Feeder Layout Optimization and Feeding Sequence Optimization in High Speed and High Precision Placement Machine

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Abstract: As for the multi-optimization mutual coupling process optimization for mounting production with multiple 1210 or 1812 resistor components and the relatively low nozzle requirement, a fast multi-objective hierarchical optimization method with low matching requirement for parallel nozzle and placement sequence optimization is proposed. In the hierarchical structure, the nozzle optimization is constructed as a 0-1 integer programming optimization model for the first master hierarchy. In the second hierarchical, feeder optimization and picking order are parallel optimized based on the first hierarchy optimization. The respective problems related algorithm strategies have been proposed. The engineering experiments show that this Feeder layout optimization and Feeding sequence optimization method can significantly improve the overall performance of the multi-head placement machine with high speed and high precision.

1. Introduction

In SMT optimization models, the combination of mounting, extracting, nozzle and feeder is the main key problem affecting the overall time of printed circuit board production line. Lee and Park put forward a dynamic programming model of the feeder distribution for Multi-head gantry machine with high speed and high precision to reduce the computation time [1]. Tian Fuhou and Li Shaoyuan solve the problem of feeder assignment optimization using the genetic algorithm under the premise of components taking order and the mounting sequences are given [2]. Li Shaoyuan et al. propose a genetic algorithm based on negative as symbol of chromosome coding to optimize the feeder position distribution [3]. The sequencing problem of the picking and mounting cycle is modeled as a directed deliverer problem by Ball M-O and Magazine M-J, and the balance and connection heuristic algorithm is used to solve this problem [4]. The SMT machine optimization is modeled as multi-objective optimization problem by Chen Tie mei and Luo Jiaxiang and the genetic algorithm is used to solve the placement sequence and feeder assignment [5]. Established model and used intelligent algorithm in the above documents has good optimization effect. However, the working efficiency of the machine is often optimized through the combination of the feeder optimization and the sequencing optimization, and nozzle optimization study considered to improve the efficiency of the SMT machine is relatively few, especially the research of the nozzle optimization is combined with them is even fewer. A
component general can be used multiple nozzles. The matching degree between nozzles and components affect the speed of the SMT machine arm movement, mounting and feeding [6-8].

In this study, the 0-1 integer programming optimization model that nozzle matching degree and change number are as optimization goal is built in the least pick-and-place cycle premise. Picking, mounting and feeder layout are further optimized based on this optimization model.

2. The picking and placing process

The structure of multi-head gantry machine with high speed and high precision includes fixed PCB table, feeding bank, feeders, gantry equipped with many heads, heads, nozzles, automatic nozzle changer (ANC) and other parts. In the process of mounting, PCB is fixed on the table. Feeding bank is fixed at both sides of the PCB table. The feeder is installed on the feeding bank. Each feeder occupies one or more of the feeding slots and each feeder can load only one type components. Equipped with nozzle heads are installed in the gantry that can move forward or backward. All the components picking and mounting is done by nozzles. The distance between the heads is equal or the integer times of the distance between the feeding banks. So heads can suction more components at the same time (maximum component number is H, H is total number of heads). Pick-and-placement process is as follows: (1) Feeders equipped with components are installed in different positions of the placement machine feeding bank. Printed circuit board (PCB) through the conveyor belt is be delivered to the table and fixed. Nozzle on the heads pick up components either simultaneously or on one by moving along the feeder bank. (2) The heads move from feeder banks first to the cameras and then to the PCB table where the mounting operation is taken place. (3) In the next pick-and-place cycle, if there is one or more components in requiring a nozzle, heads will move to ANC for exchanging nozzles. Then pick up components again in feeders. (4) The picking and placing process is referred to as a pick-and-place cycle (Figure 1). The pick-and-place cycle processes will be repeated until all components are mounted on the PCB.

