OPTIMAL MOTION PLANNING OF MULTI-ROBOT SYSTEMS PERFORMING POINT-TO-POINT ASSEMBLY OPERATIONS

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ABSTRACT

This paper reports on the development of a general point-to-point (PTP) motion-planning technique for assembly systems employing multiple coordinated motion devices. The augmented travelling salesperson problem (TSP+) is solved using genetic algorithms. The simulation results illustrate that coordinated robots exhibit superior performance in comparison to single-robot systems.

INTRODUCTION

The electronic placement problem has been addressed by many in the literature [e.g. 1-2]. Leu et al., [1], addressed the single-robot problem and Cao et al., [2], addressed a PTP planning problem for two robots performing inspection tasks. In our previous work [3], an augmented travelling salesperson problem (TSP+) was addressed for single placement robots. Herein, an extension of the TSP+ with two placement robots is addressed. In contrast to a classical TSP, where the primary objective is to find the best sequence for N tasks, [4], for multi-robot problems, one must also solve the "rendezvous-point" planning problem. Since the two placement robots share a common workspace, the collision avoidance issue must also be addressed.

PROBLEM DEFINITION

Figure 1 shows the most generalized physical setup of the placement machine modelled in this paper. The sub-problems addressed in this paper comprise: robot job assignment, placement sequencing, rendezvous location estimation, and robot movement coordination. The robot path planning sub-optimization problem is not addressed, since it has been extensively discussed in the literature. Herein, we simply assume that minimum robot-motion time can be achieved by minimizing the distance travelled by the individual robots.

The first sub-problem is, thus, simply to decide which of the two robots places which of the components. The subsequent sequencing sub-problem is a combinatorial optimization of the component placement sequence to minimize assembly time. The rendezvous-planning problem is the process of determining the meeting position of two robots (i.e., the placement robot and the printed circuit board (PCB) table, or the placement robot and the component delivery systems (CDSs)) for each placement event. Finally, since there are two placement robots, the collision avoidance issue also has to be addressed.

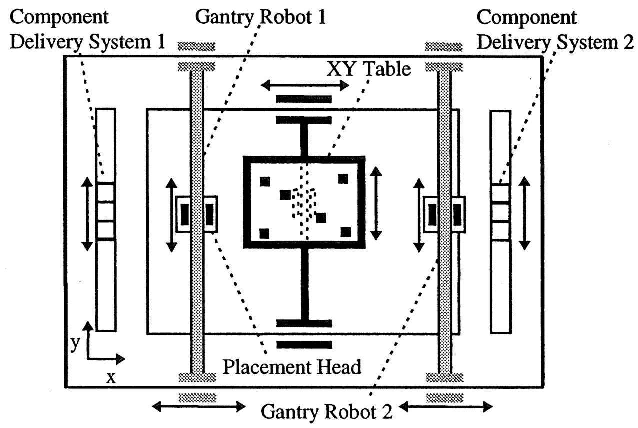

Figure 1: The generalized electronic-component placement machine configuration.

PROPOSED SOLUTION APPROACH TO TSP+

The overall optimization problem is solved herein using a genetic algorithm (GA), [5]. Information about the robot job assignment, the placement sequence and the rendezvous locations are encoded into a genome (i.e., data string). The objective function then decodes the genome, converting the information into motion times. This total-time equation is described below.

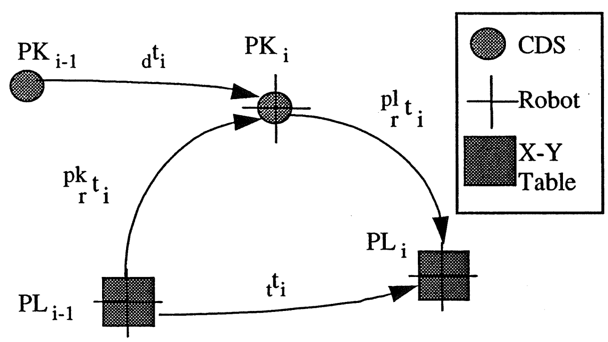

Figure 2: Illustration of cyclic device motion times.

Figure 2 above shows a complete cycle for the placement of one component: move to pick location, where the current robot moves from PL_{i-1} to PK_i in time ${}^{pk}_{r}t_i$, and the current CDS moves from PK_{i-1} to PK_i in time ${}_{d}t_i$; and, move to placement location, where the robot moves from PK_i to PL_i in time ${}^{pl}_{r}t_i$ and at the same time, the X-Y table moves from

PL_{i-1} to PL_i in time ${}_t t_i$.

