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3D Object Modeling Using Eye on Hand Approach

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ABSTRACT

This research proposed vision measurement system which consists of a camera carried on hand of a robot, which captured 2D image to the object from two sides with a constant distance of the objects. To achieve this work several experimental steps are needed: First step includes calibrating the camera by using a standard block to find the best distance between the camera and the object. The best result of a distance is (410) mm. The second step consists of using MATLAB 7.12.0 (R2011a) program to achieve image processing to get some digital information (number of pixels in each row and column), using the proposed line by line scanning algorithm, to extract 2D object dimensions. The resulted dimensions are found closer to real object dimensions that are measured using a digital vernier and 3d digital probe. Last step includes 2D image manipulating using the proposed algorithms to reconstruct the 3D objects depending on the resulted information (number of pixels).

Keywords: Camera Calibration, Image processing, 3D Reconstruction.

نموذجية الاجزاء ثلاثية الابعاد باستخدام طريقة العين في اليد

الخلاصة

يقترح هذا البحث نظام القياس المرئي والذي يتضمن كاميرا محمولة على ذراع آلي، لالتقاط صورة ثنائية الابعاد لشكل من منظورين وبمسافة ثابتة من الجسم المراد التقاط الصورة له. ولانجاز هذا العمل نحتاج الى عدة خطوات عملية :الخطوة الاولى تتضمن معايرة الكاميرا بواسطة استخدام قالب قياسي لايجاد المسافة المطلوبة بين الكاميرا والجسم، افضل بعد ناتج هو (٤١٠) ملم.الخطوة الثانية تتضمن استخدام برنامج الماتلاب ٧.١٢.٠ (R2011a) لانجاز معالجة الصورة للحصول على بعض المعلومات الرقمية (عدد عناصر الصورة في كل صف وعمود)، استخدام الخوارزمية المقترحة بمسح كل خط، للحصول على ابعاد الجسم ثنائي الأبعاد . الابعاد التي تم الحصول عليها هي اقرب الى الابعاد الحقيقية التي تم قياسها بواسطة قدمة القياس الرقمية (the digital vernier) ومجس رقمي ثلاثي الابعاد (3D Digital Probe).الخطوة الاخيرة تتضمن المعاملة على صورة ثنائية الابعاد باستخدام الخوارزميات المقترحة لاعادة تكوين الاجسام الثلاثية الابعاد بالاعتماد على المعلومات الناتجة (عدد عناصر الصورة).

INTRODUCTION

With the development of the modern technology and industry, the performance and the reliability of the work pieces are more and more remarkably requested than before. Because the manual measurement which has some defects such as inherent subjectivity, fatigability, slow efficiency, high cost, labor intensity and etc. all these defects are not able to content the need of the modern industry measurement, high precision and high efficiency. The vision measurement has incomparable virtues, such as consistency, accuracy,

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repetition and etc. [1]. **Hadeel N. Abduallah & Ali K. Nahar (2010) [2]** first, they applied method of computing one and two dimensional frame let transform.

The work of **S.Jawad, et al (2012) [3]** is greatly depends on reading out the colored reference extrusion sample image and the colored target extruded image, which are captured using ambient light only to minimize possible illumination noise, and then reduce image information by converting them into gray-scale images, gray-scale images still inhibit much information and are very noisy due to the different brightness intensities, so in order to eliminate these effects a threshold operation is applied to both reference and target grayscale images. **J. Draréni, S. Roy and P. Sturm (2011) [4]** presented a novel linear method to estimate the intrinsic and extrinsic parameters of a 1D camera using a planar object. As opposed to traditional calibration scheme based on 3D-2D correspondences of landmarks, their method uses homographies induced by the images of a planar object.

F. Zhou et al (2012) [5] presented a novel 3D optimization method based on measurement coordinate system, with the aim of constructing a new objection function which minimizes metric distance between the calculated point and the real point in 3D space. **G. Du and P. Zhang (2013) [6]** presented method requires a camera that is rigidly attached to the robot end effecter, and a calibration board must be settled around the robot where the camera can see it. An efficient automatic approach to detect the corners from the images of the calibration board is proposed. **Z. Marton et al (2009) [7]** present a method for approximating complete models of objects with 3D shape primitives, by exploiting common symmetries in objects of daily use. Experimental results are presented using real world data sets containing a large number of objects from different views at different distances and orientations, and obtained fairly robust results. **M. Sun et al (2010) [8]** present a method for solving the challenging problem of generating 3D models of generic object categories from just one single un-calibrated image. The method leverages the algorithm proposed which enables a partial reconstruction of the object from a single view. A full reconstruction is achieved in an object completion stage where modified or state-of-the-art 3D shape and texture completion techniques are used to recover the complete 3D model. The results of a number of images containing objects from five categories (mice, staplers, mugs, car, and bicycle) show photo realistic and accurate reconstructions. **N. Mahmood, C. Omar and T. Tjahjadi, (2012) [9]** work investigated the use of an inexpensive passive method involving 3D surface reconstruction from video images taken at multiple views. The results of 15 measurements of different length between both reconstructed and actual dummy limb are highly correlate. **M.Barrero et al (2013) [10]** work proposes a novel probabilistic method to reconstruct a hand shape image from its template. The experimental results show that there is a high chance of breaking a hand recognition system using this approach. Furthermore, since it is a probabilistic method, several synthetic images can be generated from each original sample, which increases the success chances of the attack.

Aim of Work

The aim of this work are explaining the process of camera calibration to determine the best distance between objects and a camera that carried on Robot's hand, finding dimensions of objects and compared the results with real dimensions that measured by a digital vernier and by a digital probe, reconstruction the object depending on the extracted dimensions.

System Configuration

The system of this experimental work consists of hand of robot and a camera caught by the gripper of a robot, with condition the plane of camera putted as parallel form to a plane of the face for object that want to be measured as shown in figure (1). In this work, camera (SONY) model No. (DSC-W380) is used with (5X) magnitude of optical zoom and (14.1 MEGA PIXELS) magnitude of resolution.

