DESIGN AND MANUFACTURE A 5 DOFCOORDINATE MEASURING ARM

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ABSTRACT: *The 5 DOF coordinate measuring arm is an equipment used to determine the coordinate of points in 3D space at the tangent point of the probe and object. The calculating of the coordinate at the tip of the probe is based on forward kinematic equation of a 5 DOF robot arm, by defining the transpose of the 5 knuckles. Accordingly, we can calculate and measure some geometric elements, such as distance, angle...rebuild surface of object and store data in files. So that, the equipment can be applied in many fieldS: measuring, examining, molding, reverse engineering…*

Keywords: *Manufacture, 5 DOF coordinate, measuring arm.*

1.INTRODUCTION

Nowadays, to have products that can compete in domestic market as well as international market, the producing process must guarantee the accuracy, the models must be abundant and regularly changed, the cost of manufacturing, measuring and examining must be affordable. Accordingly, the need of an equipment that can measure accurately the coordinate of points in object’s surface is very essential. Beside using in measuring, examining the quality of products, the equipment can also simulate and regenerate the object and store data in CAD files. One of the earliest technologies is coordinate measuring technique, applied in coordinate measuring machines.

Measuring arm is applied in many fields, such as automobile industry, product development, medical biology, archeology, reverse engineering…

2.THEORY

This measuring arm has the mechanism of a robot arm because this structure can satisfy the requirement of flexibility.The structure includes 5 knuckles allows us to use synchronous sensor in every knuckle, as everyone corresponds with a degree of freedom. The arrangement of the 5 knuckles makes the working process more easy.

Figure 1. Coordinate measuring arm

Angular transposing signal is read from sensors and stored in computer memory. When the probe contact the object, the datas are calculated to determine the coordinates of points in Cartesian coordinate system and then will be displayed in computer monitor. The theory diagram is in figure 2.

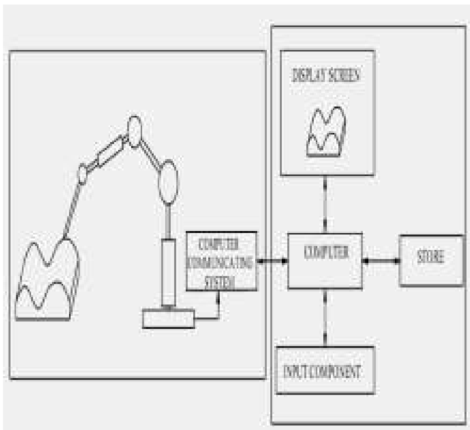


Figure 2. Theory diagram

Forward kinematic calculation:The dynamic diagram of the measuring arm is demonstrated in figure 3.

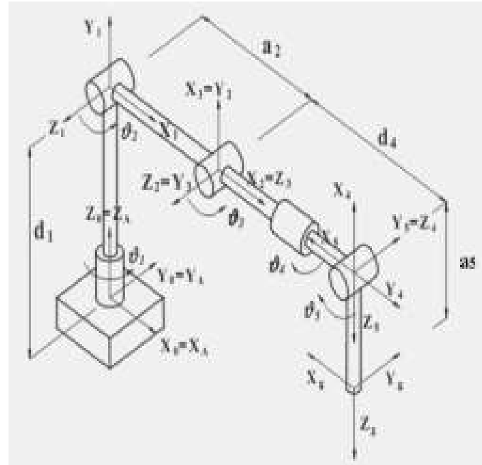


Figure 3. Dynamic diagram of measuring arm

a_i: distance along x_i from O_i to the intersection of the x_i and z_{i-1} axes.

d_i: distance along z_{i-1} from o_{i-1} to the intersection of the x_i and z_{i-1} axes.

α_i: the angle between z_{i-1} and z_i measured about x_i

ϑ_i: the angle between x_{i-1} and x_i measured about z_{i-1}.

The dynamic diagram contains coordinate systems placed at each knuckles, according to Denavit – Hartenberg convention.