![Fig.1: A pick-and-place cycle](image)

In the mount process, Main factors influencing the efficiency of placement are component assignment, sequence of component placements, nozzle change and heads loads. Therefore, minimizing the replacement times of nozzle, maximizing the heads loads and arranging the location of the feeder reasonably and pick-and-place cycle of components can reduce the overall time of mount process and improve the efficiency. In this paper, the optimization goal includes: the minimum number of replacement of nozzle, the minimum number of pick-and-place cycle, as well as the minimum whole appropriateness degree of each pair of nozzle with the components, the most optimal sequence of component placements, the least number of feeding and the shortest moving distance.
3. Hierarchical multi-objective optimization method.
To solve optimization problems of the multi-head gantry machine with high speed and high precision, the two-hierarchy multi-objective optimization method has been proposed. Three optimization sub-problems is dealing with parallel at the same time in the second hierarchy. (1) Placement sequencing optimization of components. (2) Assignment optimization of feeders. (3) Sequencing optimization of components picking up. The second question is the main content of this paper.

3.1 Nozzle optimization and Sequencing optimization of placement
the total number of nozzle exchange and matching degree have defined the optimal goal. The following head-nozzle optimization model (1) is established.

$$\min a \sum_{k=1}^{K} \sum_{h=1}^{H} \left( X_{khq} - X_{(k+1)hq} \right) + b \sum_{k=1}^{K} \sum_{h=1}^{H} X_{khq} Z_{hhq} A_{q} \quad (I)$$

Sequencing optimization of placement site is defined $U = \{u_1, u_2, ..., u_N\}$, that $u_i$ is location coordinates on PCB for the ith sequence components in the set U. $r$ is the coordinates of the feeder bank in the most left. Based the $c_k$ and $m_{kt}$ obtained in the first hierarchy, the optimization model for each pick-and-place cycle is defined as Eq (II).

$$D = \min \left( \sum_{n=1}^{N-1} d(u_n, u_{n+1}) + \sum_{k=1}^{K} d(u_{\sum_{i=1}^{k} c_i}, r) - w \sum_{k=1}^{K} d(u_{\sum_{j=1}^{k} c_j}, u_{1} + \sum_{i=1}^{k} c_i) \right) \quad (II)$$

3.2 Feeder layout optimization and Feeding sequence optimization

Unilateral feed bank layout is considered in this paper. In subsequent process, feeding is done as far as possible at the same time to reduce the total number of feeding. Voting and grading are used to construct feeder layout according to the upper information. Flow diagram is shown in Fig.2. Then design exchange mechanism to guarantee each type of components in bank has a feeder. Flow diagram is shown in Fig.3. Voting and grading rule are as follows. Two components are picked up at the same
time which can win 2 points. Three components are picked up at the same time which can win 3 points. And so on, H components are picked up at the same time which can win H points (H is the number of heads).

The details of the algorithm are introduced:

Fig.3: The flow chart of replace mechanism for feeder layout

1. Initialization: There are S feeder bank on the feeding shelf. Let s=0, most of the components types (t) will be needed for PCB are put on the s feeder bank (s=0 which is corresponding center of the feeder shelf). \( t_s \) is the feeder bank that components of type t are assigned to s. Components of type t are counted \( \Gamma_t = \{ \pi_{tr1}, \pi_{tr2}, ..., \pi_{tr(h-1)}, \pi_{tl1}, ..., \pi_{tl(h-1)} \} \) according to its corresponding \( Z_{kh} \).

   \[ \pi_{tr} = \left\{ \left( r_{tr_i}, tol_{tr_i} = i \times \text{num} \right), \ldots \right\} \]
   \[ \pi_{tl} = \left\{ \left( l_{tl_i}, tol_{tl_i} = i \times \text{num} \right), \ldots \right\} \]

   note the components of type \( r_{tr} \) are assigned to ith nozzle from the right when the current nozzle installed components of type t. num is the number of times the combination appears in the whole mounting. \( tol_{tr} \) is score. Similarly, \( \pi_{tl} \) is arranged respectively in descending order.

2. Let s=s+1, if s is odd: When s<H, the total scores are counted according to the part \( \pi_{tr} \) of \( \Gamma_t \):

   \[ tol_{tr} = \sum_{i=1}^{s} tol_{tr_{s-i}} \]

   When \( s \geq H \), the total scores are counted according to the part \( \pi_{tl} \):

   \[ tol_{tl} = \sum_{i=1}^{H-1} tol_{tl_{s-i}} \]

3. The corresponding components of the maximum for \( tol_{tr} \) are installed on the s. if s<S-1, go to (2).

4. Based on the position that s = 0 is the center of feeder bank, the overall is translated to the feeder shelf. The feeder initial layout is constituted. If the current scheme can guarantee all the component types to have feeder bank, feeder layout scheme (W) is completed, end; otherwise, turn the following exchange mechanism.

