

Research on measurement regions for Articulated Arm Coordinate Measuring Machines based on DBSCAN

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Abstract. The measurement accuracy of the articulated coordinate measuring machine (AACMM) is different in different sub measurement regions. In order to improve accuracy, The method for dividing and merging of sub measurement region based on Density-Based Spatial Clustering of Applications with Noise (DBSCAN) is presented. The whole measurement regions were divided into some sub regions which had equal volume. Sample data which had contiguous measurement error and contiguous position had been clustered by DBSCAN. The high and low precision regions were merged into many sub regions based on the result of cluster. The experiment showed that the measurement accuracy was greatly influenced by the measurement regions, and precision could be improved by measuring in high precision regions.

1. Introduction

Compared with the coordinate measuring machine (CMM), because AACMM have some merits of simple operation, large measurement region, convenient carrying, so it is widely used in the field of automobile manufacturing, quality control, parts assembly, reverse engineering and other fields[1]. Also, because of the many factors such as the structure of AACMM and the accumulation of structural errors, The measurement error is affected by the measurement regions[2]. In order to improve the accuracy of the measuring machine, a lot of researches have been done on the measurement regions. The optimal measurement region of double joint coordinate measuring machine had been found by German scholar Lotze Werner, in his thesis, the optimal measurement region had been used in actual measurement environments[3]. Through the analysis of the principle of the AACMM, a conclusion that the AACMM has a optimal measurement region had been obtained by Ai Zhu-jun [4]. In his thesis, he also predict the application prospect of optimal measurement region. Zheng Dateng had researched error characteristics of whole measurement region by functional analysis, and found that error distribution was similar nuts, the shell of nut had low accuracy, core of nut had high precision [5]. However, the error of ACCMM is complex in whole measurement, the efficiently method for measuring regions division have not been founded. In this thesis, high precision region and low precision region been obtained by the method which based on DBSCAN. It is significant for accuracy evaluation, measurement plan, error compensation and so on.

2. Mathematical mode of AACMM

The model of the AACMM is based on the D-H model proposed by Denavit[6]. In Fig.1, $\{O_0, X_0, Y_0, Z_0\}$ is defined by base coordinate system, and $\{O_{tp}, X_{tp}, Y_{tp}, Z_{tp}\}$ as probe coordinate system, $\{O_i, X_i, Y_i, Z_i\}$ ($i=1\sim6$) as the i joint coordinate system. Arm length d_i is the distance between the

neighboring X axis, joint length is the distance between the neighboring Z axis, twist angle α_i is angle between adjacent Z axis, joint angle θ_i is angle between adjacent Z axis. The transformation matrix from $\{O_{i-1}, X_{i-1}, Y_{i-1}, Z_{i-1}\}$ to $\{O_i, X_i, Y_i, Z_i\}$ ($i=1\sim 6$):

$$T_{i-1, i} = \begin{bmatrix} \cos \theta_i & -\sin \theta_i \cos \alpha_i & \sin \theta_i \cos \alpha_i & a_i \cos \theta_i \\ \sin \theta_i & \cos \theta_i \cos \alpha_i & -\cos \theta_i \sin \alpha_i & a_i \sin \theta_i \\ 0 & \sin \alpha_i & \cos \alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

If the homogeneous coordinate is $L=[l_x, l_y, l_z, 1]^T$ in the sixth joint coordinate $\{O_6, X_6, Y_6, Z_6\}$, in the base coordinate system $\{O_0, X_0, Y_0, Z_0\}$, the probe coordinate $P_0=[x, y, z, 1]^T$:

