Image Based 3D Object Reconstruction System

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ABSTRACT

The concepts of image processing, computer vision and computer graphics have very important using in different laterals science. 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 including 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 consist 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), by scanning the image line by line, 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 to reconstruct the 3D objects depending on the resulted information (number of pixels).

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

إعتماد الصورة في إعادة بناء الأجسام ثلاثية الأبعاد

الخلاصة:

المفاهيم التالية (image processing, computer vision and computer graphics) لها استخدامات مهمة في مختلف مجالات العلوم. هذا البحث يقترح 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 نقاط الصورة في كل صف وعمود)، استخدام طريقة مسح 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

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صورة ثنائية الابعاد لغرض اعادة تكوين الاجسام الثلاثية الابعاد بالاعتماد على المعلومات الناتجة (عدد نقاط 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, repetition and etc. [1]. Some articles that explain the relationships between image processing, computer vision and computer graphics, as shown in figure (1), are: **Ali Abbar Khleif and Mohanned Abbood (2011) [2]** proposed a digital image correlation (DIC) algorithm to measure the full-range strain distribution during a tensile test, a feature that is not available through conventional techniques. The results derived from this method compared with the results derived from the traditional methods by using the tensile devise and also with results derived from the finite element analysis (FEA).

The measurement results indicate that the proposed algorithm is an accurate and reliable for obtaining stress-strain curves even in the necking region. **A.abd-allah (2013) [3]** has reconstructed 3D model by summing extracted edges from images as layers for model which images captured with different heights. So the edge of every image of model got by concept of edge detection to a binary image. And the articles that deal with camera calibrations are: A joint camera calibration that integrate the camera calibration and the hand-eye calibration simultaneously proposed by **F. Chun et al (2010) [4]**. The joint calibration algorithm based on one camera calibration and one hand-eye calibration that were proposed to solve the camera parameters and hand-eye parameters separately. Their joint calibration is more convenient in practice application. Experimental data shows their algorithm is feasible and effective. **Caron et al (2011) [5]** paper extends the method of monocular perspective camera calibration using virtual visual servoing. The simultaneous intrinsic and extrinsic calibration of central cameras rig, using different models for each camera, is developed.

Y. Wang et al (2012) [6] proposed easy calibration method. In the calibration procedure, iterative optimization is adopted to reduce the influence of noise on the calibration results. They give the closed-form solution based on the projective properties of equidistant parallel lines as the initial guess for iterative optimization. The articles that deal with 3D reconstruction are: **N. Burrus, et al (2010) [7]** show how they can benefit to using a TOF (time of flight) camera for 3D object model acquisition, detection and pose estimation in the context of robotic manipulation. On the modeling side, they propose a volume carving algorithm capable of reconstructing rough 3D shape with a low processing cost. **J. Zhang, G. Chesi, and Y. S. Hung (2011) [8]** paper addressed the problem of estimating the 3D model of an object from a sequence of images where the object is visible from different point of views. In particular, they consider the case of turntable image sequences, the images captured under circular motion. Results with both synthetic and real data validate and illustrate the proposed method. **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 method that focuses on fitting the reference model of an object to the target data is presented. The results of 15 measurements of different length between both reconstructed and actual dummy limb are highly correlate. **M.Barrero et al (2013) [10]** the work proposes a novel probabilistic method to reconstruct a hand shape image from its template. They analyze the degree of similarity between the reconstructed images and the original samples in order to determine whether the synthetic hands are able to deceive hand recognition systems. This analysis is made through the estimation of the success chances of an attack carried out with the synthetic samples against an independent system. The experimental results show that there is a high chance of breaking a hand recognition system using this approach.

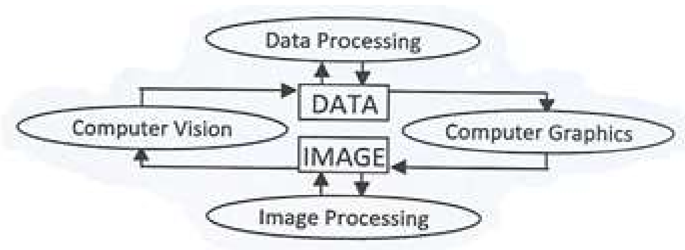

Figure (1) the relationships between image processing, computer vision and computer graphics [11]

Thresholding

Thresholding (T) is a commonly used enhancement whose goal is to segment an image into object and background [12]. A grayscale image is turned into a binary (black and white) image by first choosing a grey level T in the original image, and then turning every pixel black or white according to whether its grey value is greater than or less than T: [13] A pixel becomes White if its grey level is > T and Black if its grey level is ≤ T.

