Optimized Path Planning For Dimensional Inspection on Coordinate Measuring Machine (Cmm)

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Abstract

Coordinate measuring machine (CMM) has been an important inspection tool, designed to move a measuring probe to determine coordinates of points on a work piece surface. Probe measures different points by mapping the x,y,z coordinates of features as per the sequence selected. Effectiveness of inspection plan obtained depends on measurement cycle time. Therefore determination of optimized measurement path is important for reduced measurement time. The measuring head of the CMM is considered as a travelling sales person. To find the shortest measuring path is equivalent to solving a travelling sales person problem. The objective of this work includes determination of best possible probing sequence to measure different features of a part using MATLAB program and C++. The proposed methodologies have been utilized and tested on a mechanical part with certain

Keywords: *CMM, MATLAB Program, Cycle time, Probing sequence*

INTRODUCTION

The main challenge of the manufactures is to increase the production rate and to decrease the production cost without affecting the quality, for which selection of suitable inspection process place an important role. In the past companies used primarily conventional machining techniques to manufacture parts and traditional variable gaging such as micrometers, height gages and comparators, as well as attribute gages such as plug gages and function go/no-go gages to inspect dimensional features.

From the last few years Coordinate Measuring Machine (CMM) equipped with contact probe has been standard and most frequently used measuring instrument for dimensional inspection. Regardless of the availability of large number of non-contact measuring devices, CMMs mounted with touch probe have been preferred choice for inspection purposes. This is due to the fact that it can offer very high accuracy depending on the environment within which it operates. Since, CMMs requires huge capital investment therefore their proper utilization has been primary concern in industries. Moreover, ever increasing demand of high quality components and stiff competition in market requires manufacturers to reduce inspection time without compromising inspection quality. It becomes even more important to speed up inspection process on manufacturing line when number of features being measured increases. CMM probe travels to various features on the part depending on inspection plan during the inspection process. Therefore, determination of most appropriate inspection path has been critical for improved performance of CMMs. In any inspection plan, CMM measurement probe can travel to measure any feature but efficient inspection plan results in measurement sequence that minimizes inspection time. Thus, effective inspection path provides shortest route to measure number of features on the part being inspected. Overall improvement of CMM inspection process can also include minimizing number of probe re-orientation, reduction of stand-off distance (clearance, retract, approach distances etc.) etc., during inspection run besides measurement sequence. However, in present work, only measurement sequence has been considered because it is most critical aspect and contributes significantly to the performance of CMM. The motivation for this work has been provided by demands of effective methods and techniques that can be used to improve efficiency of inspection process thus reducing inspection time. The objective of this work includes determination of best possible probing sequence to measure different features on part. This problem requires generation of ideal path that measurement probe should take while moving between different features. The work at hand focuses on application of various methods and their comparisons to minimize measurement time. Although, applications of CMM for inspection purposes has extensively been spread throughout manufacturing industries yet measurement sequence planning especially by using heuristics such as permutation in matlab, C++ has not fully been developed. Therefore, in this work, methodologies to implement well established techniques such as permutation in matlab, C++ have been proposed for improvement of inspection process.

METHODOLOGY

Describes about various steps used in this project and different for finding the optimum path. There are two methodology permutation method using matlab and dijkstra's shortest path program in c++ are used.

Permutation method using matlab

Permutation method using matlab is an exact method that generates and evaluates every possible solution. The approach generates all possible measurement sequences for given number of features and computes total distance moved in each of the measurement sequences. Different steps for Permutation method using matlab method can be described as follows.

The primary step in this method is to give input coordinates of eleven features of the wokpiece selected, then identifying the number of features based on the given coordinate values. After this by using the permutation method generating all possible measurement sequences for identified number of features. In permutation method factorial of the number is used to find the no of sequences. Then calculate the distance travelled for each of the measurement sequence generated. After finding all the sequences distance sorting it based on their distance. From the sorted distances sequence with shortest is identified. Steps in matlab program is shown in fig 1 and matlab program used is shown in fig2.

