

# Object Dimension Inspection Utilizing 3D Laser Scanner

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## Abstract

In this paper, the processes of 3D LASER scanning and dimension inspection were simulated for certain dimensions object. The scanning operation is divided into two major modes, Searching Mode and Scanning Mode. In scanning mode two sub-processes (*scanned point validation* and *plane fitting*) are introduced, i.e. to find the plane which contains most of scanned points. The final step is the decision making, which gives a decision about acceptance or rejection of the scanned manufactured object. The proposed algorithm is successfully applied to seven cases. One of them which has the exact dimensions and this case has been accepted. The other six cases, which have different dimensions, have been rejected.

**Key words:** 3D laser scanning, dimension decision making

## Introduction:

The 3D laser scanner is a device that analyzes a real-world object or environment to collect data on its shape or appearance. The collected data are reused to construct digital data and 3D models which can be used in a variety of application such as industry, arts, environmental surveying, virtual reality, etc...[1].

The main elements of any 3D laser scanning operation are: 1) laser source, point or profile source, 2) a stepper motor to control the motion of the laser source, 3) The receiver or the detector that will collect the laser data, and finally 4) The body that will be scanned [2].

## Mathematical Representations:

The four main elements, which are mentioned above, may be functionally represented by mathematical models, where the scanned body can be represented by 3D planes and their parameters, the stepper motor is functionally represented by two scanning angles (elevation angle represented by  $\alpha$  and azimuth angle represented by  $\beta$ ). The function of the receiver which detects the points that belong to the body surface, is been replaced by point validation algorithm. The laser source simulated in this work is a point laser source. It is replaced by finding a point on the body surface

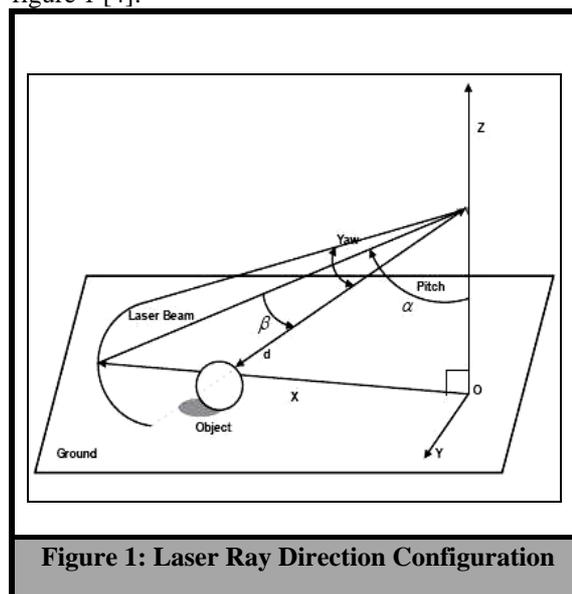
according to an original point represent the position of the laser source and the direction of the laser ray which is controlled by the stepper motor.

Any plane in 3D space has a specific equation that explains its behavior [3]:

$$Ax + By + Cz + D = 0 \quad | \quad 1$$

where  $x$ ,  $y$ , and  $z$  are the coordinates of any point on the plane and satisfy its equation, and  $A, B, C$ , and  $D$  are the plane parameters of the plane. The plane parameters are unique four constants for each plane that control the behavior of the plane in 3D space. The plane parameters could be found by solving a system of plane equations with 3 known points using co-factoring method.

The function of the stepper motor is "changing the direction of the laser ray to scan over all the scanner range". Its function can be simulated by two angles  $\alpha$  for the vertical scanning angle and  $\beta$  for the horizontal scanning angle as shown in figure 1 [4]:



**Figure 1: Laser Ray Direction Configuration**

The direction of the laser ray, according to the scanning angles  $\alpha$  and  $\beta$ , is represented by the following direction cosine vector matrix

$$\left. \begin{aligned} l &= \sin \alpha \cos \beta \\ m &= \sin \beta \\ n &= -\cos \alpha \cos \beta \end{aligned} \right\} 2$$

The laser source function is to illuminate the body so that its reflection could be recorded by the receiver. This function is replaced by finding a point on the body face in terms of an original point and specific direction. The point coordinates are calculated as [3]:

$$\left. \begin{aligned} x_2 &= x_1 + dl \\ y_2 &= y_1 + dm \\ z_2 &= z_1 + dn \end{aligned} \right\} 3$$