Threshold could be estimated experimentally or computed automatically from histogram by function level = graythresh (I). This function uses Otsu's method, which chooses the threshold to minimize the variance of the black and white pixels and finding threshold at the minimum between the histogram's peaks. Non-uniform lighting images are using variable thresholds in which the threshold value varies over the. Thresholds are determine independently in each sub image and is then processed with respect to its local threshold [14].

Experimental Work

The aims 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 its dimension.

Robot Used

This experimental is utilized the 5 DOF (degree of freedom) Lab-Volt R5150 Robot arm manipulator. The design coordinates Lab-Volt R5150 arm manipulator with respect to arm frame assignment and structure of robotics system identified in figure (2). This robot system exists in the automation lab in the department of Production Engineering and Metallurgy in the University of Technology.

Figure (2) 5 DOF Lab-Volt R5150 Robot manipulator systems

Camera Used

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 as shown in figure (3).

Figure (3) the digital camera used

System Configuration

The system of this experimental work consist 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 (4).

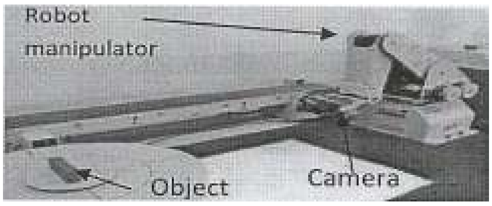

Figure (4) eye on hand robot system configuration

Camera Calibration

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. Table (1) lists the obtained measurements. On the other hand, Figures (5) and (6) graphs the results needed for acquiring the mathematical presentation of the equation that best fits the acquired results.

Table (1) Acquired conversion of units

Distance between camera and Object	Real Length of object in (mm) unit	Real width of object in (mm) unit	Length of object in (pixel) unit	width of object in (pixel) unit	Distance equivalent For length in(mm) Unit	Distance equivalent For width in(mm) Unit
100	100	30	3313	1143	146.6904	145.6642
110	100	30	2965	1025	112.9240	113.1985
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390	100	30	778	273	396.6899	396.7169
400	100	30	756	266	403.8920	403.3387

410	100	20	729	250	409.5166	410.0339

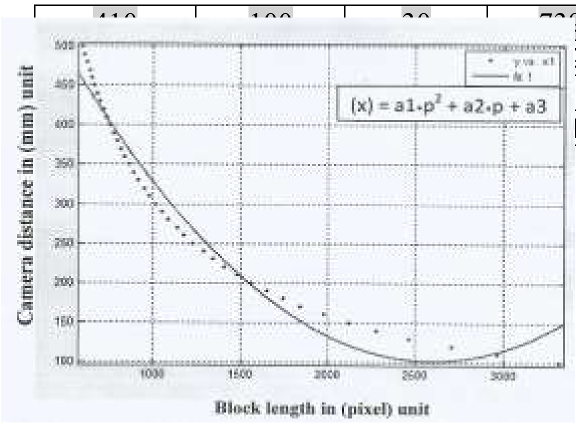


Figure (5) the relation of camera distances and lengths of block and their fitting curve

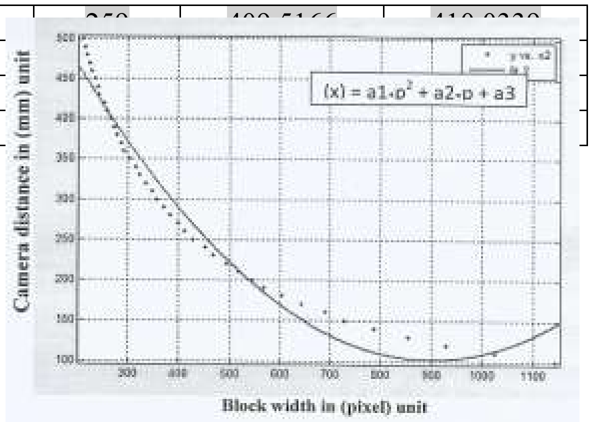


Figure (6) the relation of camera distances and widths of block and their fitting curve

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 , and 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 , and 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

E_W = real distance – distance required from No. of pixel in width

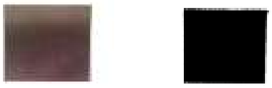
$E_W = 410 - 410.0339$

$= -0.0339$ mm

- Therfor the scale factor (S) = ――――――――
- The scale factor for length (S_L) = ――― = 7.39 (pixel/mm)
- The scale factor for width (S_W) = ――― = 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 (60*30 mm) and (40*30 mm) as shown in figure (7) and (8), those blocks putted at a distance with a camera (410mm) and



captured images for their by using scanning program computed a number of pixels in length and width for both objects.