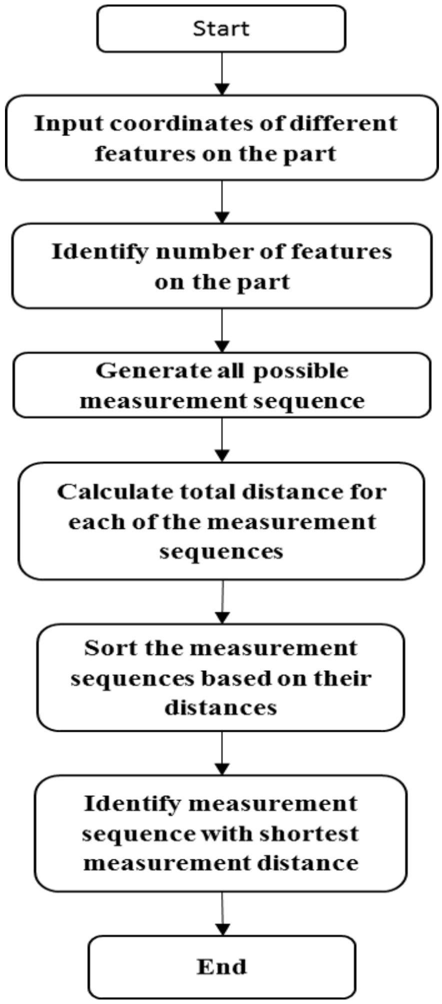

Fig 1.Steps in permutation method using matlab


```
close all
clear
clc
%%
x = [-68 -62 -68 -40 -40 -40 -12 -18 -12 -40 -40];
y = [35 75 115 53 75 97 35 75 115 15 135];
z = [-3 -3 -3 -3 -3 -3 -3 -3 -3 -3 -3];
%%
iseqn = perms(1:11);

r = length(iseqn);
min_dist = zeros(1,r);
for cnt = 1 : r
   min_dis = 0;
   v(1,:) = iseqn(cnt,:);
   for k = 1 : (length(v)-1)
      i = v(1,k);
      j = v(1,k+1);
      min_dis = min_dis + sqrt((x(i)-x(j)).^2 + (y(i)-y(j)).^2 + (z(i)-z(j)).^2);
   end
   min_dist(1,cnt) = min_dis;
end

[val, pos] = min(min_dist);
minimumDistance = val
sequence = iseqn(pos,:)

[val1, pos1] = sort(min_dist);
minimumDistance10(1:10,1) = val1(1,1:10);
sequence10_min = iseqn(pos1(1,1:10),:);
```

Fig 2. Matlab program

Dijkstra's algorithm

Dijkstra's algorithm is very similar to Prim's algorithm for minimum spanning tree. Like Prim's MST, we generate aSPT (shortest path tree) with given source as root. We maintain two sets, one set contains vertices included in shortest path tree, and other set includes vertices not yet included in shortest path tree. At every step of the algorithm, we find a vertex which is in the other set (set of not yet included) and has minimum distance from source.

Below are the detailed steps used in dijkstra's algorithm to find the shortest path from a single source vertex to all other vertices in the given graph?

Algorithm

1. Create a set sptSet (shortest path tree set) that keeps track of vertices included in shortest path tree, i.e., whose minimum distance from source

is calculated and finalized. Initially, this set is empty.

2. Assign a distance value to all vertices in the input graph. Initialize all distance values as INFINITE. Assign distance value as 0 for the source vertex so that it is picked first.

3. While sptSet doesn't include all vertices

….a) Pick a vertex u which is not there in sptSetand has minimum distance value.

….b) Include u to sptSet.

….c) Update distance value of all adjacent vertices of u. To update the distance values, iterate through all adjacent vertices. For every adjacent vertex v, if sum of distance value of u (from source) and weight of edge u-v, is less than the distance value of v, then update the distance value of v. Steps in C++ program is shown in Fig 3.