Where l,m,n are the direction cosine matrix elements and d is the distance from the original point to the plane in a specific direction. d was calculated using the following equation [3]:

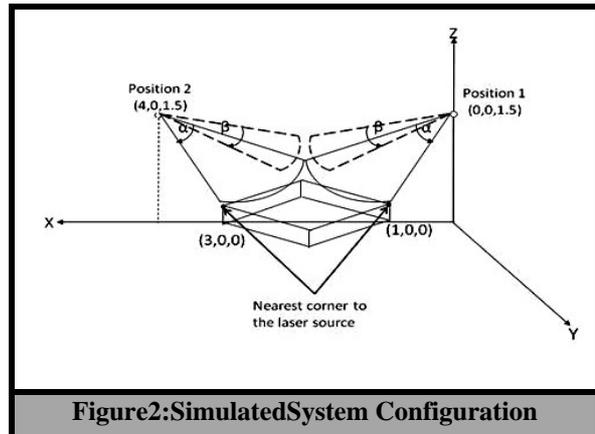
$$d = -\frac{(Ax_1 + By_1 + Cz_1 + D)}{A^2 + B^2 + C^2} \quad 4$$

Since the receiver function is to detect the reflected light from the scanned body by the scanned point validation algorithm. To validate a point with a specific face, the face is first divided into multiple small triangles, by connecting the point with the triangle vertices and calculating the sum of the angle formed by them. The sum of angles will be  $2\pi$  if and only if the point is in the face and lay on the same plane, any otherwise the sum will be less than  $2\pi$ .

The scanning operation is divided into two modes in order to decrease the computation time needed. The first mode is searching mode which detects the limits required to scan the body and omits the unwanted areas. The second mode is the scanning mode which scan the body as robust as possible this mode uses the limits found in searching mode as scanning limits.

The system configuration simulated in this work is shown in figure ( 2 ). The scan is accomplished from two angles of view. The system scanning limits are  $5^\circ$  to  $75^\circ$  for the elevation scanning and from  $-50^\circ$  to  $50^\circ$  for azimuth

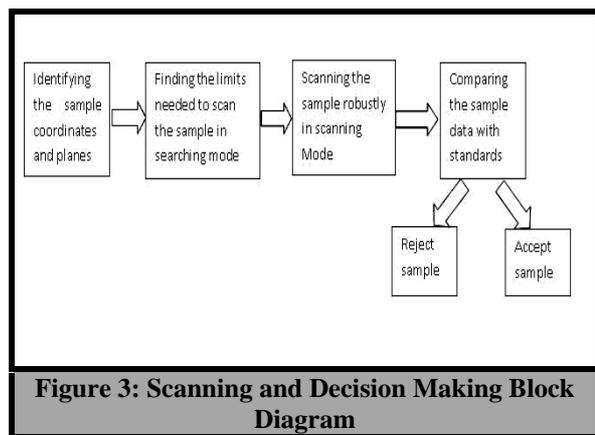
scanning. The standard object scanned is a parallelepiped with a rectangular base of  $\sqrt{2} \times \sqrt{2} \times 0.2$  units. Its diagonal is placed on the x-axis.



### Methodology:

The operation of 3D laser scanning is summarized by four steps:

- 1) Finding Model<sub>0</sub> (scanning the standard object and find the standard data).
- 2) Scanning the sample object.
- 3) Comparing the scanning data with standards which will result in accepting the sample or rejecting the sample.



### Scanning Model<sub>0</sub>:

Model<sub>0</sub> is the model with standard data that the scanned data compared with. So the resulted data will not pass the testing step. Scanning model<sub>0</sub> operation could be summarized by the following steps:

1. Scan the model from the first angle of view.
2. Scan the model from the opposite angle of view.
3. Calculating the standard dimensions

### Object testing:

The other steps of dimension control operation (scanning the sample body, and testing the body) are gathered in one program “ sample scanning program” where first it starts with defining the body faces and finding plane parameters. By performing searching mode the scanning limits to scan the body is found. The laser source is now set to the first position and scans the body by scanning mode from the first angle of view. To have a full view of the body, the laser source is now set to the opposite position to scan the body from the second angle of view. From the scan data of both angles of view the body dimensions are now found, and by these dimensions the sample is tested using the dimensions testing step which will accept the sample if and only if it was a rectangular box and its dimensions are coincident with standard dimensions, any other case the sample is rejected. Finally the scanning data is now gathered and the sample is visualized with the standard to show the difference and similarity.

