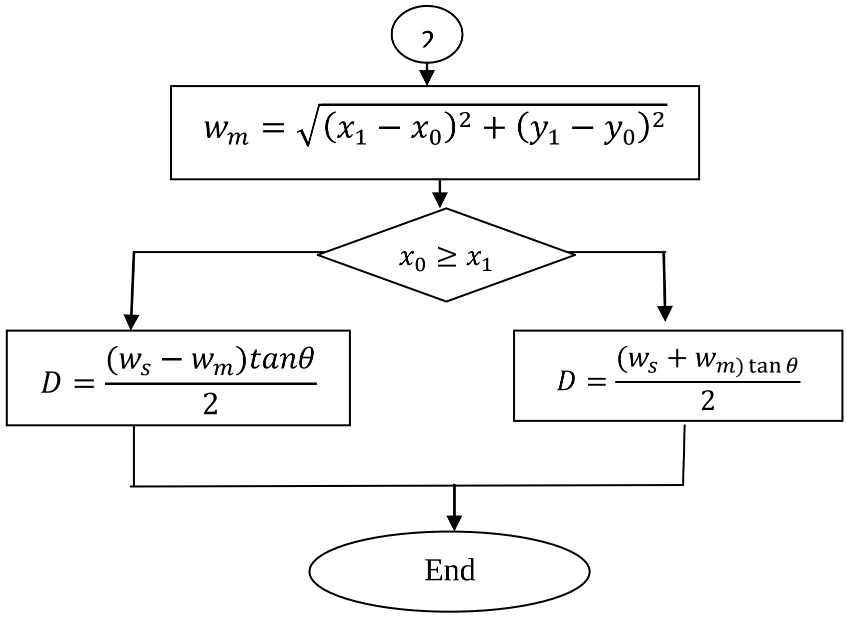


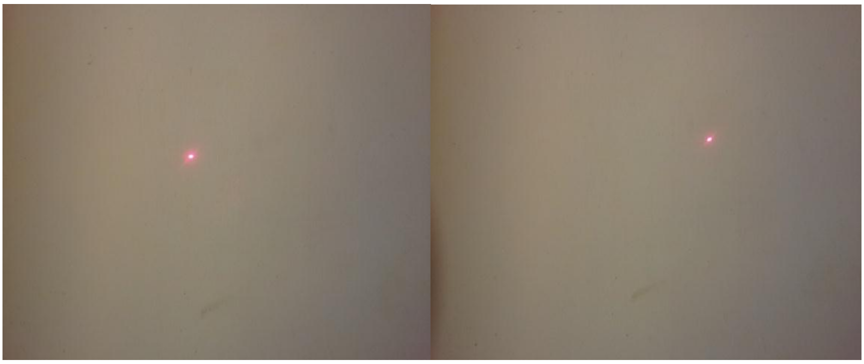
Figure 6: The proposed algorithm flow chart

4. Results

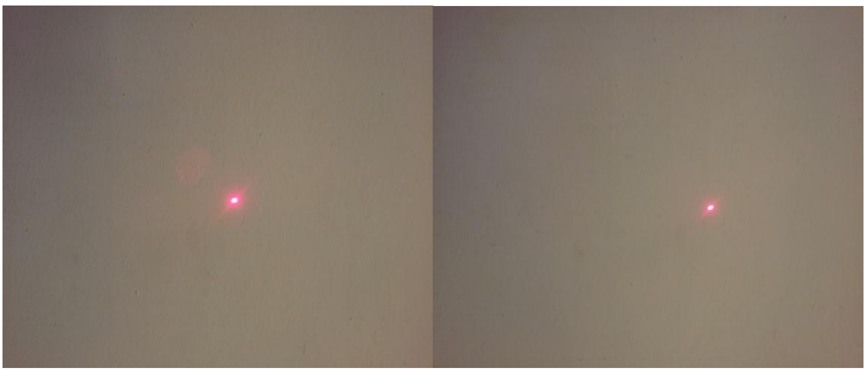
The proposed system is tested through six cases, the information of the selected cases is listed in table 1 and the relevant images are shown in figure 7.