Real Image Image after processing

Figure (7) standard block with dimension (40 * 30) mm

Real Image Image after processing

Figure (8) standard block with dimension (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. The table (2) lists all results for both objects, this magnitude of errors will added for each dimensions measured from image for length and width.

Table (2)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

After compute the values of dimensions for objects, the objects will be reconstructed by them pixels values. 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 (9), whitch take pictures in front view with respect to the objects, and in figure (10) , whitch take pictures in top view of it .

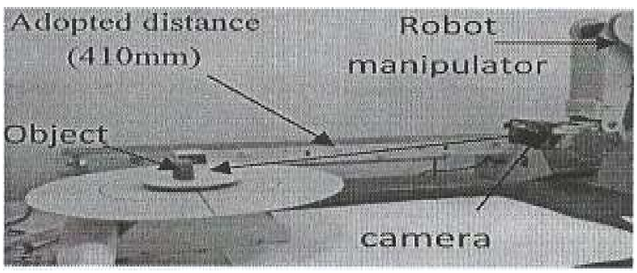


Figure (9) capturing front view picture

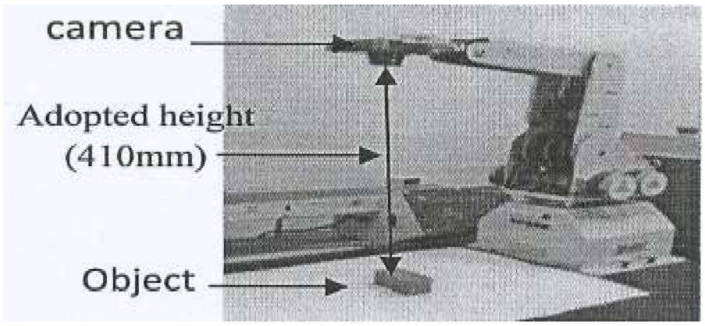


Figure (10) capturing top view picture

After computed the dimensions for every object, compure the results with real dimension witch get from using digital vernier with accuracy (0.01 mm) to measure dimensions for every object, and computed the error for every object as found in next tables.

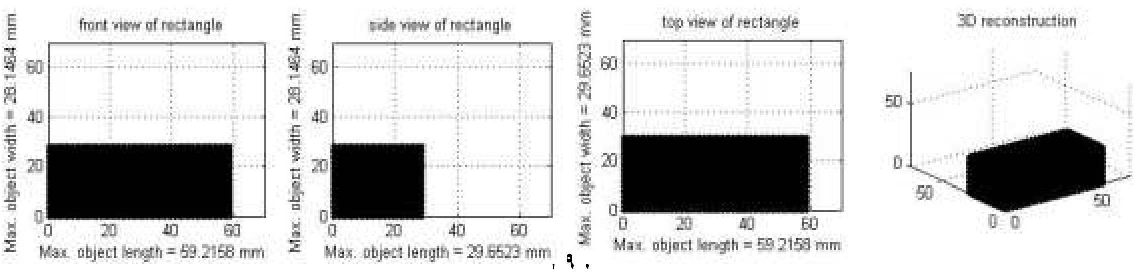
5.1 PARALLEL SHAPE OBJECT

A parallel shape, is measured by two measurement devices of, which makes one reading on each face, once by using a digital vernier and another by using a 3D digital probe. The real dimensions by a digital vernier are: (60.11, 27.86, 29.23)mm length, width and thickness respectivelly and by using a 3D digital probe they are: (60.105, 27.755, 29.15)mm length, width and thickness respectivelly. The object with parallel shape was captured at adopted distance (410)mm from two views, the first is front view and the second is the top view of it, as shown in Figure (11).

a **b**

Figure (11) Parallel shape object (a) Front view (b) Top view

The results of dimensions were converted from pixel unit to metric unit (mm) which helped on reconstruction the 3D reconstruction of parallel shape object with three projections to it as shown in figure (12).



a **b** **c** **d**

Figure (12) 3D reconstruction of parallel shape object with its dimensions and three projections.