The sample scanning is described in the figure (4).

Figure 4 contains several subroutines. The first subroutine is Searching Mode, which is used to find the scanned angle limits. Scanning limits are found only from one angle of view. The elevation scanning angle ( $\alpha$ ) limits are first determined, where it is initiated with the minimum  $\alpha$  of the system and fix  $\beta$  to zero. The direction cosine matrix, distance from the laser source to the upper face of the scanned body and finally the new point coordinates on the upper face are found for each  $\alpha$ , each point is validated with the upper face when the point first appear on the face its  $\alpha$  will be  $\alpha_{min}$  and when the point first disappear after that its  $\alpha$  will be  $\alpha_{max}$ . Using the same procedure,  $\beta$  limits are also found after setting  $\alpha$  to  $\alpha_{mid}$ , and proceeds through the same process. Searching mode subroutine is summarized in figure (5).

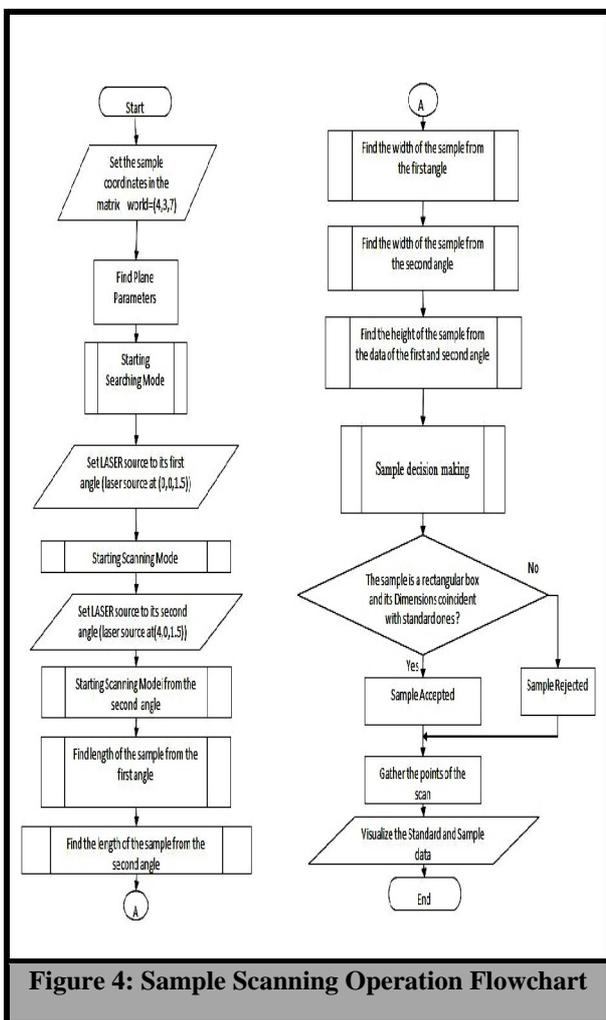
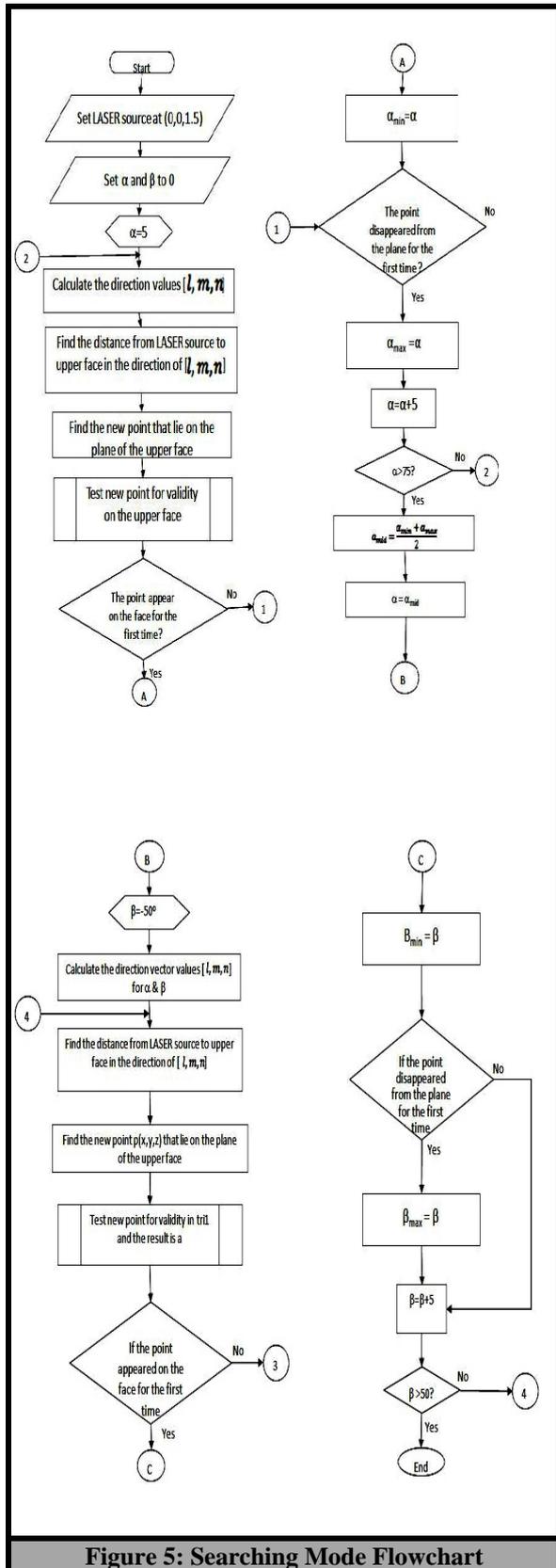