Table 1. Denavit – Hartenberg parameters

Link	α	ϑ	a	d
1	$\frac{\pi}{2}$	ϑ_1	0	0
2	0	ϑ_2	a_2	0
3	$\frac{\pi}{2}$	ϑ_3	0	0
4	$-\frac{\pi}{2}$	ϑ_4	0	d_4
5	0	ϑ_5	a_5	0

The homogeneous transformation matrices

$$A_i^{i-1} = \begin{bmatrix} c_{\theta i} & -s_{\theta i}c_{\alpha i} & s_{\theta i}s_{\alpha i} & a_i c_{\theta i} \\ s_{\theta i} & c_{\theta i}c_{\alpha i} & -c_{\theta i}s_{\alpha i} & a_i s_{\theta i} \\ 0 & s_{\alpha i} & c_{\alpha i} & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$A_1^0 = \begin{bmatrix} c_1 & 0 & s_1 & 0 \\ s_1 & 0 & -c_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$A_2^1 = \begin{bmatrix} c_2 & -s_2 & 0 & a_2 c_2 \\ s_2 & c_2 & 0 & a_2 s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$$A_3^2 = \begin{bmatrix} c_3 & 0 & s_3 & 0 \\ s_3 & 0 & -c_3 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$$A_4^3 = \begin{bmatrix} c_4 & 0 & -s_4 & 0 \\ s_4 & 0 & c_4 & 0 \\ 0 & -1 & 0 & d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

$$A_5^4 = \begin{bmatrix} c_5 & 0 & s_5 & a_5 c_5 \\ s_5 & 0 & -c_5 & a_5 s_5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

Homogeneous matrix

$$A_5^0 = A_1^0 A_2^1 A_3^2 A_4^3 A_5^4 \quad (7)$$

$$A_5^0 = \begin{bmatrix} n^0(q) & s^0(q) & a^0(q) & p^0(q) \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (8)$$

q:angular transpositionvector

-p:positionvector

-n, s, a: basic unit vectors

coordinate at the tip of the probe can be determined:

$X=((c_1c_2c_3-c_1s_2s_3)c_4+s_1s_4)a_5c_5-(c_1c_2s_3+c_1s_2c_3)a_5s_5+(c_1c_2s_3+c_1s_2c_3)d_4+c_1a_2c_2$ (9)

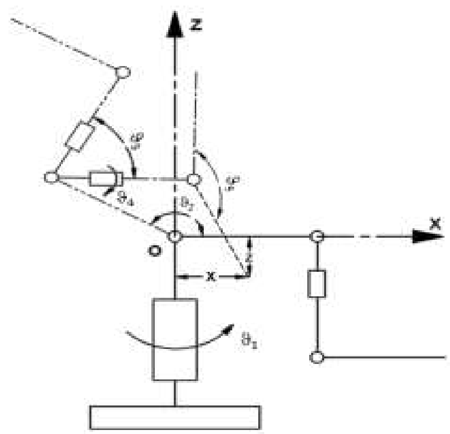
$Y=((s_1c_2c_3-s_1s_2s_3)c_4-c_1s_4)a_5c_5-(s_1c_2s_3+s_1s_2c_3)a_5s_5+(s_1c_2s_3+s_1s_2c_3)d_4+s_1a_2c_2$ (10)

$Z=(s_2c_3+c_2s_3)c_4a_5c_5+(c_2c_3-s_2s_3)a_5s_5+(s_2s_3-c_2c_3)d_4+a_2s_2$ (11)

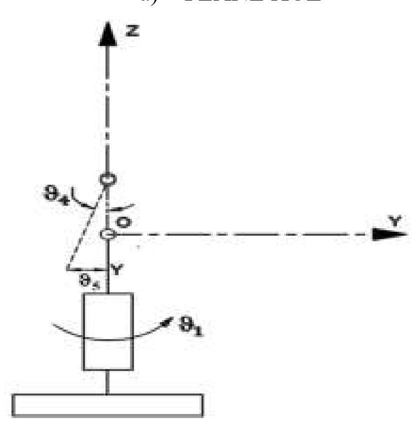
3. ADJUSTING REFERENCE COORDINATE

Calibration point is set up as reference point. The positions of these points fix the links 2, 3, 4 and 5.

