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電子部品装着機の装着順序決定アルゴリズムの研究

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概要：近年の新製品開発サイクルの短縮に伴い，生産工場においては，製造機械の高速化は大きな課題となっている．プリント基板作成における電子部品の装着機械は，部品あたり，0.1 秒以下まで高速化され，ハードウェアによるこれ以上の向上はは見込めないところまできている．そのため，製造速度は部品の装着順序や，部品供給部の配置などの最適化に大きく依存するようになっている．本研究では，この問題を 3 次元空間上の巡回セールスマン問題としてモデル化し，最適化を行った．

An Algorithm of the Optimal Order of Component Mounting on an Electronic Circuit Board

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Abstract *Among the most important and difficult parts of automatic component mounting on an electronic circuit board is the problem of determining the optimal mounting order. In the present paper we formulate the problem as the 3 dimensional traveling salesperson problem and solve by a simplified chained Lin-Kernighan algorithm. We also show how the mounting time depends on the arrangement of the component feeders. We show how our approach gives satisfactory results.*

1 Introduction

Roughly speaking, the process of manufacturing electronic circuit boards consists of *Solder paste printing, Component mounting, Heating and fixing,* all of which are carried out automatically. Among them the most important and difficult is the stage of component mounting. High speed mounting machine, which the present paper is related to, places a component within less than 0.1 sec; this speed is almost the limit of the hardware. Hence, in order to make full use of the performance of the machine it is important to find the order of component mounting such that the total time of walking through mounting positions is the minimum.

In the following we formulate and solve the problem of the optimal ordering of component mounting as the 3-dimensional traveling salesperson problem.

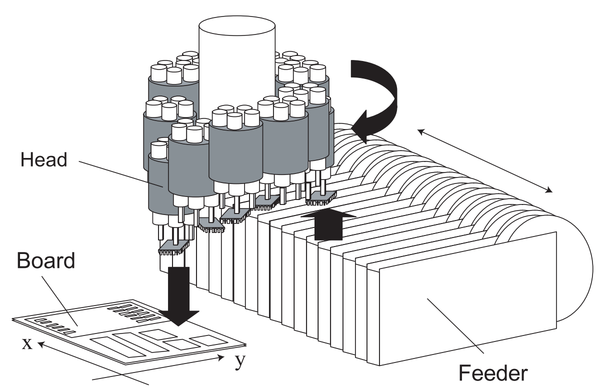

Figure 1: High speed mounting machine

2 High speed mounting machine

The process of component mounting consists of

- Picking up a component from a feeder by a nozzle,
- Placing the component to the designated position on the board from the nozzle.

The high speed mounting machine includes rotary heads located on a circle, where each head has several types of nozzles, and executes the above two acts while the heads are rotating (Figure 1).

Since the place of picking and that of placing in a high speed mounting machine are fixed, the feeders and the board are moved in order to pick the proper component and place it in the proper position. In general, the number of individuals of a component in a board is more than two. Thus, the nozzle has to move to the same feeder as often as the same number of individuals of the component. If the movement of the board to the next mounting position and/or the movement of the feeders to the next component are not finished, the mounting machine has to wait, which we call the time loss. The speed of nozzle rotation varies in eight steps; after that the speed of rotation is decreased, it can never be increased through the mounting of the same board.

3 Making use of the traveling salesperson algorithm

3.1 Outline of the optimal component ordering algorithm

Since the speed of nozzle rotation cannot increase, our algorithm mounts components in the ascending order of weights, i.e., the lightest one the first and the heaviest one the last. Thus, the outline of our algorithm is as follows:

Step 1 Classify components into groups according as their weight.

Step 2 For each group of components, arrange the feeder and determining the order of mounting.

Step 3 Combine the order of the groups.

In the following we consider only the step 2.

3.2 The traveling salesperson and component ordering

The optimal mounting in step 2 minimizes the total amount of movement of the board and the feeders. We describe this problem as a 3-dimensional traveling salesperson problem (3-dim TSP). It is well known that the traveling salesperson problem is stated as follows:

$$
\begin{array}{lll}
\text{Minimize} & \displaystyle\sum_{e=1}^{m} c_e x_e & \\
\text{subject to} & & \\
\displaystyle\sum_{e\in\delta(i)} x_e = 2 & \text{for } i = 1, 2, \ldots, n & \\
\displaystyle\sum_{e\in\delta(S)} x_e \geq 2 & \text{for any nonempty} & \\
 & \text{proper subset } S \in \{1, 2, \ldots, n\} & \\
x_e = 0 \text{ or } 1 & \text{for } e = 1, 2, \ldots, m &
\end{array}
$$

where n is the number of vertices, m is the number of edges, $\delta(i)$ is the set of edges incident to the vertex i, and $\delta(S)$ is the set of edges incident to one of the vertex in S. If the solution walks through the edge e, the variable x_e takes the value 1; otherwise the value 0.

In order to formulate our problem as a 3-dim TSP, we first construct a graph by connecting every pair of the mounting positions by an edge in a three dimensional space(Figure 2). For every vertex (x, y, z) of the space, x and y reflects the position of the corresponding component on the board, whereas z stands for the location of the feeder. The length of the edge is the ordinary Euclidean norm. The scales along the axes x and y and that along z, however, are not the same. Since we have no information on the ratio of these scales at present, we tried on several values of the ratio.