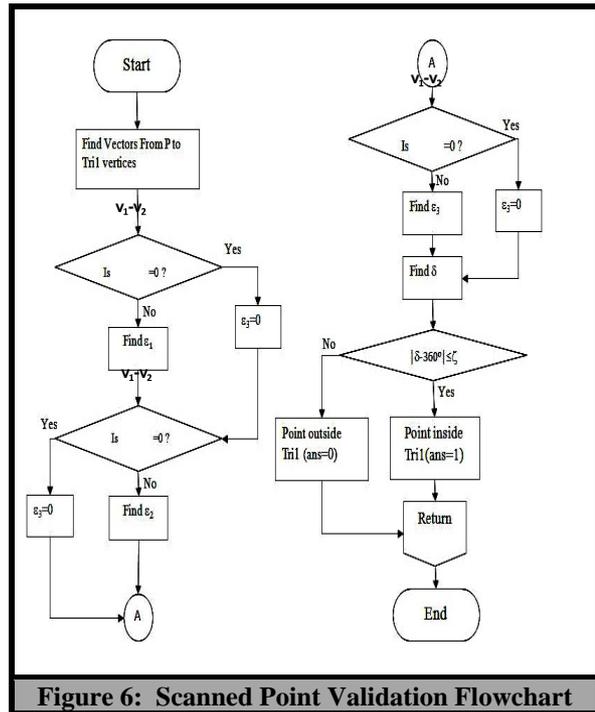
Figure 4: Sample Scanning Operation Flowchart



**Figure 5: Searching Mode Flowchart**

The second subroutine is Scanned Point Validation. To validate any point on the sample faces in both searching and scanning modes, scanned point validation algorithm is been used.

The first step to validate a point with a triangle, vectors is made from the point to triangle vertices. The angles between each sequenced vectors are found, and from their summation the point is decided to be inside the triangle if the summation is equal to  $360^\circ$  ( $2\pi$ ), otherwise the point is outside the triangle.