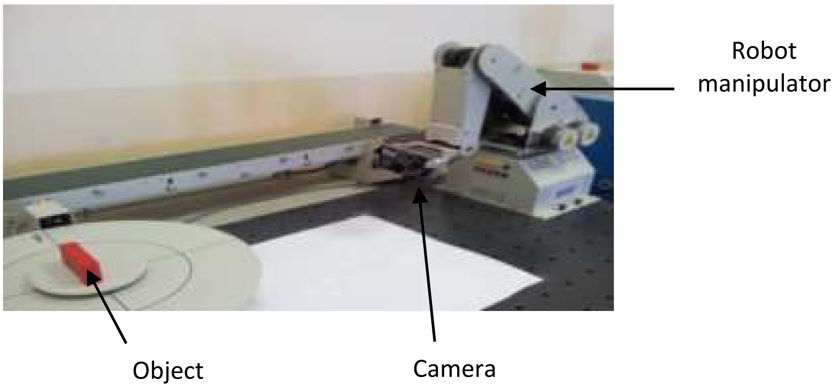


Figure (1) eye on hand robot system configuration

Camera Calibration

In this work, images must be calibrated to achieve approximate dimensional image presentation. Camera calibration is the heart of this measuring system, therefore the calibration results are very critical for the accuracy of the system equipment and directly used for image rectification. A small value of calibration inaccuracy will affect the accuracy results of the measurement significantly. All measurements performed on digital images refer to a pixel coordinate system, whereas real world measurements refer to the metric coordinate system, hence, calibration was made and results obtained over a number of experimental runs. The calibration is achieved using the front view of standard rectangular block of (100 mm) length and (30mm) width. A set of images is captured using different camera distances (D). Each image is then processed to get the average length and width of the rectangular component in pixel units. Therefore, the actual object dimensions (length & width) are compared to the extracted dimensions from the images captured. Consequently the relationship between actual and acquired dimensions is computed, Figures (2) and (3) graphs the results needed for acquiring the mathematical presentation of the equation that best fits the acquired dimensional results.

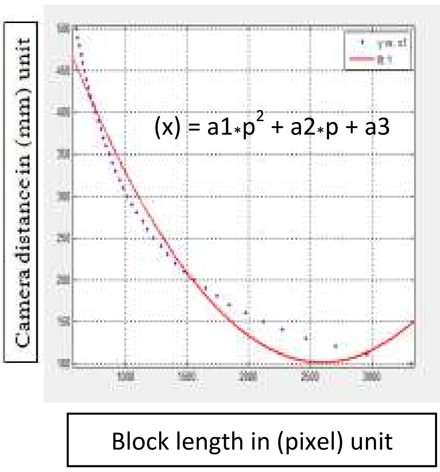


Figure (2) the relation of camera distances and lengths of block and their fitting curve

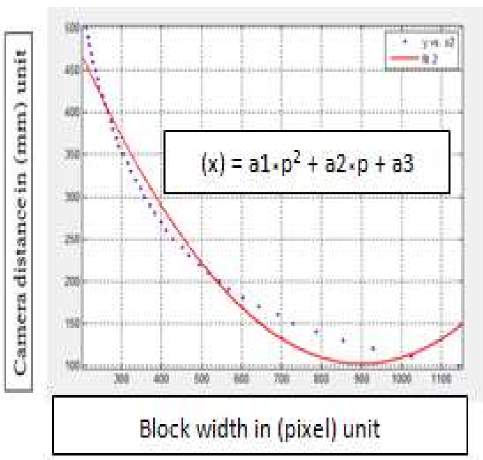


Figure (3) the relation of camera distances and widths of block and their fitting curve

It is worth noting that due to the non-linear characteristic of obtained measurements, iterations are performed to find best equation that fits the data, where the best obtained mathematical relationships are:

(a) The relationship between camera distance (x_L) in (mm) unit and (p_L) length of image in (pixel) unit. Where:

$(x_L) = a1 * p_L^2 + a2 * p_L + a3$ ….. (1)

a1 = $8.94 * 10^{-5}$

a2 = -0.4646

a3 = 704

(b) Relationship between camera distance (x_W) in (mm) unit and (p_W) width of image in (pixel) unit. Where:

$(x_W) = a1 * p_W^2 + a2 * p_W + 3$ … (2)

a1 = 0.0007496

a2 = -1.35

a3 = 709.4

From table (4-1) found the nearest value to real distance in (410 mm), the magnitudes of absolute error for length (E_L) and width (E_W) are:

E_L = real distance – distance required from No. of pixel in length

$E_L = 410 – 409.5166$

$= 0.4834$ mm

dimension (60 * 30) mm E_W = real distance – distance required from No. of pixel in width.

$E_W = 410 – 410.0339$

$= -0.0339$ mm

- Therfor the scale factor (S) = No. of Pixels/Object Real Dimensions
- The scale factor for length (S_L) = 739Pixels/100mm = 7.39 (pixel/mm)
- The scale factor for width (S_W) = 259 pixels/30mm = 8.633 (pixel/mm)

Real Test of Camera Calibration

To ensure the results measurements dimensions of objects by using the pixels that required from images, used two standard blocks with dimensions (40*30 mm) and (60*30 mm) as shown in figure (4), those blocks putted at a distance (410mm) and captured images for their by using scanning program computed a number of pixels in length and width for both objects.

Real image Binary image Real image Binary image

a b

Figure (4) (a) Standard block (40 * 30) mm, (b) Standard block (60 * 30) mm

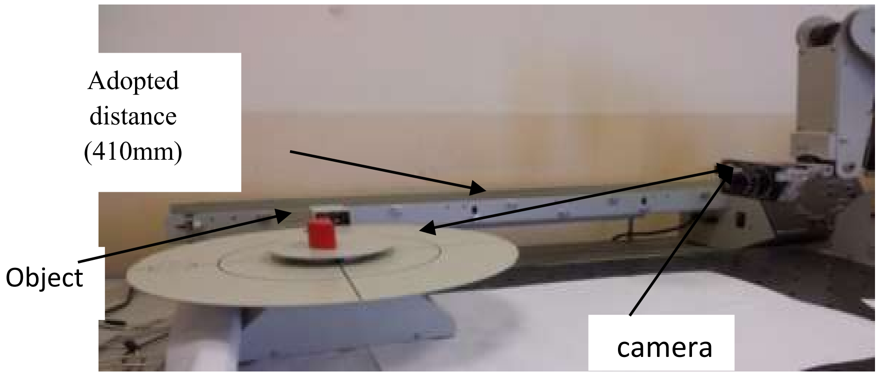
By using the previous relationships, the results obtained are the dimensions which compared with real dimension and computed the error between them. Table (1) lists all results for both objects, this magnitude of errors will added for each dimensions measured from image for length and width.

