The optimization of contact sensors motion path in carrying out control operations

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Abstract The article examines the problem of raising control operations efficiency through measurement mechanisms transference optimization. For solving the problem it is proposed to use the discrete optimization method, based on solving the “traveling salesman” problem. The article demonstrates the comparison of the “greedy” algorithm and the branch – and – bound method and proves the necessity to use optimized algorithms, as even approximate algorithms make it possible to reduce the length of the way monitoring sensor passed. Reducing the length of the way the monitoring sensor passes leads to reducing the control operation time. The time gain depends on the quantity of controlled parameters.

1. Introduction
One of the most important conditions of providing the efficiency of a machine building production is the reception of operative and reliable information about technological details processing. The most important information about the exactness of details processing is formed during their measurement. This information has a complex character as a great number of objective and subjective factors have an influence on the precision of processing. Control operations make an essential contribution to the balance of technological expenses.

The necessary precision of measurements increases. The operativeness of the information about the precision of details processing increases too. As a result technological expenses for the control rise quickly, because the investments for means of control and the time of fulfilling a control operation rise too.

In a mass type of production, where the technological process is repeated, it is possible to select the most expedient places of disposition of control operations in “narrow” critical points of technological process.

In flexible production investment for the precision control of processing have a larger influence on the general balance of technological expenditures. And this influence rises if the launch party of details in processing decreases.

In a modern flexible automated production (FAP) coordinate measuring machines (CMM) [1-5], and zero heads are used for the control. These heads are set into the spindle of the CNC machine [6]. Only the coordinate principle of measurement corresponds at present to the flexibility and universality criterions on the one hand and possibility of automation on the other hand.

In large volumes CMM are used in FAP. Final precision estimation of the detail processing is done with the help of CMM. Besides in-process measurement is fulfilled too.

The estimation of the position of the work piece on the machine platen before the processing is done directly on the machines with the help of measuring heads. The evaluation of precision of fulfilling some
transformations and the results of carrying out the operation up to the work piece removal are done on these machines too.

Expenses connected with control operations are rather great and according to some reports are equal from 3 to 18 % of the cost of emitted commodity.

With using CMM the investment is defined by the cost per minute and properly by the time of fulfilling control operation.

The cost per machine is influenced by CMM cost, its operation costs and planned dates of the depreciation of this equipment.

In small – scale and especially in single-piece production there is one more kind of investment connected with control. The thing is that during launching a new party of details into production before evaluation of the results of measurement of processing the preceding detail the machine often stays idle before processing the next one. The time of standing idle in this case is completely determined by the control time and negatively affects at technological investment as a whole.

Using zero measuring heads at the machines you can see a similar pattern – control investment is defined by the cost per minute and the time of control transformation.

Thus, in both cases the time of control operations at CMM and control transformations at the machine directly affects at technological expense. Searching the ways of cutting down the control time during fulfilling coordinate measuring is an actual problem.

Of course the time of fulfilling control operation depends on the transference speed of the measuring transmitter and the speed of reading coordinates. It is not difficult to notice, that any succession of reading control points during appreciation of detail accuracy can change considerably the joint way of the contact measuring transmitter and affect at the control operation time (Figure 1).

2. Mathematical formulation of the problem
For searching optimal succession of coordinate determination of control points it is expedient to use classical method of discrete optimization known as the “traveling salesman problem” [7].

This problem is formulated in the following way. “There are N towns. Living the initial town A1 the traveling salesman must visit all the towns once and return to the town A1. The problem is in
defining the succession of visiting the towns, with the help of which the traveling salesman has to minimize some efficiency criterion: driving cost, driving time, summary distance.”

For costing there is a matrix of conditions C, containing investment for moving from every town to every one, taking into consideration that it is possible to move from any town to any one, expect for just the same one (there is no diagonal in the matrix). The idea of solution is finding the route answering all conditions and having the minimum expenditure. For formal formulation of the problem the towns are numbered ($j_1, j_2, \ldots, j_n$), and all $j_1, j_2, \ldots, j_n$ are different numbers $j_i$ repeating at the beginning and at the end shows that the rearrangement is caught in cycles. Distances between pairs of towns $C_{ij}$ form the matrix C. The problem is to find such a route that can minimize the functional:

$$L = L(t) = \sum_{k=1}^{n} C_{ik} C_{ik+1}.$$  

As the quantity $C_{ij}$ describes the distance it cannot be negative $C_{ij} > 0$. To prevent looping in the route $C_{ij} = \infty$. There is a variety of the problem, but in the classical formulation it is taking into consideration that the distance between the point I and point j is equal the distance between point j and point I, that is $C_{ij} = C_{ji}$ (so called symmetric problem). One more limitation is the observance the “triangle rule” according which $C_{ij} + C_{jk} \geq C_{ik}$. This method is wide-spread in different spheres of activities [8-10].

Thus if in classical formulation of the traveling salesman problem you substitute the word “town” for the term “control point”, then you’ll get the formulation of the problem of optimization of succession of control points coordinates.