**Figure 6: Scanned Point Validation Flowchart**

The third subroutine is Scanning Mode. This mode scans the sample as accurate as possible all over the scanning range and its limits are the scanning limits found in Searching Mode. For each pair of angles the direction of laser ray is found. The distance from laser source to the face plane, and the laser ray-sample intersection points are found for all sample faces. The points resulted from above are all validated with all faces to find which one of them is the right intersection point, and it could be that none of them belongs to the sample. The intersection point is now updated to the final point, and all intersection points are gathered together. The intersection points are now classified to four groups according to where they lie-on the sample, these groups are right, left, curb, and ground planes. From the right, left, and curb planes the nearest corner to the laser source is found. The flowchart of scanning mode subroutine is shown in figure (7)

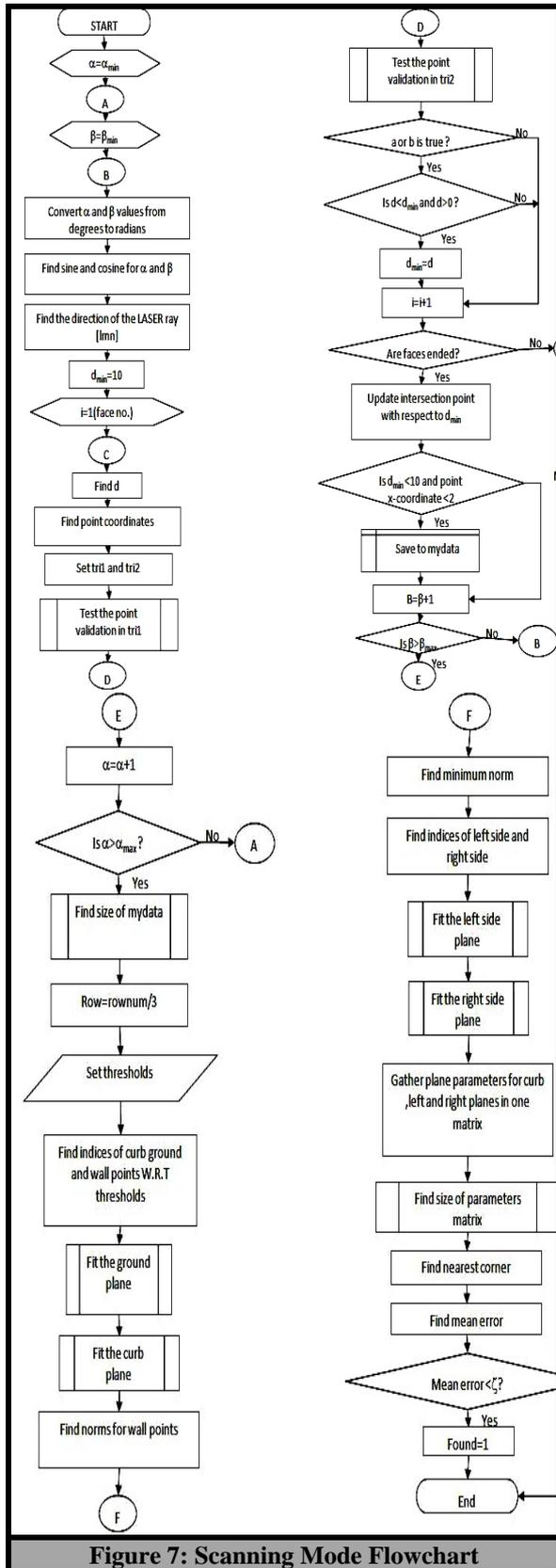


Figure 7: Scanning Mode Flowchart

The fourth subroutine is Plane Fitting. The four planes found in the scanning mode (right, left, curb and ground) planes are all fitted using “plane fitting subroutine”. The role of plane fitting is to find the best plane that contains most of the points that

belong to that group. As in finding plane parameters mentioned above, the plane parameters in plane fitting subroutine are found by solving the plane equation (eq.1) for all points that belong to group simultaneously using the singular value decomposition method [3].

The final subroutine of the process described in figure (4) is Decision Making. The sample is first tested for shape validity the difference between each parallel side of it to determine whether it’s a parallelepiped or not. If it’s not a rectangular box the sample is rejected directly, if the sample is a rectangular box the body is passed to the dimension testing by calculating the difference between these dimensions and standard dimensions if they exceed a specific limit the sample will be rejected if not the sample would be accepted.