Where: a : is front view of parallel shape, b : is side view of parallel shape, c : is top view of parallel shape. and d : is 3D reconstruction of parallel shape.

By compared a results of dimensions with a real dimensions of parallel object that measured by using a vernier and adigital probe, the magnitude of dimensions and errors explained in table (3). And comparesion the errors between scanning program with vernier and scanning program with a digital probe are explained in figure(13).

Table (3) comparing the results of parallel shape object

View	Front	Top
Length (mm) in vernier (V_l) reading	60.11	60.11
Width (mm) in vernier (V_w) reading	27.86	29.23
Length (mm) from scanning (L_s) program	59.2158	59.2158
Width (mm) from scanning (W_s) program	28.1464	29.6523
Length (mm) in digital probe (P_l) reading	٦٠.105	٦٠.105
Width (mm) in digital probe (P_w) reading	27.755	٢٩.15
Eroor in length with vernier (mm) $\lvert V_l-L_s \rvert$	٠.٨٩٤٢	٠.٨٩٤٢
Eroor in width with vernier (mm) $\lvert V_w-L_s \rvert$	0.2864	٠.٤٢٢٣
Eroor in length with digital probe (mm) $\lvert P_l-L_s \rvert$	0.8892	0.8892
Eroor in width with digital probe (mm) $\lvert P_w-L_s \rvert$	0.3914	0.5023

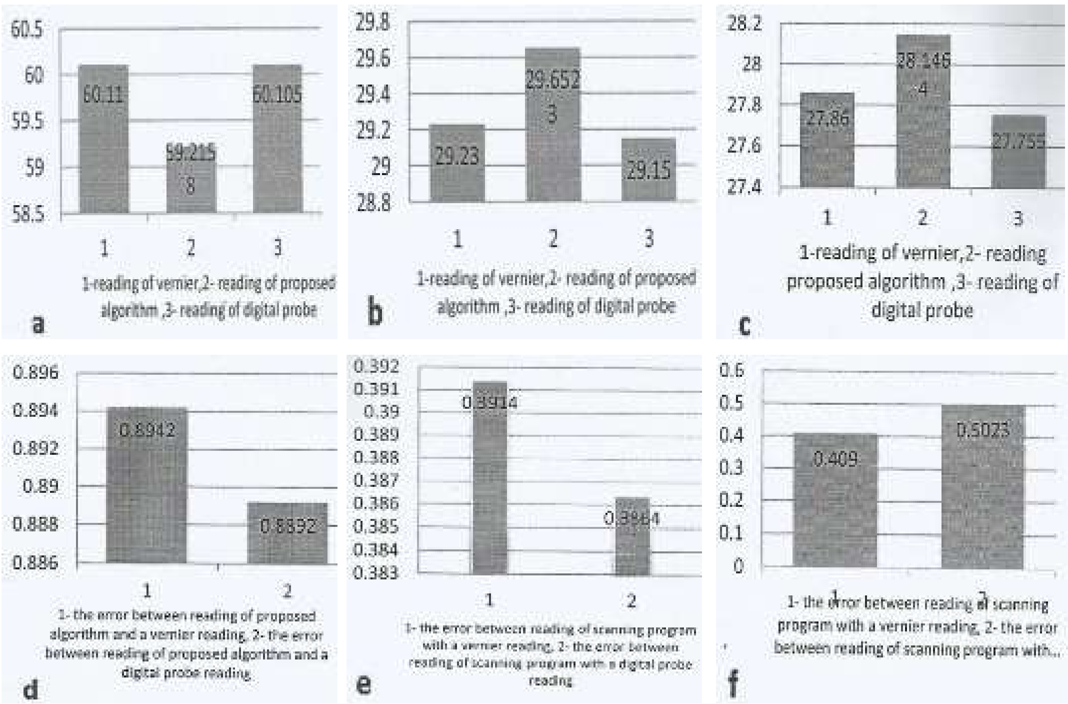


Figure (13) (a,b,c) comparison of digital vernier, scanning program and digital probe reading, (d,e,f) comparison the eroor of dimension for rectangular shape