Table (1) Testing the result of camera calibration

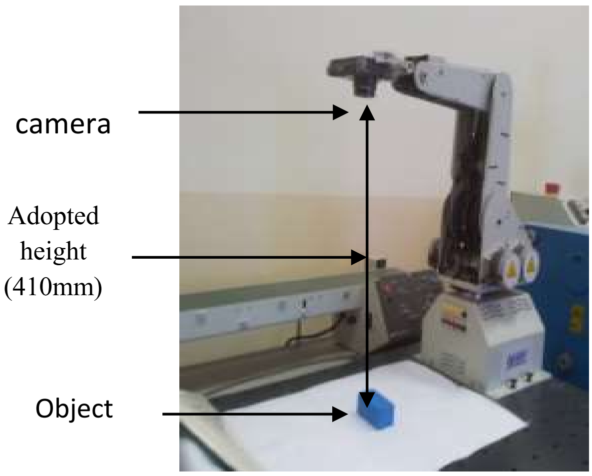
Length of object in (mm) unit	width of object in (mm) unit	Length of object in (pixel) unit	width of object in (pixel) unit	Experime-ntal length in (mm) Unit	Experiment-al width in (mm) unit	Error in length (mm) unit	Error in width (mm) unit
60	30	443	255	60.054	29.536	-0.054	0.462
40	30	296	255	40.054	29.536	-0.054	0.462

3D Reconstruction Process

For every object taken two pictures the first from front view and the second from top or side view depending on the need of dimension for object that want to be reconstructed as shown in figure (5), which take pictures in front view with respect to the objects, and in figure (6) , which take pictures in top view.



Figure(5) capturing front view picture



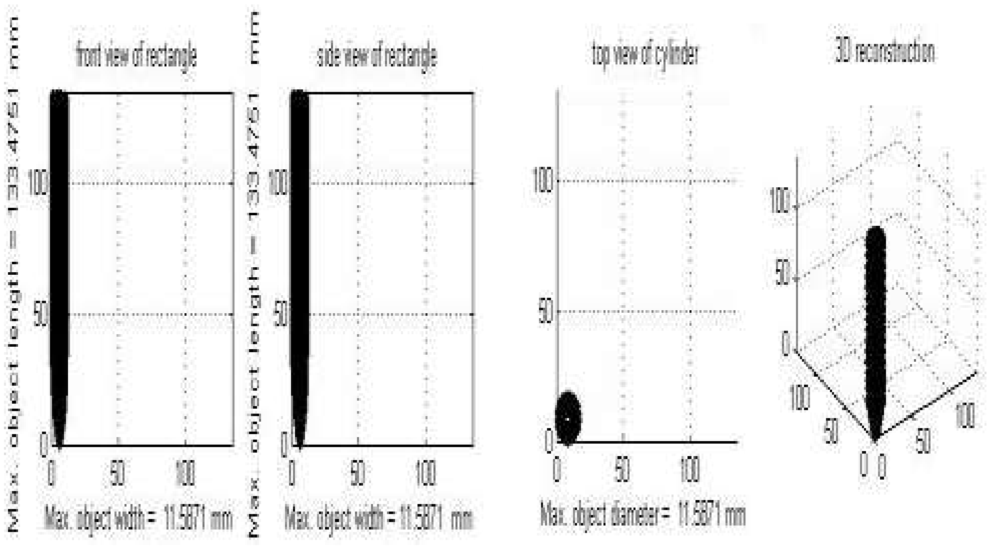
Figure(6) capturing top view picture

Digital vernier with accuracy (0.01 mm) to measure real dimensions for every tested object. And computed the error for every object as listed in next tables.

A Pen Shape Object

The real pen dimensions are: (10.18, 134.79)mm and by using a 3D digital probe they are: (10.775, 134.8)mm. The object with pen shape was captured at adopted distance (410)mm, as shown in Figure (7). By using the proposed algorithm the dimensions of this object are obtained in three coordinates x,y and z. The results of dimensions were converted from pixel unit to metric unit (mm) which helped on reconstruction the 3D model of pen shape object as shown in figure (8). Comparing the real dimensions of pen object with that measured by using a vernier and adigital probe, the magnitude of dimensions and errors listed in table (2) and the errors is shown in figure(9)

Figure (7) Front View of A Pen



Front View Side View Top View 3D Model

Figure (8) Pen Views and 3D model

Table (2) comparing the results of pen shape object

View	Front
Length (mm) in vernier (V_l) reading	10.78
Width (mm) in vernier (V_w) reading	134.79
Length (mm) from scanning (L_s) program	10.5871
Width (mm) from scanning (W_s) program	134.4751
Length (mm) in digital probe (P_l) reading	10.775
Width (mm) in digital probe (P_w) reading	134.8
Eroor in length with vernier (mm) $\|V_l-L_s\|$	0.1929
Eroor in width with vernier (mm) $\|V_w-L_s\|$	0.3149
Eroor in length with digital probe (mm) $\|P_l-L_s\|$	0.1879
Eroor in width with digital probe (mm) $\|P_w-L_s\|$	0.3249

