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Modeling Optimal Path of Touch Sensor of Coordinate Measuring Machine Based on Traveling Salesman Problem Solution

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Abstract

The article justifies the necessity of reducing the measurement time of the part surfaces in the coordinate measuring machine by minimizing the trajectory of the sensor. It is established that the search of the minimal path by the sensor corresponds to the travelling salesman problem that can be solved by exact or approximate method. The branch and bound method and ant colony optimization are selected for comparison. We perform computer simulation for finding the optimal path of the sensor by controlling different numbers of points on plane, cylindrical and spherical surfaces. It is established that ant colony algorithm gives close to optimal solution and requires far less time for its search in contrast to the branch and bound algorithm. Application of the ant colony optimization will significantly improve the performance of the measurement of the part surfaces in the coordinate measuring machine.

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Keywords: coordinate measuring machine; optimization; travelling salesman problem; branch and bound method; ant colony optimization.

1. Introduction

As is known [1-3], the measurement accuracy depends on the number of control points chosen by the operator. The more control points are measured, the higher is the measurement accuracy. However, with the increase in the number of control points, the trajectory of the sensor and, consequently, the inspection time increase. If it is necessary to measure a large range of products, the operator faces the task of finding the optimal measurement strategy of the surface, the purpose of which is the reduction of measurement time.

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The measurement strategies, used at enterprises, depend a lot on the operator skills, and the improvement of measurement performance of scientifically-based approaches [1-10] is based on the search of the location of the minimum sufficient number of points needed in order to achieve the required measurement accuracy. The possibility of improving the measurement performance by selecting an optimal sequence of control points that provides the minimum trajectory of the CMM sensor is practically unused. With the aim of improving measurement performance, there was conducted a study based on simulating the optimal path of the sensor in the coordinate measuring machine.

2. Problem statement

To conduct the study it is necessary to choose the most frequently used surfaces as geometric images of real surfaces so that they have a simple analytical description, and do not cause any difficulties during the transition between the Cartesian, cylindrical, and spherical coordinate systems. Hence there were chosen a plane, cylinder, and sphere, described by parametric equations in the Cartesian coordinate system.

To make control points describe the measured surface with the greatest accuracy, the location of these points should be uniform. Uniform distribution of points can be specified either through stochastic simulation of their coordinates according to the law of uniform distribution, or the analytical spacing between the closest points. Since stochastic simulation is justified only when there are a large number of points, analytical approach to the determination of the points coordinates was chosen to conduct the study.

To determine the coordinates of evenly distributed N points on a plane surface and to simplify the calculations, the surface was aligned with the plane XOY and is limited by four planes ($x_1=-L/2, x_2=L/2, y_1=-L/2, y_2=L/2$), whose intersections with the surface form a square with the side L. The points are located in the plane with equal pitch along the OX axis and OY axis respectively $h_x=h_y= L/N^{1/2}$. To determine the coordinates of evenly distributed N points on a cylindrical surface, the axis of the cylinder was aligned with the axis OZ, and the surface was limited by the planes $z_1=-L/2, z_2=L/2$. The points on the cylindrical surface are located with angular pitch $d\varphi=2\pi/N^{1/2}$ in the plane XOY and linear pitch $h_z= L/N^{1/2}$along the axis OZ. The points on the sphere were located with zenith d and azimuth $d\theta=2\pi/N^{1/2}$ angular pitch.

For computational convenience the centres of square area of the plane, cylinder and sphere are aligned with the origin of the coordinate system OXYZ.

The length of the sensor path for each surface depends on the strategy of the control points bypass, which is a sequence of control points. To get full information about the location of all the surface points, it is necessary to make the sensor touch each control point at least once. Upon completion of a full bypass of the surface, the sensor returns to the starting point. In this case, the sensor trajectory is a closed broken line which defines the duration of the measurement. Having presented the path of the sensor as a graph whose nodes are the control points and ribs of the graph are the trajectories between two points, we get the Hamiltonian circuit. Then the problem of path optimization is reduced to finding the Hamiltonian circuit which has the minimum length, and represents the travelling salesman problem.

Let us describe the travelling salesman problem as an integer linear programming problem. Let us represent the movements of the probe from the i-th control point to the j-th in the form of a displacement matrix $L_{i,j}$, where $i, j \in \overline{1,n}$ is for a certain number of control points $n \in \mathrm{N}$. Let us represent the direction of movement from i-th point to j-th in the form of a number matrix $l_{ij} \in \{0,1\}$ for $i, j \in \overline{1,n}$, where $l_{ij} = 1$, if the bypass path has a rib (i, j), and $l_{ij} = 0$ otherwise. Then the problem is reduced to finding a solution l when the path will be minimal:

$$G(\bar{x}) = \sum_{i=1}^{n} \sum_{j=1}^{n} L_{ij} l_{ij} \rightarrow \min \tag{1}$$

Depending on the surface, elements of the displacement matrix Li,j are determined by the expressions:

- for the plane:

$$L_{ij} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - z_i)^2} \tag{2}$$