3D Triangular Shape Object

A 3D triangular shape, the real dimensions by a digital vernier are: (42.59, 27.76, 22)mm base, height and thickness respectivelly and by using a 3D digital probe they are: (42.59, 27.775, 22.005)mm base, height and thickness respectivelly, figure (14).The gotten dimensions converted from pixel unit to metric unit (mm) which helped on reconstruction the 3D triangular shape object with three projections to it as shown in figure (14). By compared a results of dimensions with a real dimensions of 3D triangular object that measured by using a vernier, the magnitude of errors explained in table (4). And comparesion the errors between scanning program with vernier and scanning program with a digital probe are explained in figure (15).

c

a b

Figure (14) 3D triangular shape object (a) Front view (b) Top view

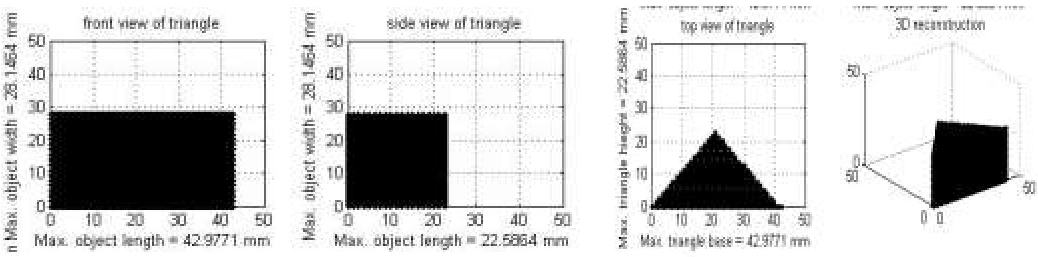
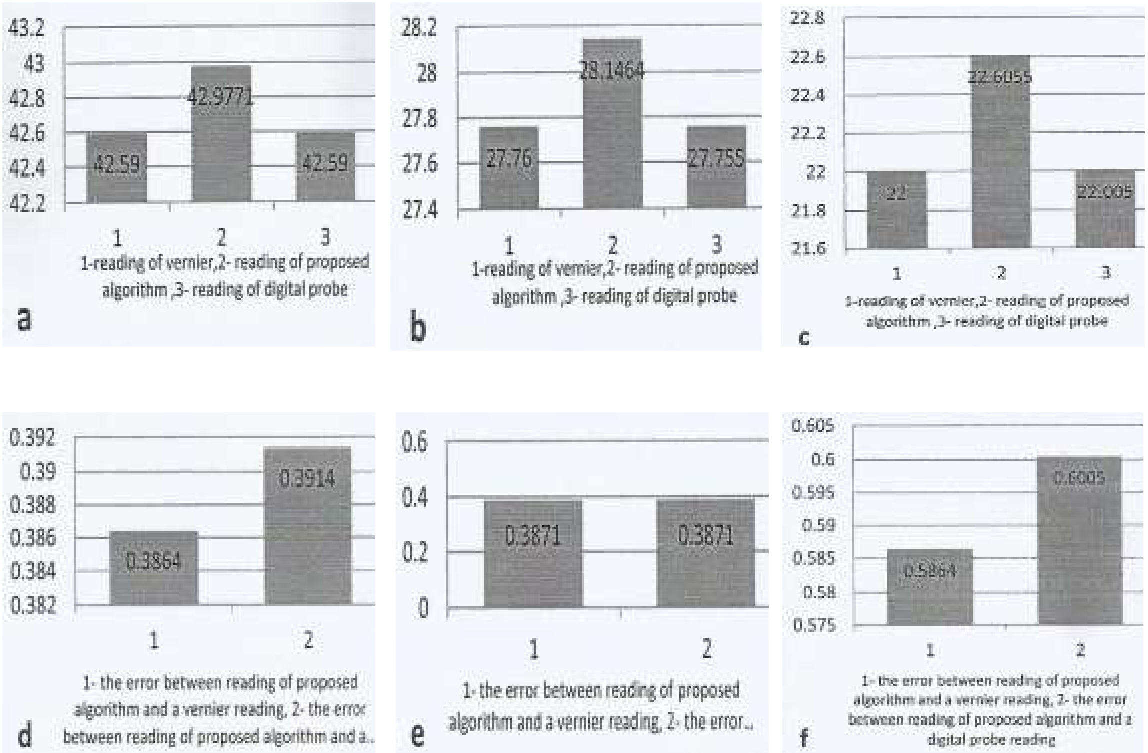


Figure (15) 3D reconstruction of 3D triangular shape with its dimensions and its projections