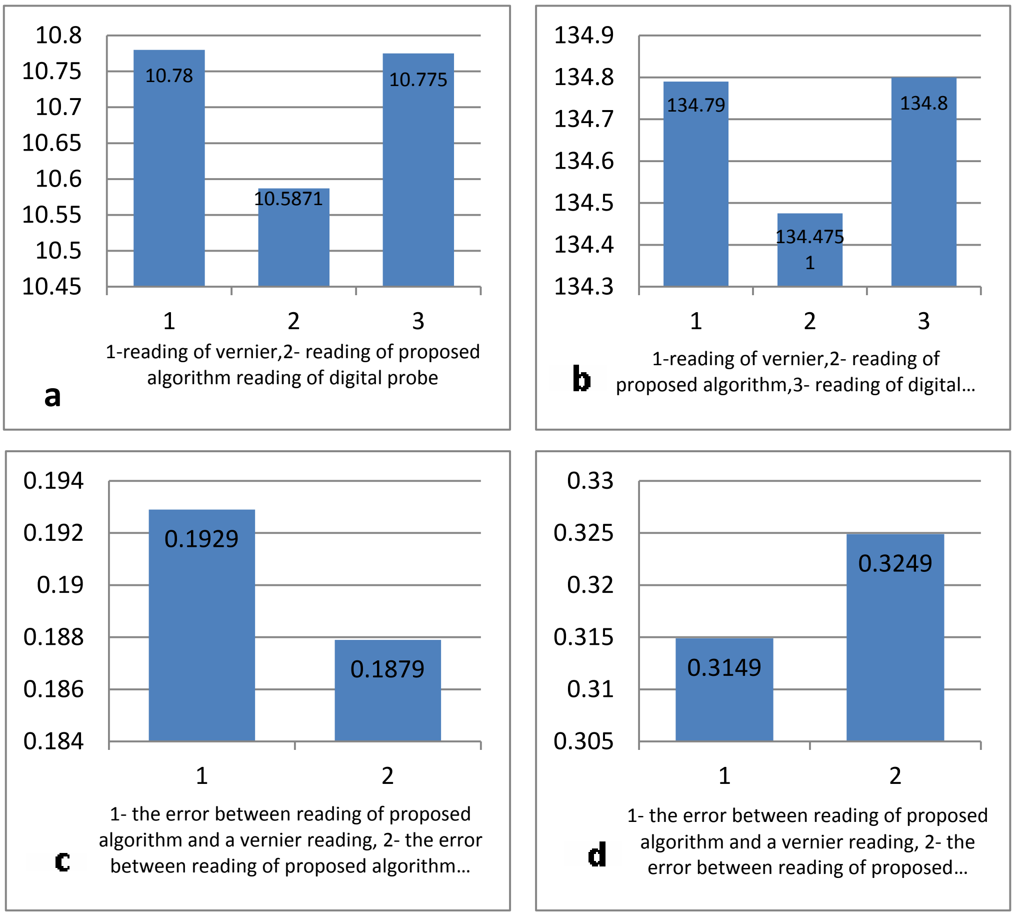


Figure (9) (a,b) comparison of digital vernier, scanning program and digital probe reading, (c,d) comparison the eroor of dimension for pen shape.

A Bottle of Drug Shape Object

A bottle of drug, is with real dimensions of (119.02, 49.19)mm. The object with bottle of drug shape was captured at adopted distance (410)mm, as shown in Figure (10). By using the proposed algorithm the dimensions of this object are obtained in three coordinates x,y and z. The dimensions are converted from pixel unit to metric unit (mm) as shown in figure (11). By compared a results of dimensions with a real dimensions of 3D bottle of drag object that measured by using a vernier, the magnitude of errors listed in table (3) and shown in figure(12)

Figure (10) A Bottle Shape Object

Table (4) Comparing the results of bottle shape object

View	Front
Max.Length (mm)in vernier (V_l) reading	119.02
Max.Width (mm)in vernier (V_w) reading	49.19
Max.Length (mm) from scanning (L_s) program	118.07861
Max.Width (mm) from scanning (W_s) program	49.6917
Length (mm) in digital probe (P_l) reading	119.03
Width (mm) in digital probe (P_w) reading	49.185
Eroor in length with vernier (mm) $\|V_l-L_s\|$	0.94139
Eroor in width with vernier (mm) $\|V_w-L_s\|$	0.5017
Eroor in length with digital probe (mm) $\|P_l-L_s\|$	0.95139
Eroor in width with digital probe (mm) $\|P_w-L_s\|$	0.5067