Table 1: The tested true data

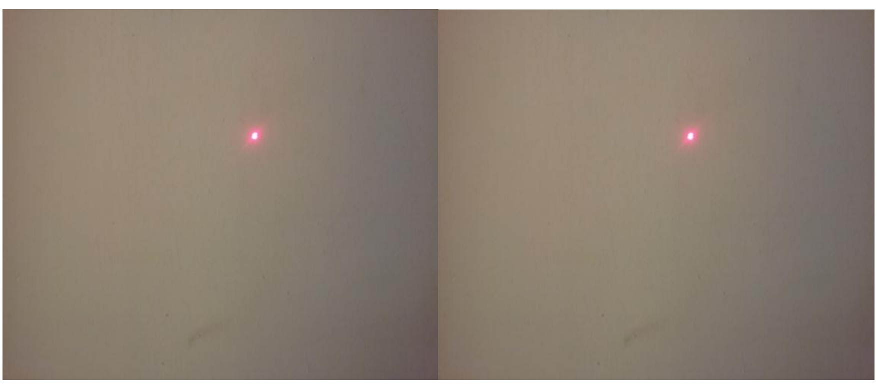
case	w_s(cm)	w_m(cm)	D(cm)
1	33	12	18
2	33	7.5	22
3	33	0	29
4	33	43	66
5	33	46	68
6	33	95	111



(a) case 1(D=18cm) **left laser ON** **(b)** case 1(D=18cm) **right laser ON**

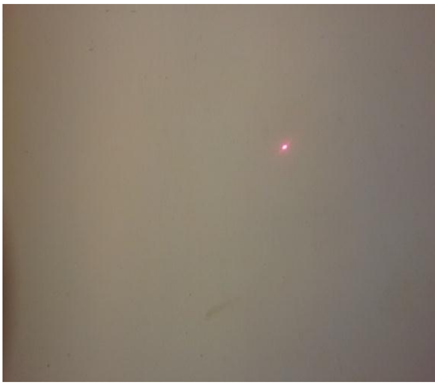


(c) case 2(D=22cm) **left laser ON** **(d)** case 2(D=22cm) **right laser ON**

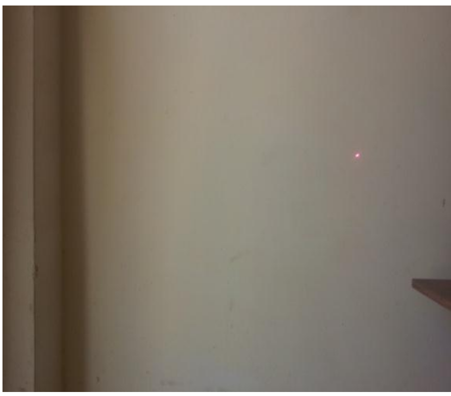
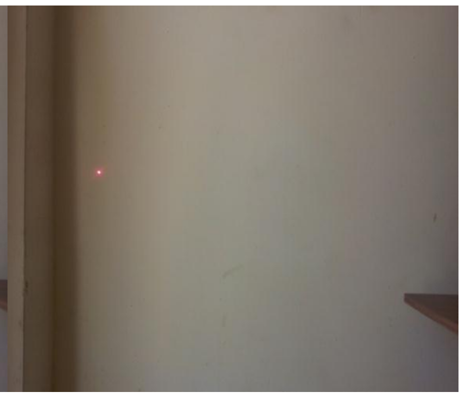


(e) case 3 (D=29cm) **left laser ON** **(f)** case 3 (D=29cm)**right laser ON**

Figure 7: The projection of a laser spots at the detected wall




(g) case 4 (D=66cm) **left laser ON** **(h)** case 4 (D=66cm) **right laser ON**

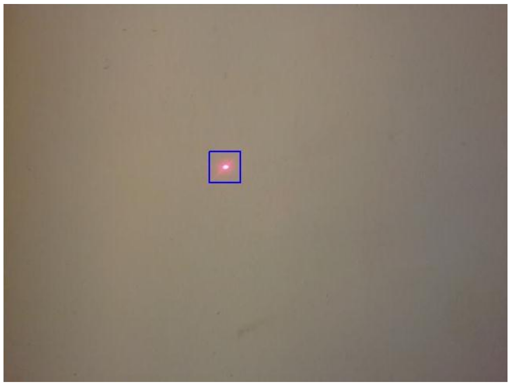



(i) case 5(D=68cm) **left laser ON** **(j)** case 5(D=68cm) **right laser ON**

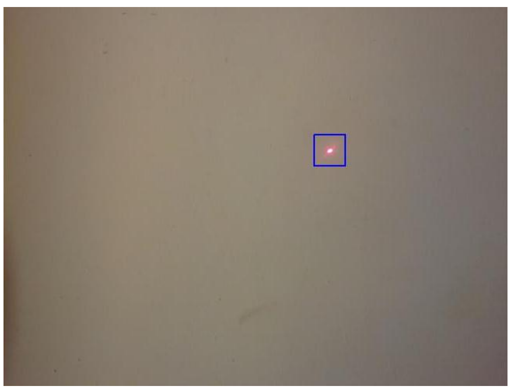

(k) case 6 (D=111cm) **left laser ON** **(l)** case 6 (D=111cm) **right laser ON**

Figure 7: The projection of a laser spots at the detected wall (cont.)