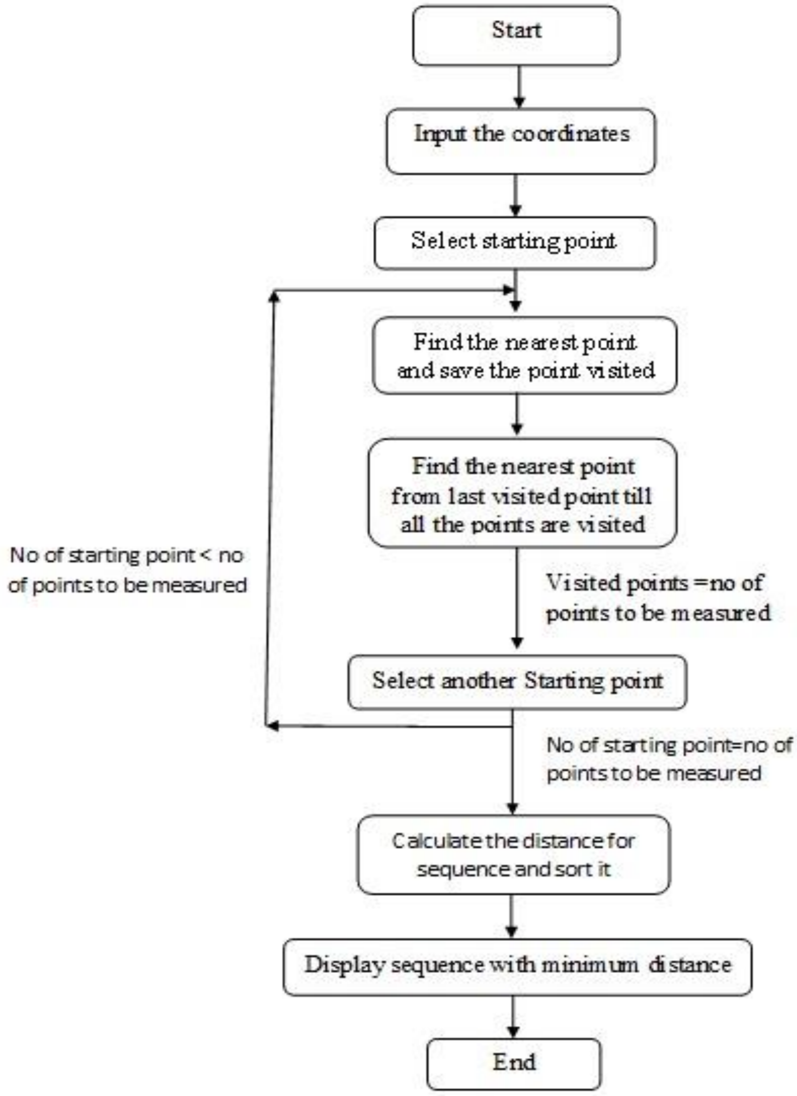

Fig 3. Steps in C++ program

Successful application of above mentioned approaches have been realized through real time inspection of part on CMM.

Generally, CMM programmers define measurement path for multi-feature component based on their experience and expertise. This measurement path which do not follow any standard or systematic procedure have been described here as randomly selected measurement sequence. In this work given part has first been measured randomly using any measurement sequence and then through identified measurement sequence to compare performance of different inspection processes. To maintain consistency of measurement process, retract distance (=5 mm), clearance distance (=30 mm) and starting point (0, 0,

30) have been kept constant throughout all inspections. Measurement sequences with corresponding designation, inspection time and total measurement distance can be seen in Table 2& 3

Fig 4. Coordinate measuring machine

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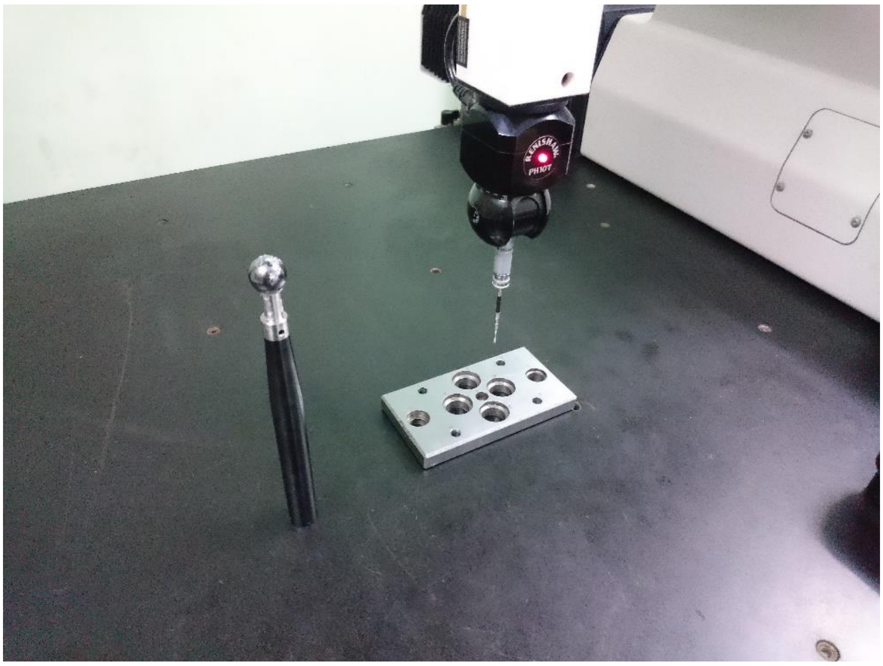