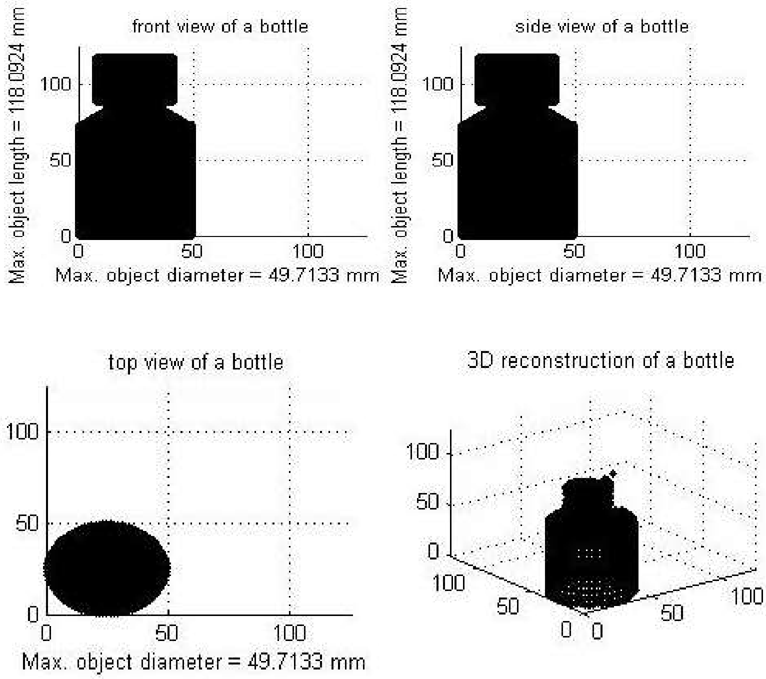


Figure (11) Bottle Views and 3D Model

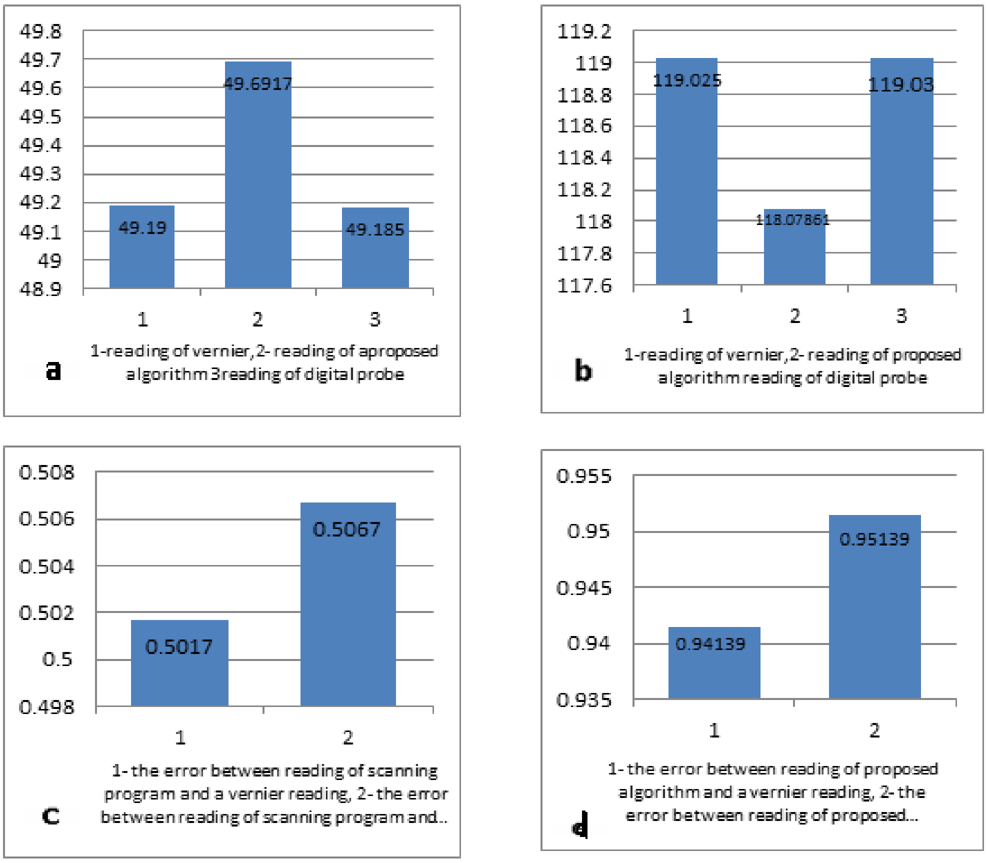


Figure (12) (a,b) comparison of digital vernier, scanning program and digital probe reading, (c,d) comparison the eroor of dimension for bottle shape.

A Span Shape Object

A span object is with (104.42, 11.47, 11.06 and 4.95)mm. The object with span shape was captured at adopted distance (410)mm, as shown in Figure (13). Figure (14) shows span views and the resulted 3D model. Table (4) and (5). list errors between scanning program with vernier and scanning program with a digital probe are explained in figures (15) and (16).

a b

Figure (13) Span Object Shape (a) Top view (b) Front view

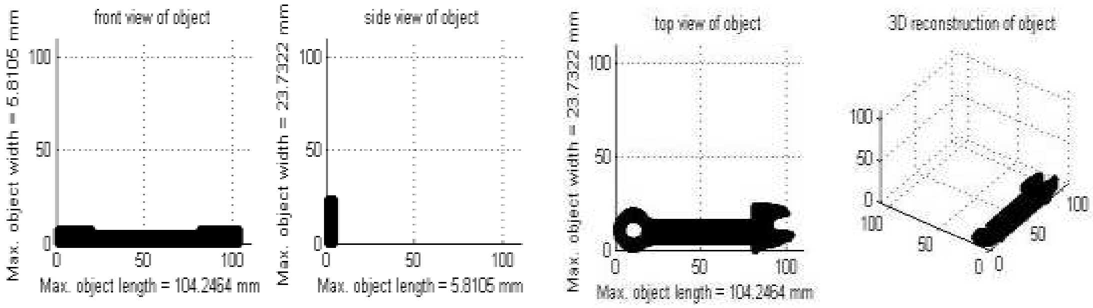


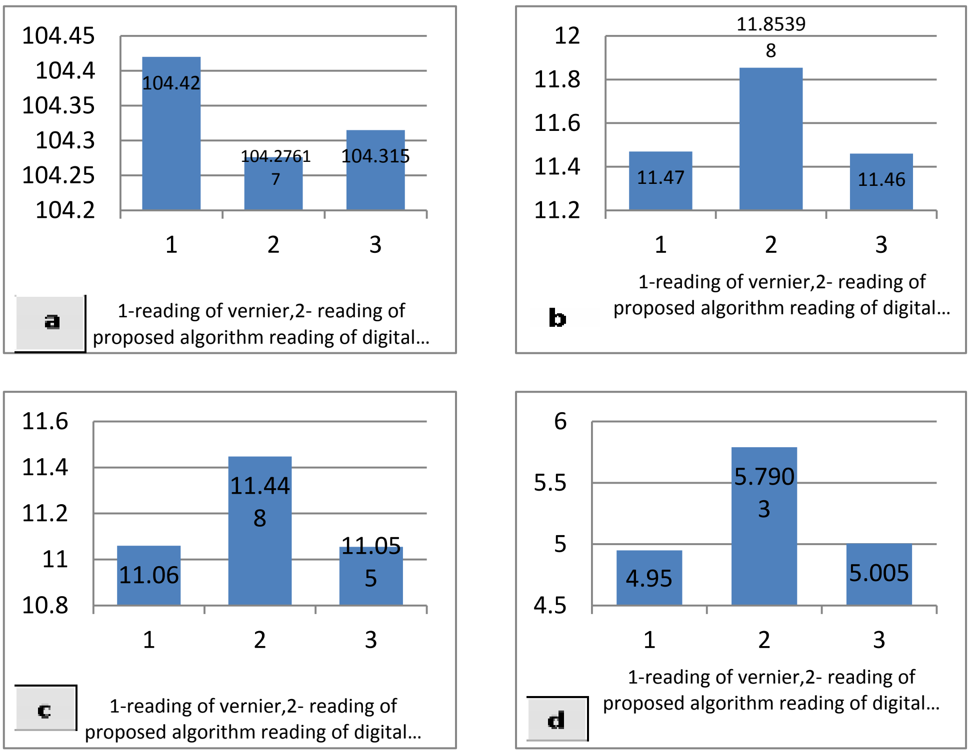
Figure (14) Span Views and 3D Model.