$$P_0 = \left(\prod_{i=1}^6 T_{i-1, i} \right) L \quad (2)$$

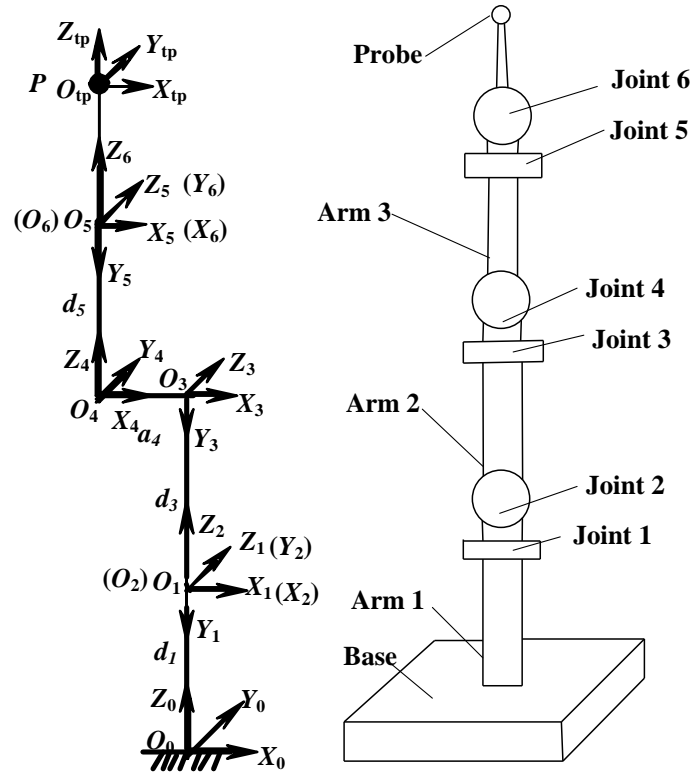


Fig.1 The structure of articulated coordinate measuring machine

The structure parameter of the AACMM is $\xi_{str} = \{l_1, l_2, l_3, d_i, a_i, a_i\}, i=1\sim 6$, and its extra parameter is $\xi_{ex} = \{\theta_i\}, i=1\sim 6$. Structure parameter error is the main factor to cause the measurement error. It produce in the process of part manufacture, part installment. Besides, it affected by thermal deformation. So error of AACMM can be summarized as follows:

$$\delta = \left| \frac{\partial p_0}{\partial \xi_{str}} \right| \Delta \xi_{str} + \left| \frac{\partial p_0}{\partial \xi_{ex}} \right| \Delta \xi_{ex} = \sum_{m=1}^3 \left| \frac{\partial p_0}{\partial l_m} \right| \Delta l_m + \sum_{i=1}^6 \left(\left| \frac{\partial p_0}{\partial a_i} \right| \Delta a_i + \left| \frac{\partial p_0}{\partial a_i} \right| \Delta a_i + \left| \frac{\partial p_0}{\partial d_i} \right| \Delta d_i + \left| \frac{\partial p_0}{\partial \theta_i} \right| \Delta \theta_i \right) \quad (3)$$

3. Division and combination of sub measurement regions

In the measurement process, the measurement region is defined as the maximum range of the probe. It is a even ball region[7]. Structural parameters as table 1[8].The center coordinates is(0,0,337) ,and radius is 1200mm, the ball region:

$$x^2 + y^2 + (z - 337)^2 \leq 1200^2 \quad (4)$$

In fact, the inner cube of the ball region is considered as actual measurement region. In X,Y,Z direction, nodes are took every step, cubes consist of four nodes which are regarded as sub measuring region. Mean error μ_δ and variance S_δ^2 as evaluation index of sub measuring region. According to the error characteristic of AACMM, the step size was selected 50mm.

Table.1 structure parameters of articulated coordinate measuring machine

i	1	2	3	4	5	6
d_i/mm	33 9	0	54 2	0	52 2	0
a_i/mm	0	0	0	0	0	0
$\alpha_i/^\circ$	-90	9 0	-90	9 0	-90	90
l_i/mm	0	0	14 0			

It shows in Fig.2 that high accuracy measurement region and low precision measurement region are combined by sub measuring region. The components of four dimensions consist of probe coordinates and measurement error in measurement region. The number i sample can be expressed as $(x_i, y_i, z_i, \delta_i)$.

DBSCAN is a base algorithm for density based clustering. It can find out the clusters of different shapes and sizes from a large amount of data, which is containing noise and outliers[9-11]. As a kind of density-based clustering, the neighborhood of a given radius (Eps) has to contain at least a minimum number (MinPts) of objects. Some basic concepts related with DBSCAN are as follow:

Definition 1 The Eps-neighborhood of a point p, denoted by NEps(p), is defined by $\text{NEps}(p) = \{q \in D \mid \text{dist}(p, q) \leq \text{Eps}\}$.

Definition 2 An object p is directly density-reachable from an object q wrt. Eps and MinPts in the set of objects D if

- (1) $p \in \text{NEps}(q)$ (NEps(q) is the Eps-neighborhood of q),
- (2) $|\text{NEps}(q)| \geq \text{MinPts}$ (Core point condition).

Definition 3 An object is core object if it satisfies condition (2) of Definition 2, and a border object is such an object that is not a core object itself but is density-reachable form another core object.

Definition 4 A point p is density reachable form a point q wrt. Eps and MinPts if there is a chain of points $p_1, \dots, p_n, p_1=q, p_n=p$ such that p_{i+1} is directly density-reachable from p_i .

Definition 5 An object p is density-connected to an object q wrt. Eps and MinPts in the set of objects D if there is an object $o \in D$ such that both p and q are density-reachable from o wrt. Eps and MinPts in D.