At link 1, we move the coordinate long z axis, place the origin at the second knuckle. So that, if the value of link 1 change, it will effect the arm coordinate.



a) PLANE XOZ



b) PLANE YOZ

Figure 4. Angular displacement of knuckles

Calibration point is determined by measuring X_r , Y_r , Z_r . The angular transposition of knuckles are very hard to be determined exactly, because they have errors from the resolution of sensors. We preliminarily measure the angles and then transfer them to loop programs, and they approximate to $\pm$ 5 degree (the incremental step of sensors is 5). 4 loop programs are used to scan all the values in the gap of 4 angular transposing sensors.

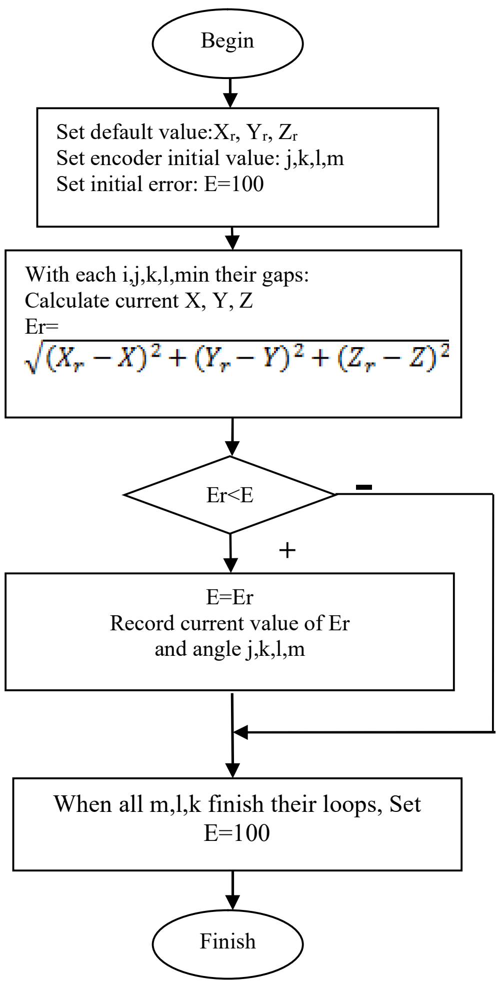


Figure 5. Algorithm diagram using loop program to determine exact values of transposing angles

For each values of sensor i, the value of angle ϑ_i is:

$$\vartheta_i = i * 2\pi / 8192 \qquad (12)$$

as 8192 is the resolution of sensors

Error between last point and calibration point will be

$$Er=\sqrt{(X_r-X)^2+(Y_r-Y)^2+(Z_r-Z)^2} \qquad (13)$$

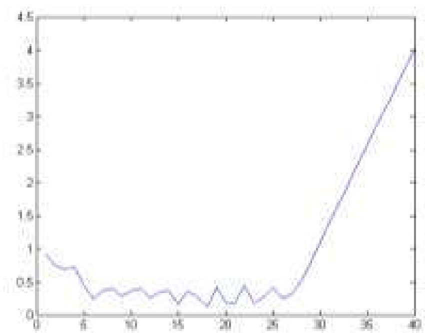


Figure 6. Error at loop positions

4.EXPERIMENT

Experimental measuring with 100mm gauge block (Mitutoyo516-996-10).

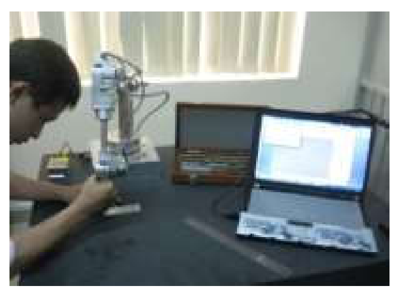


Figure 7. Measure Mitutoyo gauge block

Angular transposition values are selected at the minimum points (figure 6). Measure the gauge block at many different angles and directions,the results are given in table 2

$\bar{X}$andσ are figured with the 3σformulars:

$$X = \bar{X} \pm 3\sigma \qquad (14)$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}} \qquad (15)$$

Table 2. Angles (encoder values) and related errors

No	ϑ_{02}	ϑ_{03}	ϑ_{04}	ϑ_{05}	$\bar{X}$	σ
1	3330	-1210	-130	-3730	100.47	0.52
2	3345	-1195	-115	-3715	100.34	0.36
3	3360	-1180	-100	-3700	100.33	0.21
4	**3375**	**-1165**	**-85**	**-3685**	**100.23**	**0.23**
5	3390	-1150	-60	-3670	100.42	0.24
6	3405	-1135	-45	-3655	100.57	0.46
7	3415	-1125	-35	-3645	100.63	0.43
8	3425	-1105	-15	-3625	100.76	0.51

where ϑ_{0i} is the encoder value for angle ϑ_i

5.APPLICATIONS AND RESULTS

5.1.Application in scanning complex surface

Use the Measuring arm to get the coordinates and transfer to dedicated softwares to be rendered with complex surfaces.