Table (4) Comparing the results of span shape object for top view

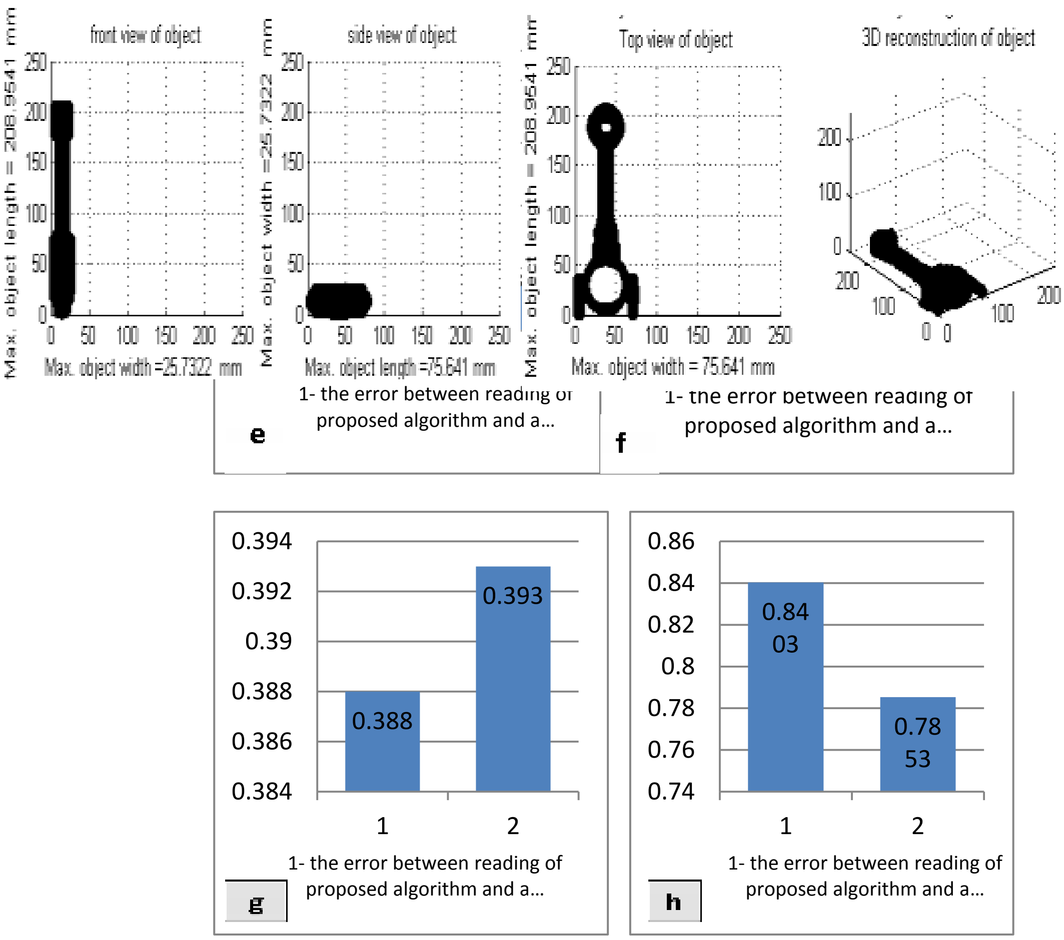
View	Top
Length (mm) in vernier (V_l) reading	104.42
Internal diameter of ring (mm) in vernier (V_{d1}) reading	11.47
Internal diameter of second end (mm) in vernier (V_{d2}) reading	11.06
Length (mm) from scanning (L_s) program	104.27617
Internal diameter of ring (mm) from scanning (D_{s1}) program	11.85398
Internal diameter of second end(mm) from scanning (D_{s2}) program	11.448
Length (mm) In digital probe (P_l) reading	104.315
Internal diameter of ring (mm) in digital probe (P_{d1}) reading	11.46
Internal diameter of second end (mm) in digital probe (P_{d2}) reading	11.055
Eroor in length with vernier (mm) $\lvert V_l-L_s \rvert$	0.14383
Eroor inInternal diameter of ring with vernier(mm) $\lvert Vd_1-D_{s1} \rvert$	0.3839
Eroor in Internal diameter second end with vernier(mm) $\lvert Vd_2-D_{s2} \rvert$	0.388
Eroor in length with digital probe (mm) $\lvert P_l-L_s \rvert$	0.03883
Eroor inInternal diameter of ring with digital probe (mm) $\lvert Pd_1-D_{s1} \rvert$	0.39398
Eroor in Internal diameter 2nd end with digital probe (mm) $\lvert Pd_2-D_{s2} \rvert$	0.393

Table (5) Comparing the results of span shape object for side view

View	Side
Max.Length (mm) in vernier (V_l) reading	104.4248
Max.Width (mm) in vernier (V_w) reading	4.95
Max.Length (mm) from scanning (L_s) program	104.27617
Max.Width (mm) from scanning (W_s) program	5.7903
Max.Length (mm) in digital probe (P_l) Reading	104.415
Max.Width (mm)in digital probe (P_w) reading	5.005
Eroor in length with vernier (mm) $\|V_l-L_s\|$	0.14862
Eroor in width with vernier (mm) $\|V_w-L_s\|$	0.8403
Eroor in length with digital probe (mm) $\|P_l-L_s\|$	0.13883
Eroor in width with digital probe (mm) $\|P_w-L_s\|$	0.7853



Figure(15) (a,b,c,d) comparison of digital vernier, scanning program and digital probe reading for span shape.