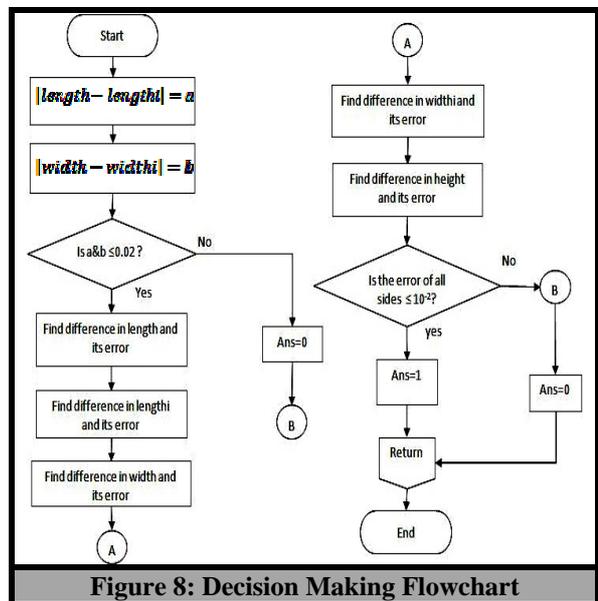
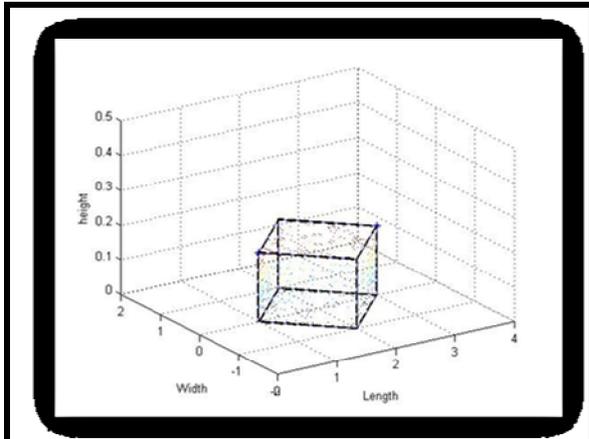


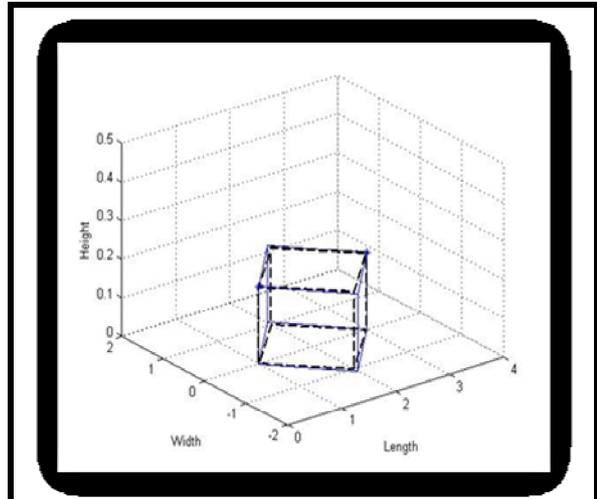
Figure 8: Decision Making Flowchart

### Case Study:

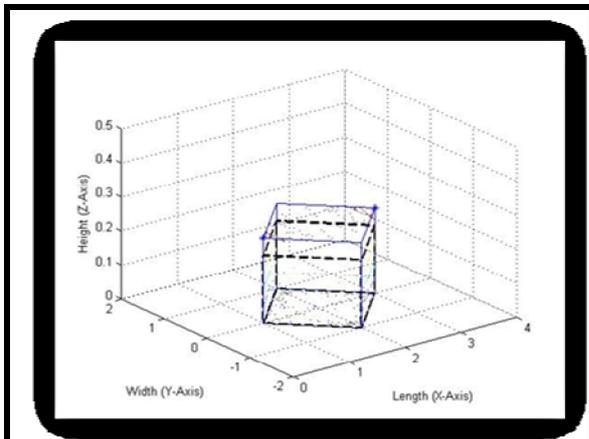
Seven cases are studied here one of an exact dimensions as the standard body and the other six cases differs from the standard by length, width and height one at a time. The simulated system accepts only the first case as shown in figure (9) (the case with exact dimension), and rejects the other six cases as shown in figures (10-12).