The proposed detection algorithm is tested for the selected cases and figure 8 shows the detection of the laser spot in case 1.



(a) Detected spot for the right laser source



(b) Detected spot for the left laser source

Figure 8: The location of the laser spots for case 1

For the six cases, the measurement results are listed in table 2. The error between true and measured distances is shown in figure 9.

Table 2: The measurement results

case	w_m(pixel)	w_m(cm)	D(cm)
1	80	12.8	17.49
2	50	8	21.65
3	0	0	28.58
4	284	45.44	67.93
5	307	49.12	71.12
6	625	100	115.18

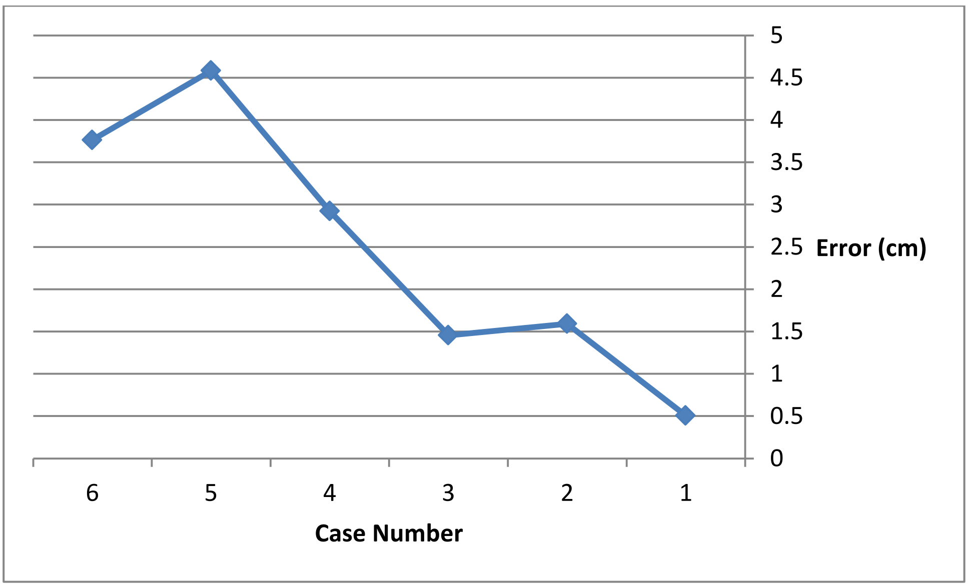


Figure 9: The different between Real distance and Measure distance for the selected cases (Error = real distance - measured distance)

The effective range for the measurement system is 15 cm to 200 cm with maximum error of 4.5 cm. The system proposed in [12] claimed to measure distances with 10 cm maximum error. This gives preference to our measurement system from the side of accuracy.

5. Conclusions

In this paper we have proposed a digital camera based method of measuring distances. The proposed system focuses on reducing the cost significantly but not at the expense of accuracy of the system which is up to 4% .This accuracy is considered good when compared to similar systems and the speed of processing high due to the simplicity of the algorithm used in the discovery of spots laser falling on the surface of the required object. We expect that the proposed system would work with comparable performance.

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قياس المسافة باستخدام مصدر مزدوج لليزر وتقنيات معالجة الاشارة

م.م. عمر ياسر عبد القادر
omarkorjia@yahoo.com
كلية المأمون الجامعة - قسم هندسة تقنيات القدرة الكهربائية
م.م. وميض رياض عبد العظيم
wam_alqudsi@yahoo.com
كلية المأمون الجامعة - قسم هندسة تقنيات القدرة الكهربائية

المستخلص

الانظمة التي تعتمد الكاميرات تكتسب شعبية في أنظمة مساعدة السائقين حيث يتم أستخدامها لكشف العقبات وعلامات الطريق المختلفة بالاضافة الى مستخدمي الطريق الاخرين. اليوم, حتى الكاميرات واطئه الكلفة تتيح تقنية الحصول على دقة ووضوح عاليين جدا. يمكن أستخدام النظام المقترح في هذا البحث لقياس المسافة من أي جسم من خلال تطبيق بصريات الليزر وعلم المثلثات. يتكون نظام الرؤية المستخدم من مصدر ليزر مزدوج وكامرة رقمية لتسجيل صور التي يتم معالجتها لتحديد المسافة. تقنيات المعالجة الصورية المستخدمة تتكون من عمليتين رئيسيتين هما تحسين الكشف عن بقعة الليزر بأستخدام معالجة الصور وحساب المسافة أعتمادا على موقع بقعة الليزر باسلوب سريع ودقيق.

الكلمات الرئيسية: تقسيم الصور، العمليات البنيوية، العزوم الهندسية.