Figure(16) (e,f,g,h) comparison the eroor of dimension for span shape.

A Connected Rod Shape Object:

A connected rod object, with real dimensions of (208.24, 45.46, 17.5 and 25.85)mm, and by using a 3D digital probe they are: (208.305, 45.465, 17.49 and 25.81)mm maximum length, the big end, the small end and thickness respectivelly. The object with connected rod shape was captured at adopted distance (410)mm from two views, as shown in Figure (17).

The dimensions are converted from pixel unit to metric unit (mm) which helped on reconstruction the connected rod object with three views and 3D model as shown in figure (18). By compared a results of dimensions with a real dimensions of connected rod object that measured by using a vernier, the magnitude of errors listed in tables (6) and (7). Errors between scanning program with vernier and scanning program with a digital probe are explained in figure (19) and (20).

a b

Figure (17) Connected Rod Object Shape (a) Front View (b) Top View

Table (6) Comparing the results of connected rod shape object for top view

View	Side
Max.Length (mm) in vernier (V_l) reading	208.24
Max.Width (mm) in vernier (V_w) reading	25.85
Max.Length (mm) from scanning (L_s) program	208.9514
Max.Width (mm) from scanning (W_s) program	25.7447
Max.Length (mm) in digital probe (P_l) reading	208.305
Max.Width (mm) in digital probe (P_w) reading	25.81
Eroor in length with vernier (mm) $\lvert V_l-L_s \rvert$	0.7114
Eroor in width with vernier (mm) $\lvert V_w-L_s \rvert$	0.5017
Eroor in length with digital probe (mm) $\lvert P_l-L_s \rvert$	0.1053
Eroor in width with digital probe (mm) $\lvert P_w-L_s \rvert$	0.0653

Table (7) Comparing the results of connected rod shape object for front view

View	Top
Length (mm) in vernier (V_l) reading	208.24
Internal diameter of big end (mm) in vernier (V_{d1}) reading	45.46
Internal diameter of small end (mm) in vernier (V_{d2}) readin	17.5
Length (mm) from scanning (L_s) program	208.9514
Internal diameter of big end (mm) from scanning (D_{s1}) program	46.36
Internal diameter of small end(mm) from scanning (D_{s2}) program	17.6726
Length (mm) in Digital probe (P_l) reading	208.305
Internal diameter of big end (mm) in Digital probe (P_{d1}) reading	45.465
Internal diameter of small end (mm) in Digital probe (P_{d2}) readin	17.49
Eroor in length with vernier (mm) $\lvert V_l-L_s \rvert$	0.7114
Eroor in Internal diameter of big end with vernier(mm) $\lvert V_{d1}-D_{s1} \rvert$	0.9
Eroor in Internal diameter small end with vernier (mm) $\lvert V_{d2}-D_{s2} \rvert$	0.1726
Eroor in Length With digital probe (mm) $\lvert P_l-L_s \rvert$	0.6464
Eroor in Internal diameter of big end with digital probe (mm) $\lvert P_{d1}-D_{s1} \rvert$	0.895
Eroor in Internal diameter of small end with digital probe (mm) $\lvert P_{d2}-D_{s2} \rvert$	0.1826