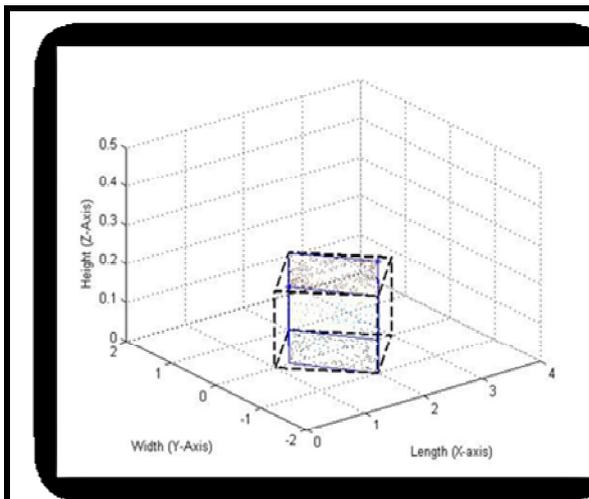
**Figure 9: Exact Dimension Sample Scanning Result**



**Figure 12: Sample with Larger Width**



**Figure 10: Sample with Bigger Height**



**Figure 11: Sample with Smaller Length**

The scanning system is tested for six different angle step sizes. The results of this test are summarized in table (1).

**Table 1: Test results for different angle step sizes**

	$\alpha$ step size (deg/step)	$\beta$ step size (deg/step)	Error (system accuracy)	Computation Time needed (sec.)
Case A	1	1	0.05 units	82
Case B	0.5	1	0.05 units	270
Case C	1	0.5	0.02 units	268
Case D	0.5	0.5	0.02 units	1102.18
Case E	1	0.25	0.01 units	610
Case F	0.25	0.25	Unavailable	More than 3 hours

The most interested cases are A,C, and E cases, where case A is the fastest operating case and case E is the most accurate case, while case C is faster than case E and more accurate than case A.

**Conclusions:**

From the obtained results it can be concluded that the real parts of the real system were functionally simulated using mathematical models successfully. The division of the scanning operation into searching mode and scanning mode decrease the computation time by decreasing the scanning range and omitting the unwanted areas. It was found that the system accuracy and computation time were both affected in an inverse relation with the scanning step size. From table (1) it was found that the most reliable scanning step size was 1°/step in the elevation scanning angle and 0.5°/step in the azimuth scanning angle.

## References

- [1] Online free encyclopedia. [http://en.wikipedia.org/wiki/3D\\_scanner](http://en.wikipedia.org/wiki/3D_scanner). last opened (27-June-2008)
- [2] Ayre, H., Stephens, R., and Mock, G. D. *Analytic Geometry: Two and Three Dimensions (Second Edition)*, D. Van Nostrand Company, Inc. Princeton, 332 pages. 1967.
- [3] Song, Z. *A 2D Laser Ray Tracing for the Simulation of Laser Perception*. Utah State University Technical report no.: USU-CSOIS-TR-04-11. <http://mechatronics.ece.usu.edu/reports/>. Pages 1-14. 2004.

## الخلاصة:

تم في هذا البحث محاكاة عمليات المسح الليزري بالأبعاد الثلاثية لجسم محدد الأبعاد. أن عملية المسح تتكون من طورين هما طور البحث و طور المسح وفي هذا الطور تتم عمليتين ثانويتين هما التحقق من النقطة الممسوحة ليزريا و عملية مطابقة المستوي ، أي إيجاد المستوي الذي يحتوي على أكبر عدد من النقاط الممسوحة. أما الخطوة الأخيرة فهي التحقق من أبعاد النموذج المنتج فإذا كان ضمن الأبعاد و الدقة المسموحة يتم قبول النموذج و بعكسه يتم رفضه. لقد تم التحقق من الخوازمية المقترحة بتطبيقها على سبع حالات من النماذج المنتجة أحدها كانت مطابقة لأبعاد الجسم القياسي حيث تم قبول هذا النموذج أما بقية الحالات كانت لنماذج مختلفة الأبعاد و قدم تم رفضها جميعا.

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