5. Collection of components type that are not assigned to feeder bank in layout scheme (W) is \( \Lambda = \)
\{t_A \in T: t_A \text{ without feeder bank}\}. Randomly choose the type of components from \Lambda to be as exchange type \(t_A\). Count \(\Gamma_{t_A}\).

6 Count the collection more than a component types \((\Omega_t = \{(t, s_t)\})\) in the layout \(W\). \(t\) is the component type. \(s_t\) is the set bank index number.

7 Select \(t\) from \(\Omega_t\) in turn. \(t_j\) that the corresponding bank for \(t_A\) and \((\Omega_t = \{(t, s_t)\})\) is translated into feeder bank of \(t_A\). According \(\Gamma_t\) and \(\Gamma_{t_A}\) of component \(t\), scores \(tol_{t_j}\) of component \(t\) in bank \(t_j\) and the scores \(tol_{t_A}\) that obtained by \(t_A\) is placed in \(t_j\) are counted. This can get score marginal benefit \(\Delta tol = (tol_{t_A} - tol_{t_j})\). Finally select the bank with maximum marginal benefit value for feeder bank of \(t_A\). The new layout is \(W\).

8 Remove \(t_A\) from \(\Lambda\), if \(\Lambda\) is empty, the current \(W\) is as feeder layout scheme, end; otherwise, go to (5).

3.3 Feeding sequence optimization

After completion of the feeder layout, the maximize the feeding times at the same time is as the goal. Use the upper information and heuristic greedy algorithm to optimize the feeding sequence. The process is shown in Fig.4.

\[\begin{align*}
\alpha_k & \text{ is the number of feeding for kth cycle. } HS_k^{(1)} = \{(s^1, hs^1), (s^2, hs^2), (s^{a_1}, hs^{a_1})\} \text{ is set of corresponding feeding for the heads in k cycle. } s^i \text{ is feeder index on the corresponding shelf of head index is in ith feeding under this cycle. } hs^i \text{ is the 0-1 vector of H dimension, which is used to represent the load of each nozzle. 0 show that the nozzle on the heads without loading components. We can get the picking information every time by } HS_k. \text{ The greedy algorithm is used to construct new heuristic algorithm as following.} \\
(1) & \text{ Let } k = 1, k \leq K \\
(2) & \text{ Let } \alpha_k = 1, hs^0 = (0,0,...,0), HS_{k} = \emptyset. \text{ According to the upper information } m_{kt}, \text{ the components set is } F_k = \{t \in T: m_{kt} > 0\} \text{ in k pick-and-place cycle. According to the feeder layout } W, \text{ the Optimization set } \omega_k = \{s_t \in S: t \in F_k\} \text{ of the feeding position can be obtained. Combined with } F_k \text{ and } \omega_k \text{ of the maximum }
\end{align*}\]
feeding at the same time are searched. \( HS_k = HS_k \cup H_{S_k}^\alpha \); If \( F_k = F_k - F_{k}^{\alpha_k} \neq \emptyset \), let \( \alpha_k = \alpha_k + 1 \), Continue(3).

(4) The element in \( HS_k \) is arranged according to the size of the s bank by ascending order, let \( k = k + 1 \), if \( k > K \), end; otherwise, go to (2).

4. Results and discussion
Literature [1] only consider feeder optimization and sequence optimization problem, nozzle optimization does not take into account. This method with the component type and nozzle type are less that the optimization results are better than the algorithm in this paper. But through the nozzle and components matching optimization, the whole optimization efficiency of procedure time is better than the method of literature [1]. From the second group experiments can be clearly seen: Along with the more demands on nozzle types, the method in this paper obviously can get the whole mounting performance better than Literature [1].

5. Conclusion
The second level parallel consideration with mounting sequence optimization and feeding optimization of the feeder layout are parallel considered in the second hierarchy. In the feeding optimization problems of feeder layout, as much as possible to feed at the same time and reduce the total picking times. Voting and grading are used to construct optimization scheme according to the layout of the feeder problem. Heuristic greedy algorithm is used to construct the maximized feeding sequence scheme at the same time. The method in this paper has obviously performance optimization for the requirements are relatively high in the PCB mounting process.

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