As such quantity of connections on the graph will make it difficult to read it, we’ll limit ourselves with making the distance matrix, which is show in Table 1.

|   | 0   | 1   | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|---|-----|-----|------|------|------|------|------|------|------|------|------|
| 0 | $\infty$ | 322.2 | 102  | 139  | 65.6 | 115.4 | 120  | 126.5 | 80   | 80   | 160  |
| 1 | 322.2 | $\infty$ | 37.5 | 53   | 75   | 143.2 | 118.8 | 173.5 | 117.9 | 174.1 |
| 2 | 102  | 37.5 | $\infty$ | 37.5 | 37.5 | 98   | 152.3 | 197.9 | 141.4 | 205.9 |
| 3 | 139  | 53   | 37.5 | $\infty$ | 75   | 196.2 | 170.6 | 226.1 | 170   | 226.5 |
| 4 | 65.6 | 53   | 37.5 | 75   | $\infty$ | 153.3 | 142.3 | 173.5 | 117.9 | 190.5 |
| 5 | 115.4 | 75   | 37.5 | 53   | 37.5 | $\infty$ | 203.7 | 187.4 | 226   | 170   | 239.4 |
| 6 | 120  | 143.2 | 98   | 196.2 | 153.3 | 203.7 | $\infty$ | 60   | 40   | 40   | 40   |
| 7 | 126.5 | 118.8 | 152.3 | 170.6 | 142.3 | 187.4 | 60   | $\infty$ | 80   | 56.6 | 56.6 |
| 8 | 80   | 173.5 | 197.9 | 226.1 | 173.5 | 226   | 40   | $\infty$ | 56.6 | 56.6 | 56.6 |
| 9 | 80   | 117.9 | 141.4 | 170   | 117.9 | 170   | 40   | 56.6 | $\infty$ | 80   |     |
| 10| 160  | 174.1 | 205.9 | 226.5 | 190.5 | 239.4 | 40   | 56.6 | 56.6 | 80   | $\infty$ |

3. Algorithm analysis
There are many algorithms of decision of this problem, beginning with the direct sorting out the variants and ending with algorithms, making it possible to avoid it. And these algorithms may be divided into algorithms always leading to optimal solving and algorithms, which can lead to optimal solving in some cases.

The most often used algorithm of the second type is the “greedy algorithm”. Its idea is the choice the least of possible variants of every next step of the decision. But this algorithm does not always give an optimal result, because at the last steps you often have to use unprofitable variants which will bring to nothing all the economy obtained at the first stages. The result of the solution of the problem of the reference points walk for the openings shown in Figure 1 using the “greedy algorithm”, is shown in Figure 2. The length of the way in this case is 736.6 mm.

The algorithm “Monte – Carlo” is based on the determining some number of accidental routes and searching among them an optimal one, as the quantity of possible routes according to the probability theory is equal to $(n-1)!/2$ and it will make about several millions variants. The complete sorting out of
such number of variants is impossible. The example of realization of such algorithm is shown in Figure 3. The length of the way in this case is 709.64 mm.

![Figure 2. The variant of reference points walk according to the “greedy algorithm”](image)

![Figure 3. The variant of reference points walk according to the “Monte-Carlo” method](image)

Exact algorithms are much more time-consuming both in decision manually and in program realization, and yet such algorithms provide an optimal decision. One of exact algorithms is the “branch – and – bound method” known also as Little algorithm. The main point of the algorithm consists of the fact that at first the “lower estimate” is defined that is the minimal possible cost or the length of the route. For this reason minimal elements are subtracted from every row and column and their sum is defined. This action is called matrix reduction by rows and columns. The less length does not exist. As a result of the reduction, minimum one zero element is formed in every row and every column. If we make a route according those zero elements, we will have an optimal variant. To choose a variant the zero estimation procedure is used, which consists of summing up minimal elements of the row and the column, containing the estimated zero. Little recommended to use zeroes with maximum estimation. For the prohibition loop the prohibition for mirror elements is introduced, for example, if the variant “1-2” is used, it is impossible to use “2-1”. As a result of such prohibitions rows and columns without zeroes can be formed. In this case matrix reduction is made again and the subtracted quantity is added to the “lower estimate”. Using this algorithm in this problem we got the result shown in Figure 4. The length of the way was 676.1 millimeters.

4. Results and Discussion
As you can see from this variants of the problem decision, the difference between the greedy algorithm and the algorithm of Little is about 10 per cent. Nevertheless, using approximate methods may be justified as they make it possible to get a better solution in comparison with non-optimized ones. So the solution of the brought problem without using optimized algorithms may be brought to the variant when openings of the same type will be controlled in turn, for example, 0 - 2-6 -7 -10 – 8 – 9 -1 – 3 -5 -4 -0. Though the program maintenance of modern CMM makes it possible to choose from a great number of received coordinates subsets concerning to the given parameter. The length of the way in this case will be 772.3 mm and that is about 14 per cent more than the meaning received using Little’s algorithm and by 4.8 per cent more than the meaning received with the help of the “greedy” algorithm.
5. Conclusion
As it can be seen from the results comparison even approximate algorithms make it possible to receive better meanings, so their using is justified. Using precise algorithms allows to reduce by 14 per cent the length of the way the monitoring sensor passes, and it will reduce the time of the control operation.

If the number of controlled parameters and controlled details is considerable, such time economy during the idling of mechanisms can be essential.

Using optimization algorithms makes it possible to increase control operations effectiveness through overlap processing minimizing. Using exact algorithms gives the greatest benefit, but using approximate algorithms makes it possible to reduce overlap processing of measurement mechanisms.

The numbers, received with the help of approximate algorithms will be more exact if the distances between the controlled points are of the same order.

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