The overall cycle time, t, for a complete population of a PCB with N components, is calculated herein as follows:

$$t = \sum_{i=1}^{N} C_i \qquad (1)$$

where: $C_i = \max[{}_R t_i, {}_t t_i] + {}^{pl}c_i$. (2)

In Equation (2), ${}^{pl}c_i$ is the time for cycle i spent by the robot to insert the component. The variable ${}_t t_i$ is the time for the X-Y table to move to the placement location as shown above in Figure 2. ${}_R t_i$ is the time it takes the robot to carry out all the tasks required to move from the last placement location to be ready to place the next component at the current placement location.

$${}_R t_i = \max[({}^{pk}_{r}t_i - {}^{off}_{r}t_i), {}_C t_i] + {}^{pk}c_i + {}^{pl}_{r}t_i + {}^{sd}_{r}t_i \,. \qquad (3)$$

In Equation (3), ${}^{pk}_{r}t_i$ is the robot pick time, which is the time required for the robot to move from the previous placement location PL_{i-1} to the current pick location PK_i (see Figure 2). The second term, ${}^{off}_{r}t_i$, is the time the current robot has been off since its last placement operation. If the i'th component is placed by the same robot as the (i-1)'th component, then;

$${}^{off}_{r}t_i = 0 \,. \qquad (4)$$

Otherwise, it is placed by the other robot;

$${}^{off}_{r}t_i = \sum_{j=k+1}^{i-1} C_j \,, \qquad (5)$$

where the index k represents the last cycle in which the current robot moved. The third term in Equation (3), ${}_C t_i$, is the total CDS motion time:

$${}_C t_i = {}_d t_i - {}^{off}_{d}t_i \,, \qquad (6)$$

where ${}_d t_i$ is the time it takes the CDS to move from PK_{i-1} to PK_i (see Figure 2). The variable ${}^{off}_{d}t_i$ in Equation (6) is the time period that the current CDS has not been involved in a pick operation and has had time to move toward its next pick location. If the i'th component is picked from the same CDS as the (i-1)'th component, then;

$${}^{off}_{d}t_i = C_{i-1} - \max[({}^{pk}_{r}t_{i-1} - {}^{off}_{r}t_{i-1}), {}_C t_{i-1}] - {}^{pk}c_{i-1} \,. \qquad (7)$$

Otherwise, it is picked from the other CDS;

$${}^{off}_{d}t_i = \sum_{j=k}^{i-1} C_j - \max[({}^{pk}_{r}t_k - {}^{off}_{r}t_k), {}_C t_k] - {}^{pk}c_k \,, \qquad (8)$$

where the index k in the summation corresponds to the last component picked from the CDS under consideration.

The fourth term in Equation (3), ${}^{pk}c_i$, the pick time, is the time it takes for the i'th component to be picked up by the robot from the CDS. The fifth term in Equation (3), ${}^{pl}_{r}t_i$, is the robot placement time, which is the time required for the robot to move from the pick location PK_i to the current placement location PL_i (see Figure 2).

The last term in Equation (3) is ${}^{sd}_{r}t_i$, the safety delay added by the heuristic collision avoidance function to prevent the robots from colliding with each other. The details of this function are beyond the scope of this paper.

AN EXAMPLE

To illustrate our solution method, a PCB population sequence of six components is chosen. The components are placed on a 100 x 100 mm PCB by two robots (Figure 1). The setup is identical to the one described in [3], with the exception of an additional identical placement robot. In the case presented herein, all devices are assumed mobile and the robot and CDS component assignments are optimized while ensuring no collisions occur. The optimal solution yields a total time of 0.784 s, compared to a single robot with a total time of 1.205 s. Figure 3 shows the optimal robot paths.

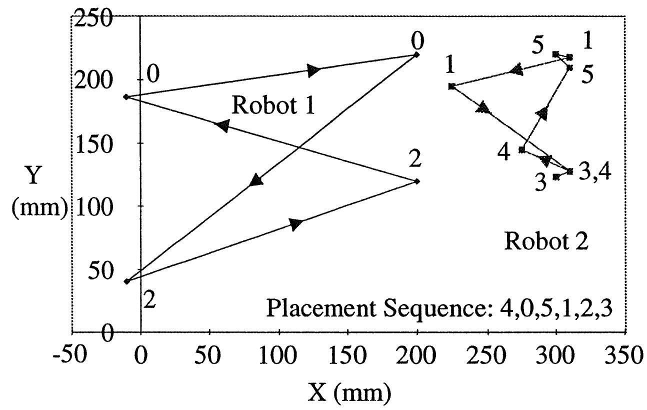

Figure 3: The two robots' placement paths.

SUMMARY

Our analyses clearly showed that further improvements in assembly time can be achieved by optimizing the movements of a two-robot assembly system, where the PCB table and the CDSs are also allowed to move.

References:

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