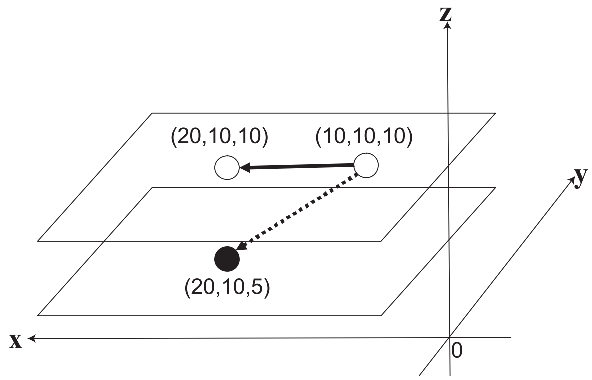

Figure 2: Vertex in a three dimensional space: x and y reflects the position of the corresponding component on the board, whereas z stands for the location of the feeder

3.3 Determining the location of component feeders — the scale for z axis

In order to solve our problem as a 3-dim TSP, we have to determine first the location of component feeders. Although this is another problem of optimization, we assumed the arrangement of the component feeders as given and fixed. We assumed two types of arrangement; one is such that components are arranged from one end to the other in an ascending order of the number of individuals (Type A), and the other is such that components of larger number of individuals in the center (Type B).

3.4 The algorithm for the 3-dim TSP

The traveling salesperson problem has been fully investigated, and a number of reports have been published, e.g., [3, 4]. Since it is desired to solve the problem in a practical time, we applied a heuristic method, namely simplified chained Lin-Kernighan algorithm [1].

4 Experiments with a simulator of high speed mounting machine

4.1 High speed mounting machine simulator

In order to determine the ratio of the x, y and z scale and then to evaluate our algorithm, we made experiments on a high speed mounting machine simulator developed by Iriuchijima [2]. This simulator exhibits the following data:

- The time loss of the movement of the board and that of the feeders. The ratio of both time loss.
- Real time presentation of the time loss.

4.2 Experimental data

In practice, two ways of treating boards are often carried out, i.e., single board mounting and multi board mounting. The multi board mounting is the way to mount components on several boards as if the boards constituted a single board.

The basic data are as follows:

- **Size of the board:** 300 mm by 300 mm
- **Speed of nozzle rotation:** fixed
- **Number of component individuals and the number of component types:** (400,10),(400,100),(800,10),(800,100)
- **Distribution of mounting position:** Uniform distribution (Multi board mounting), Normal distribution (Single board mounting)

4.3 Results of the experiment

Typical results obtained from the experiment on the high speed mounting machine simulator are shown in Figures 3 and 4. These results show that the optimal ratio of the scales of x, y and z axes lies between 20 and 30 and depends on neither the number nor the distribution of mounting positions. Figures 3 shows that the mounting time does not depend much on of the ratio of the scales of x, y and z axes, when the number of component types is small. On the contrary, Figures 4 shows the mounting time depends much on that ratio, when the number of component type is large.

Table 2 shows the result on the difference by the arrangement of feeders. From this table we see that the improvement of mounting time by optimizing feeder arrangement is within at most 5 per cent.

Table 1: Difference by the arrangement of component feeders (Single board mounting)

(# of individuals, # of types)	(400, 10)	(400, 100)	(800, 10)	(800, 100)
Arrangement of Type A	46026	57239	87848	105445
Arrangement of Type B	46101	56436	87459	105093
Random(min of 10 trials)	45501	56112	87436	105381
Random(max of 10 trials)	46133	58532	88390	107409
Random(mean)	45883.1	57450.6	87971.6	106358.7
Random(standard deviation)	236.7	694.4	339.2	626.9
((max − min)/mean) × 100	1.4	4.2	1.2	1.9

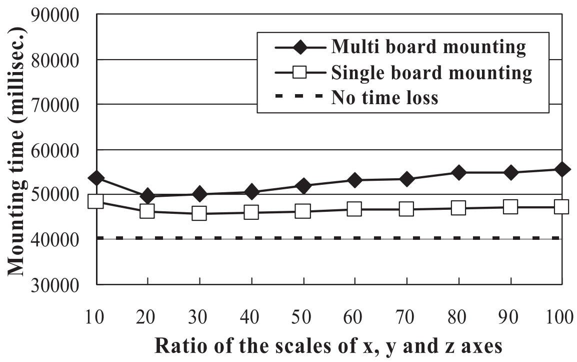

Figure 3: Dependence of mounting time on the ratio of the scales of x, y and z axes: 400 individuals, 10 types (Type B arrangement)

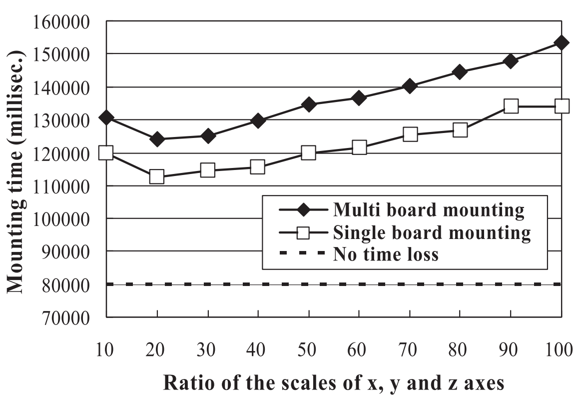

Figure 4: Dependence of mounting time on the ratio of the scales of x, y and z axes: 800 individuals, 100 types (Type B arrangement)

5 Conclusions

We have formulated the problem of mounting order as the 3-dim TSP and solved on several types of feeder arrangement. We have seen that the optimal ratio of x, y and z axes lies independent of board types. The merit of our approach is that we do not have to reconstruct the source code, when the specification of mounting machine and boards is changed; we only have to change the parameters.

For further research left are the problems of obtaining the optimal feeder arrangement and the optimal ratio of x, y and z axes by analyzing the specification of mounting machine and boards.

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