Fig 5. Measuring using CMM

Mechanical Probe

Contact type probe is used for the measurement purpose. it is very common probe, made by soldering a hard ball to the end of a shaft. This was ideal for measuring a whole range of flat, cylindrical or spherical surfaces. Other probes were ground to specific shapes, for example a quadrant, to enable measurement of special features. These probes were physically held against the workpiece with the position in space being read from a 3-Axis digital readout (DRO) or, in more advanced systems, being logged into a computer by means of a footswitch or similar device.

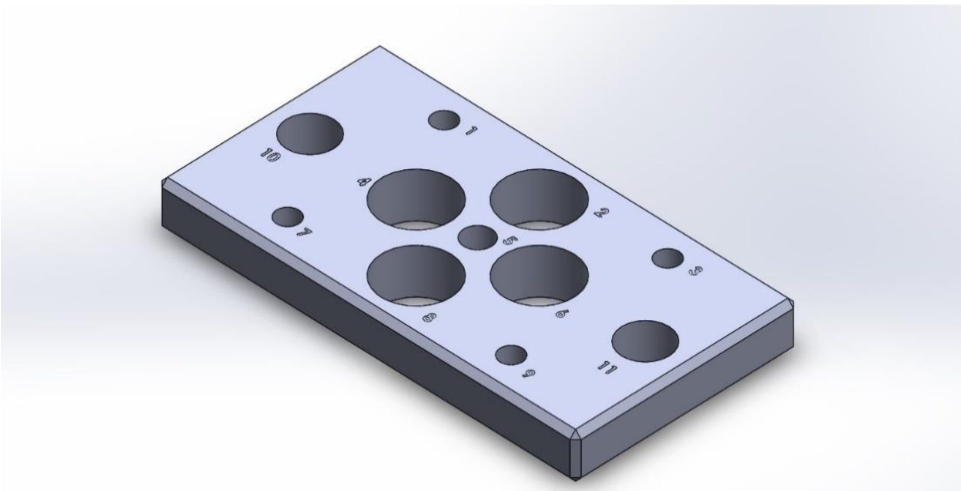

Fig 6. Object To Be Measured

Object selected for the measurement purpose is a rectangular metal block of dimension 150x80 mm, and eleven holes of different diameter are placed at different coordinate position as shown in table.1.

POSITIONS OF FEATURES FEATURES

Table 1. Position and diameter of features

FEATURES	1	2	3	4	5	6	7	8	9	10	11
X	-68	-62	-68	-40	-40	-40	-12	-18	-12	-40	-40
Y	35	75	115	53	75	97	35	75	115	15	135
Z	0	0	0	0	0	0	0	0	0	0	0
DIA (mm)	8	25	8	25	10	25	8	25	8	19	19

Measurement Sequences for minimum distance

1) 9-11-3-6-8-5-2-4-7-10-1
2) 9-11-3-6-8-5-2-4-1-10-7
3) 9-11-3-6-2-5-8-4-7-10-1
4) 9-11-3-6-2-5-8-4-1-10-7
5) 7-10-1-4-8-5-2-6-3-11-9
6) 7-10-1-4-8-5-2-6-9-11-3
7) 7-10-1-4-2-5-8-6-3-11-9
8) 7-10-1-4-2-5-8-6-9-11-3
9) 3-11-9-6-8-5-2-4-7-10-1
10) 3-11-9-6-8-5-2-4-1-10-7

Measurement Sequences randomly selected

11) 1-2-3-11-9-8-7-10-4-5-6
12) 2-8-1-9-4-6-10-11-7-3-5
13) 10-1-7-4-2-5-8-6-3-9-11
14) 7-9-3-1-10-4-2-5-8-6-11