Definition 6 Let D be a database of points. A cluster C. Eps and MinPts is a non-empty subset of D satisfying the following conditions:

- (1) $\forall p, q: \text{if } p \in C \text{ and } q \text{ is density-reachable from } p \text{ wrt. Eps and MinPts, then } q \in C.$
- (2) $\forall p, q \in C: p \text{ is density-connected to } q \text{ wrt. Eps and MinPts.}$

Definition 7 Let C_1, \dots, C_k be the clusters of the database D wrt. parameters Eps_i and MinPts_i, $i = 1, \dots, k$. Then the noise is the set of points in the database D not belonging to any cluster C_i , i.e. noise = $\{p \in D \mid \forall i : p \notin C_i\}$ [12].

In this thesis, the samples are divided into cluster A and cluster B by DBSCAN, and error of the cluster A is smaller than the cluster B. In order to get better results, edge of the clusters need to be managed. Because the shape of the cluster is irregular, sub measurement region can be discarded, if the number of its samples are too small.



Fig.2 Flow chart of combine

4. Experimental studies

Structural parameters of AACMM are shown in Table.1. The measuring region G was used in verification experiment. Both its values of x coordinates and y coordinates were range from 400mm to 800mm, its values of z coordinates range from 0mm to 400mm. 20000 samples were generated by MATLAB, their parameter deviations were shown in Table.2[8]. Because the deviation of length parameter d_1 was not affected, its value was zero[13].

Table.2 Parameter deviations of AACMM

i	$\Delta d_i / \text{mm}$	$\Delta a_i / \text{mm}$	$\Delta \alpha_i / ^\circ$	$\Delta \theta_i / ^\circ$	$\Delta l_i / \text{mm}$
1	0.0000	0.0060	0.0028	0.0000	-0.0060
2	0.0060	-0.0060	0.0028	-0.0014	0.0060
3	-0.0440	0.0060	-0.0028	0.0028	-0.0250
4	0.0060	-0.0060	0.0028	-0.0028	
5	-0.0440	0.0060	0.0028	-0.0028	
6	0.0060	0.0060	-0.0028	0.0028	

Samples were divided into 5 groups :A,B,C,D,E. Group A was used to get high error measurement region and low error measurement region. Results of it was shown in Fig.3. Others groups were used to test it. From Table.3 we could find obviously difference of measurement accuracy in different measurement regions.

Table.3 Results of test experiment

Group	Error	High precision measurement region	Low precision measurement region	region G
B	mean(mm)	0.0681	0.0840	0.0771
	variance(10^{-4} mm)	5.8580	7.0531	6.8774
C	mean (mm)	0.0682	0.0837	0.0771
	variance(10^{-4} mm)	5.9205	7.1106	6.8916
D	mean (mm)	0.0675	0.0839	0.0771
	variance(10^{-4} mm)	5.9864	7.1045	6.6946
E	mean (mm)	0.0660	0.0846	0.0771
	variance(10^{-4} mm)	5.9864	7.2835	7.0400

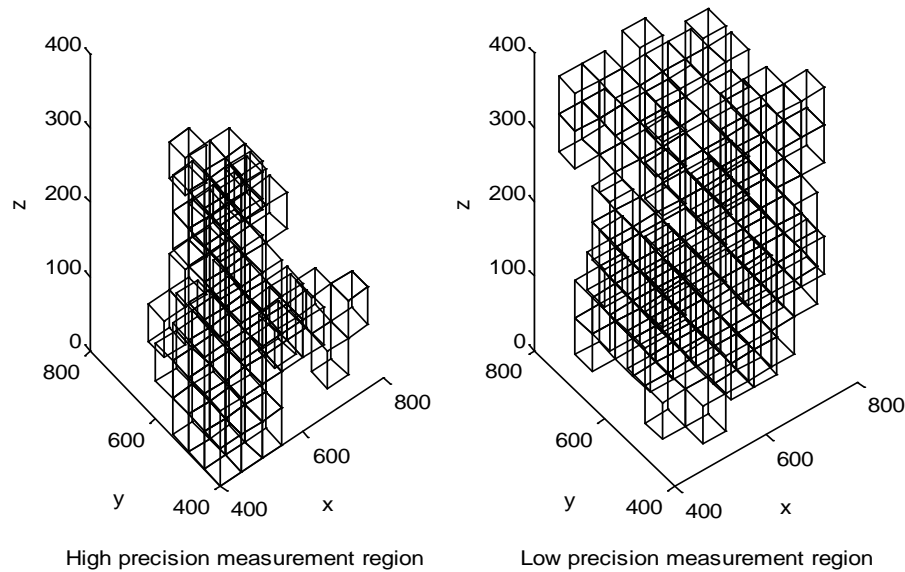


Fig.3 Results of combine

5. Summary

The experimental results show that the error of AAMCC has certain regularity in different measurement regions. Both high precision measurement region and low precision measurement region can be obtained by DBSCAN. This thesis can lay the foundation for further research on the measurement region of AACMM, as well as improve accuracy of AACMM.

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