Table (4) Comparing the results of the triangular shape object

View	Front	Top
Length (mm) in vernier (V_l) reading	42.59	42.59
Width (mm) in vernier (V_w) reading	27.76	22
Length (mm) from scanning (L_s) program	42.9771	42.9771
Width (mm) from scanning (W_s) program	28.1464	22.6055
Length (mm) indigital probe (P_l) reading	42.59	42.59
Width (mm) in digital probe(P_w) reading	27.755	22.005
Eroor in length with vernier (mm) $\|V_l-L_s\|$	٠.٣٨٧١	0.3938
Eroor in width with vernier (mm) $\|V_w-L_s\|$	0.3864	0.5864
Eroor in length with digital probe (mm) $\|P_l-L_s\|$	0.3871	0.3871

Eroor in width with digital probe (mm) $\lvert P_w\text{-}L_s \rvert$	0.3914	0.6005



Figure(15) (a,b,c) comparison of digital vernier, scanning program and digital probe reading, (d,e,f) comparison the eroor of dimension for triangular shape

Cylidrica Shape Object

A Cylindrical Shape Object,is measured by two measurement devices of, which makes one reading on each face, once by using a digital vernier and another by using a 3D digital probe. The real dimensions by a digital vernier are: (29.25, 29.87)mm diameter and height respectivelly. And by using a 3D digital probe they are: (29.25, 29.875)mm diameter and height respectivelly. The object with cylindrical shape was captured at adopted distance (410)mm from two views, the first is front view and the second is the top view of it, as shown in Figure (16).

a b

Figure (16) cylindrical shape object (a) Front view (b) Top view

The gotten dimensions converted from pixel unit to metric unit (mm) which helped on reconstruction the 3D cylindrical shape object with three projections to it as shown in figure

(17). By compared a results of dimensions with a real dimensions of cylindrical object that measured by using a vernier, the magnitude of errors explained in table (5),Errors between scanning program with vernier and scanning program with a digital probe are explained in figure (18).