15) 7-3-1-11-10-9-4-6-2-8-5

16) 10-7-4-8-5-6-9-11-3-2-1

17) 5-3-7-6-10-11-4-9-1-8-2

18) 10-4-5-6-11-9-8-7-1-2-3

19) 10-11-1-9-2-7-8-3-4-6-5

20) 7-10-1-2-4-5-6-8-9-3-11

Table 3. Sequence, distance and time for minimum selected measurement sequences

Sl No.	Sequences	Distance (mm)	Measurement time (Min:sec:millisec)
1	9-11-3-6-8-5-2-4-7-10-1	310.435	2:40:11
2	9-11-3-6-8-5-2-4-1-10-7	310.435	2:40:11
3	9-11-3-6-2-5-8-4-7-10-1	310.435	2:40:11
4	9-11-3-6-2-5-8-4-1-10-7	310.435	2:40:11
5	7-10-1-4-8-5-2-6-3-11-9	310.435	2:37:90
6	7-10-1-4-8-5-2-6-9-11-3	310.435	2:37:90
7	7-10-1-4-2-5-8-6-3-11-9	310.435	2:37:90
8	7-10-1-4-2-5-8-6-9-11-3	310.435	2:37:90
9	3-11-9-6-8-5-2-4-7-10-1	310.435	2:42:64
10	3-11-9-6-8-5-2-4-1-10-7	310.435	2:42:64

Table 3 Sequence, distance and time for randomly selected measurement sequences

Sl NO.	Sequences	Distance (mm)	Measurement time (Min:sec:millisec)
11	1-2-3-11-9-8-7-10-4-5-6	434.086	2.44.68
12	2-8-1-9-4-6-10-11-7-3-5	770.037	2.58.98
13	10-1-7-4-2-5-8-6-3-9-11	355.864	2.40.12
14	7-9-3-1-10-4-2-5-8-6-11	444.624	2.44.98
15	7-3-1-11-10-9-4-6-2-8-5	720.485	2.56.74
16	10-7-4-8-5-6-9-11-3-2-1	331.765	2.39.06
17	5-3-7-6-10-11-4-9-1-8-2	772.221	3.01.24
18	10-4-5-6-11-9-8-7-1-2-3	372.163	2.41.36
19	10-11-1-9-2-7-8-3-4-6-5	688.060	2.52.94
20	7-10-1-2-4-5-6-8-9-3-11	358.304	2.40.22

- Minimum distance measured= 310.435 mm
- Time taken for minimum distance= 2:37:90 sec
- Maximum distance measured= 772.221 mm
- Time taken for maximum distance=3.01.24 sec

- Time saved after measuring single object= 00:23:34 sec

- Time saved after 1000 objects measurement=23340 sec= 6.48 hr
- No of pieces can be measured additionally when measuring 1000 pieces=148

CONCLUSION

In this Work, methodologies have been introduced to compute sequence in which different part features should be measured in minimum inspection time. Efficient application of these methodologies is very important for improved performance of CMM inspection process. Two approaches including Matlab and C++ have been utilized to identify best possible measurement sequence for a given part. Best measurement sequence for measurement features results into minimum inspection time.

This research can be summarized as follows:

1. These techniques are compact, robust and effective as far as determination of measurement sequence for part inspection is concerned.
2. Application of present approaches can avoid repeated movement of CMM probe on one path.
3. Execution of these methods suggests that given part should be inspected in accordance to following measurement sequences.
4. 9-11-3-6-8-5-2-4-7-10-1
5. 9-11-3-6-8-5-2-4-1-10-7
6. 9-11-3-6-2-5-8-4-7-10-1
7. 9-11-3-6-2-5-8-4-1-10-7
8. 7-10-1-4-8-5-2-6-3-11-9
9. 7-10-1-4-8-5-2-6-9-11-3
10. 7-10-1-4-2-5-8-6-3-11-9
11. 7-10-1-4-2-5-8-6-9-11-3
12. 3-11-9-6-8-5-2-4-7-10-1
13. 3-11-9-6-8-5-2-4-1-10-7

- These identified measurement sequences have resulted in minimum distance of 310.435 mm.

- 13% increase in inspection time has been observed when part was measured using randomly selected measurement sequence M as compared to best measurement sequences (1 to 10).

- Implementation of such techniques is mandatory in mass production to minimize inspection time and hence overall production cost.

- Present approaches to find appropriate measurement sequence are practical and can easily be extended to obtain measurement sequence for inspecting any manufacturing part.

- This work can be extended to include other performance measures of inspection process such as minimization of number of probe re-orientation which is relatively time-consuming operation, reduction of stand-off distance (clearance, retract, approach distances etc.), strategies selection etc.

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