Figure 8. Surface needs to be net-covered

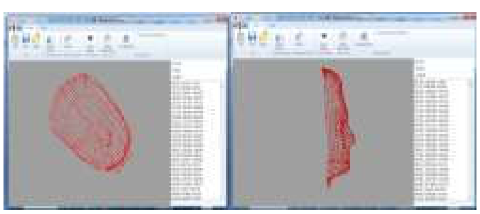


Figure 9. Result screen of the equipment

Transfer the measured coordinates to dedicated CAD softwares (in this report we used Pro-Engineer)

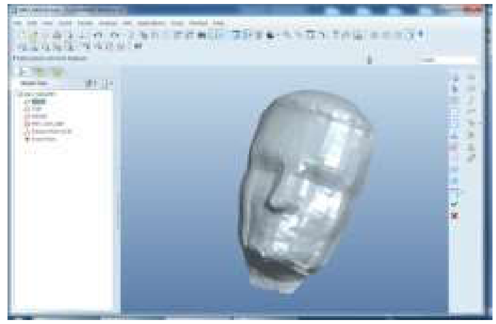


Figure 10. Net surface

5.2.Application in measuring distance

We can use the measuring arm to measure the dimensions of objects. We carried out measuring the dimension (height) of a mechanical part and compared the result with a dedicated height measuring equipment

Figure 11. Height measuring with coordinate measuring arm and result **(54,76 mm)**

Compared with Mitutoyo heightgage

Figure 12. Height measuring with Mitutoyo heightgage and result **(54,74 mm)**

5.3Application in measuring angle

We carried out the experimental process with a mechanical part with angles measured by VIVID 910D laser scanner - accuracy 0,08 mm

(a) (b)

Figure 13. Measuring Angle by VIVID 910D laser scanner

a)Angle between vertical plane and beveled plane **(42,2589 ^{0})**

b)Angle between horizon plane and beveled plane **(47,6458 ^{0})**

Measuring by Coordinate measuring arm

Figure 14. Measuring angle

Angle (a) (**42,1648^{0}**)

Angle (b) (**47,5431^{0}**)

6.CONCLUSION

We have successfully designed and manufactured a contacting method coordinate measuring equipment with working range 1270 mm, has ability to measure whole object which has dimensions 200x200x200 mm. The accuracy of this equipment is 0,5 mm. This coordinate measuring machine can alter the import equipment and overcome the weak points of them by these features:

- Determine coordinates of points
- Measure distance
- Measure angle between two planes
- Store data and directly link to other softwares : EXCEL, SolidWorks, Pro/ENGINEER, Mastercam,…
- Display coordinates of points on computer monitor, allow user to zoom in, zoom out, rotate, move object.

This small and mobile coordinate measuring arm can be applied in reverse engineering, molding, examine complex surfaces…

THIẾT KẾ CHẾ TẠO TAY ĐO TẠO ĐỘ 05 BẬC TỰ DO

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TÓM TẮT: *Tay đo tọa độ 05 bậc tự do là thiết bị dùng để xác định tọa độ điểm trong không gian 3D tại vị trí tiếp xúc của đầu dò và vật thể. Tọa độ tại đầu dò của thiết bị được tính toán dựa trên phương trình động học thuận của một cánh tay robot 05 bậc tự do, thông qua việc xác định chuyển vị của 05 khớp bản lề. Từ đó, ta có thể tính toán và đo các đại lượng hình học như: khoảng cách, góc,..dựng lại hình dáng bề mặt vật thể và có thể lưu trữ dữ liệu dưới dạng tập tin. Vì vậy, thiết bị có thể ứng dụng trong nhiều lĩnh vực như: đo lường, kiểm tra, khuôn mẫu, thiết kế ngược,…*

Từ khóa: *tay đo tạo độ 05, bậc tự do.*

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