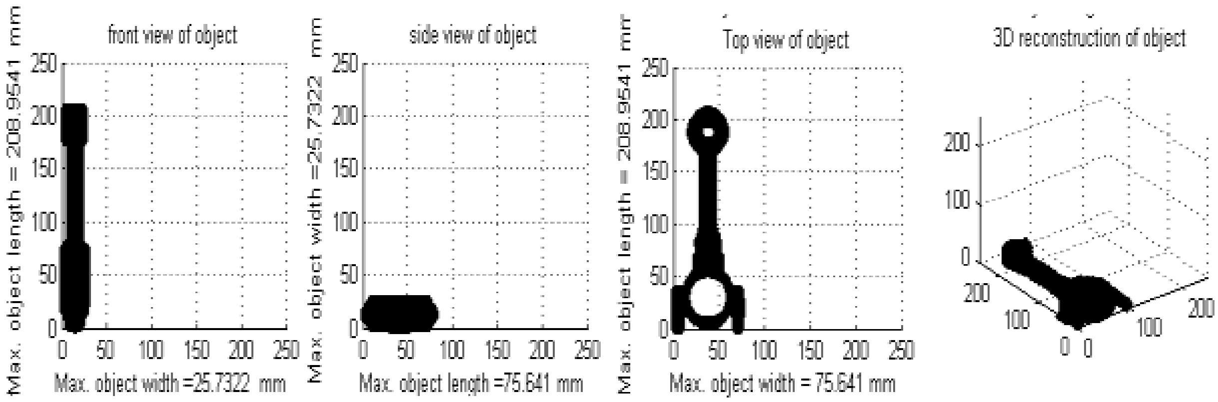
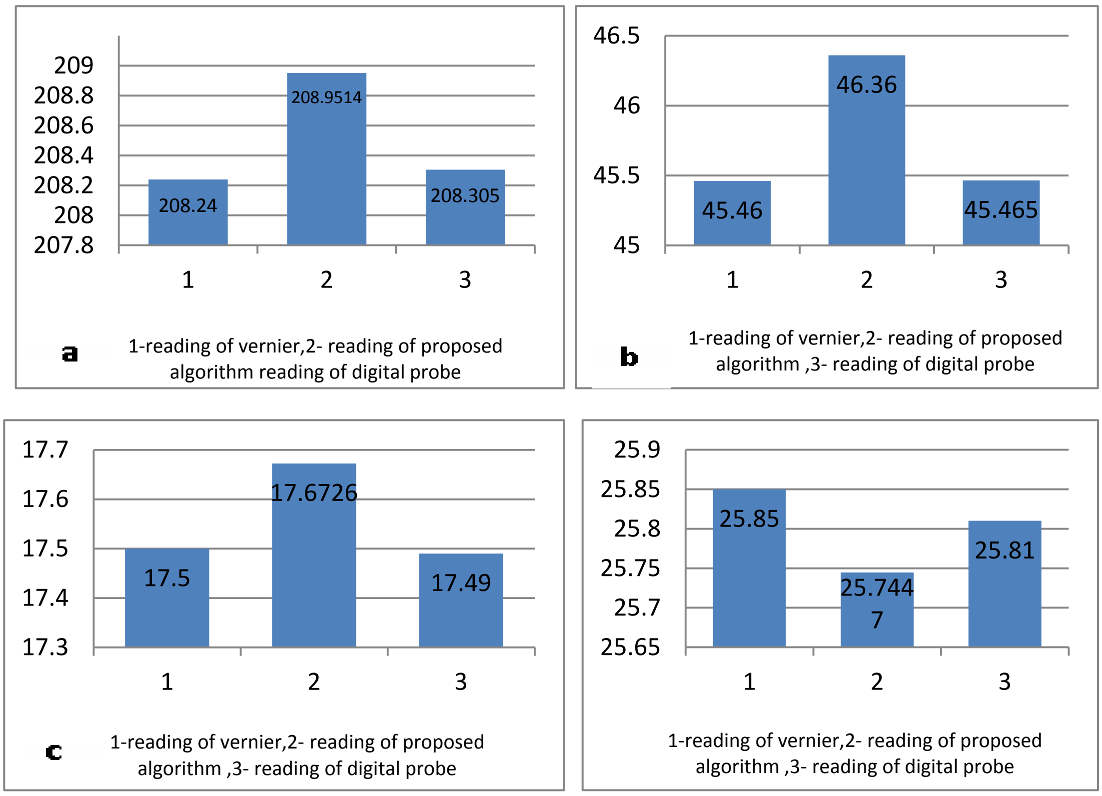
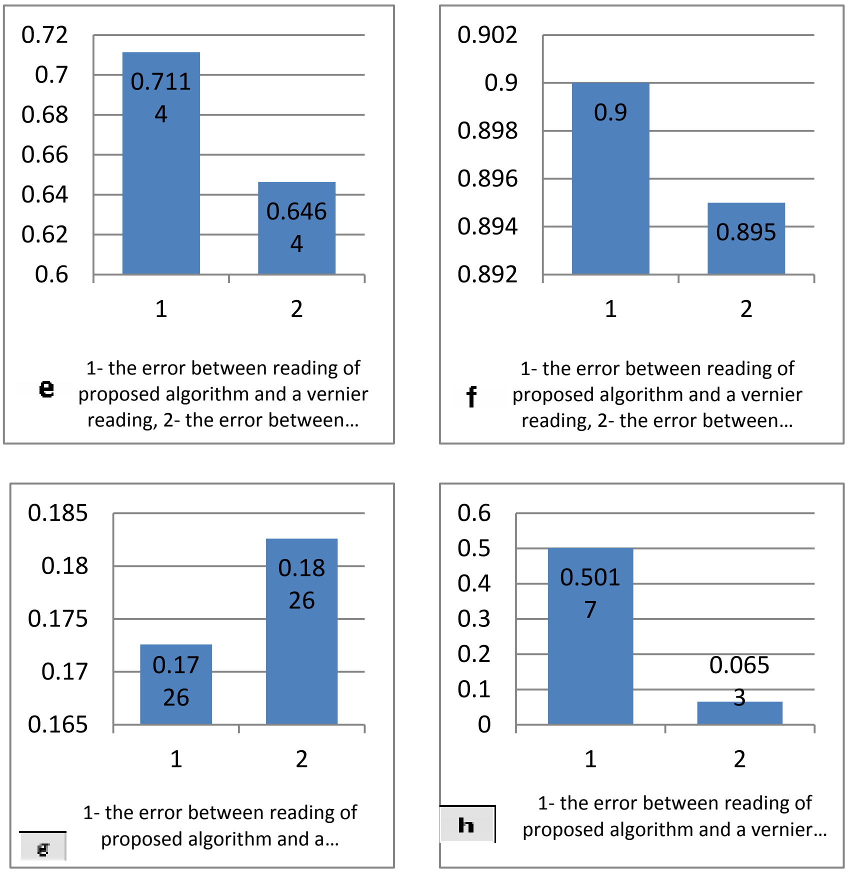


Figure (18) Connected Rod Views and 3D Model



Figure(19) (a,b,c,d) comparison of digital vernier, scanning program and digital probe reading, for connected rod shape.



Figure(20) (e,f,g,h) comparing the eroor of dimensions for connected rod shape.

RESULTS

The best distance between the object and the camera is (410) mm, this distance is applied on all objects. And the image of object processed in matlab program and by scanning program gotten number of pixels in each directions X and Y, the numbers of pixels applied in equation (1) to compute the length of object in (mm) unit and in equation (2) to compute the width of object in (mm) unit at last added the magnitude of errors for length and width from table (2). After finding the dimensions of object and compared them with the real dimensions of object that measured in digital vernier and digital probe reconstructed the object from the extracted dimensions.

CONCLUSIONS

On the basis of this study, and observations recorded experimentally, the following findings can be concluded:

1. Camera calibration is the first and an important step in this work, it determined the best distance between camera and object.
2. Select automatic thresholding method for captured images. It is suggested because it succeeded in distinguishing the object in the scene without any priory information about the object or the scene.

3. Using scanning program with MATLAB to compute number of pixels in two dimensions X and Y and converted to millimeter units lead to measure the object dimension from edge to edge with very low error and low cost.
4. It found that using curve fitting with second polynomial gave good results.
5. The results of dimensions that fond from images contain different magnitude of error that belongs to fit the center of lenses of camera with center of object.
6. Using 3D reconstruction system with benefit of image processing and computing pixels number with good accuracy.
7. Some of reconstruction image appeared points especially in the edge of figure. This appearance belongs to the density of image which depends on a step number of points in each row and column.

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