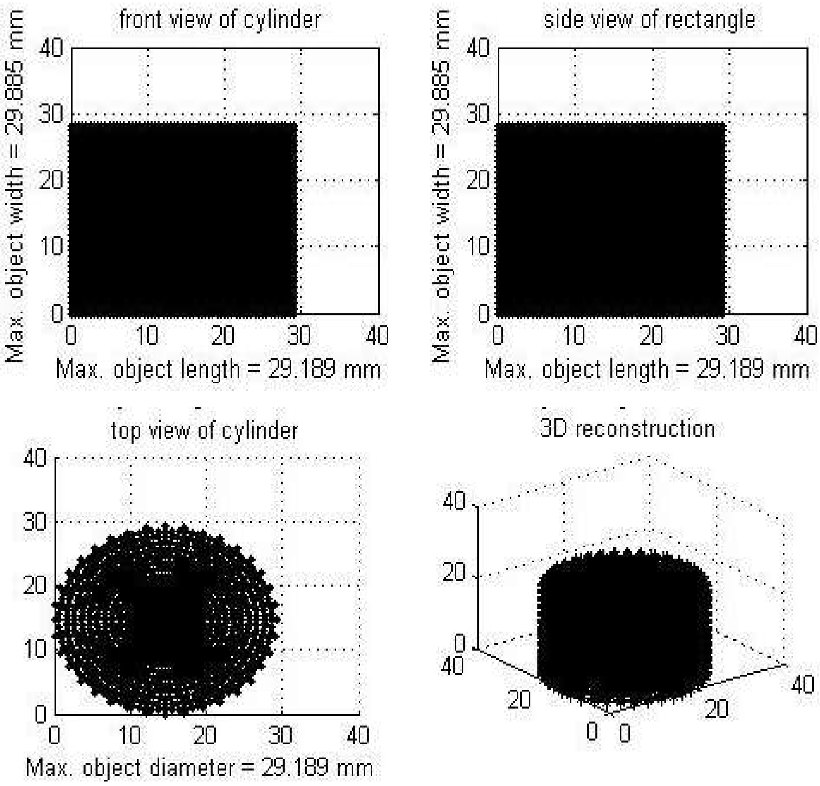
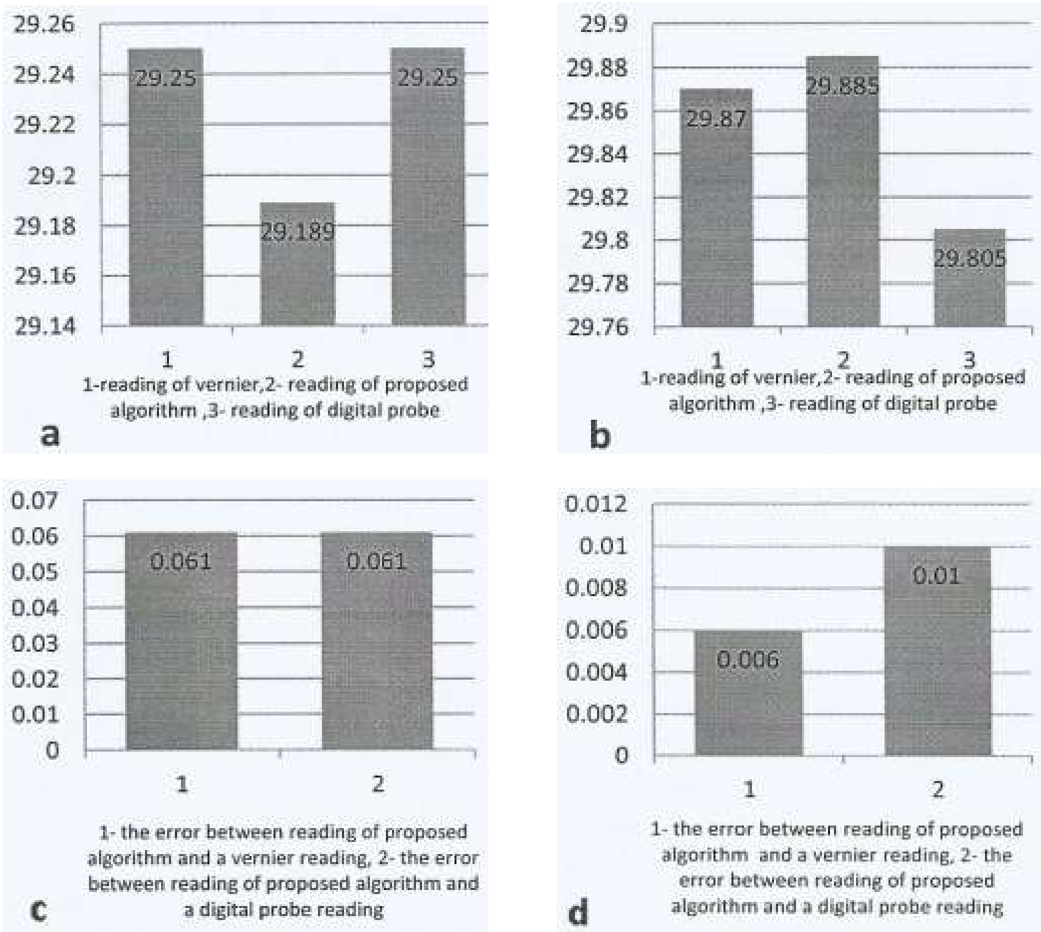


Figure (17) 3D Reconstruction of cylindrical shape with its dimensions and its projections.

Table (5) Comparing the results of cylindrical shape object

View	Front	Top
Length (mm) in vernier (V_l) reading	29.25	D_v = 29.25
Width (mm) in vernier (V_w) reading	29.87	D_v = 29.25
Length (mm) from scanning (L_s) program	29.189	29.189
Width (mm) from scanning (W_s) program	29.885	29.189
Length (mm) in digital probe (P_l) reading	٢٩.25	٢٩.25
Width (mm) in digital probe (P_w) reading	٢٩.875	٢٩.25
Eroor in length with vernier (mm) $\lvert V_l-L_s \rvert$	٠.٠٦١	٠.٠٦١
Eroor in width with vernier (mm) $\lvert V_w-L_s \rvert$	0.015	٠.٠٦١

Eroor in length with digital probe (mm) $\lvert P_l-L_s \rvert$	0.061	0.061
Eroor in width with digital probe (mm) $\lvert P_w-L_s \rvert$	0.01	0.061



Figure(18) (a,c) comparison of digital vernier, scanning program and digital probe reading, (b,d) comparison the eroor of dimension for cylindrical 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 this study, obtained results of experimental. The results 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 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 found from images contain different magnitude of error that belongs to fit the centre of lenses of camera with centre 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 belong to the density of image which depending on a step number of points in each row and column.

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