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ORIGINAL ARTICLE

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A genetic algorithm approach to optimising component placement and retrieval sequence for chip shooter machines

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Abstract A chip shooter machine in printed circuit board (PCB) assembly has three movable mechanisms: an X-Y table carrying a PCB, a feeder carrier with several feeders holding components and a rotary turret with multiple assembly heads to pick up and place components. In order to get the minimal placement or assembly time for a PCB on the machine, all the components on the board should be placed in a perfect sequence, and the components should be set up on a right feeder, or feeders since two feeders can hold the same type of components, and additionally, the assembly head should retrieve or pick up a component from a right feeder. The entire problem is very complicated, and this paper presents a genetic algorithm approach to tackle it.

Keywords Chip shooter machines · Component retrieval · Component sequencing · Feeder arrangement · Genetic algorithms

1 Introduction

Nowadays, the highly competitive electronic industry has forced the PCB manufacturers to optimise the placement process, which is the most time consuming one among the PCB assembly processes, for achieving a higher throughput rate. In order to optimise the placement process, several optimisation problems should be considered [1]. They include the assignment of components to machines, that is, the component allocation problem, the assignment of component types to feeders, that is, the feeder arrangement problem and the sequencing of component placements, that is, the component sequencing problem. In this paper, the component sequencing and the feeder arrangement problems are considered for a chip shooter machine. Along with these two problems, an additional optimisation problem is also taken into consideration. It is due to the fact that some components of the same type may be in hundreds or more. The movement of the feeder carrier can be reduced if two feeders are arranged for holding such component types with frequent use. As a consequence, the placement or assembly time can be minimised. In case some component types are assigned to two feeders, it is then necessary to determine which feeder a component should be retrieved from, that is, the component retrieval problem. So, the problem we face in this paper is to solve the component sequencing, the feeder arrangement and the component retrieval problems for the chip shooter machine, with the objective of minimising the total placement time.

Since the placement time is also dependent on which type of components a feeder holds besides the pick and placement sequence in the chip shooter machines, hence the three sub-problems should be simultaneously studied and solved. Actually, the individual sub-problems are already very hard and complex [2]. Moreover, the problem sizes in the real cases prohibit the effective use of deterministic approaches. So, a genetic algorithm is developed to solve the combined problem of the three sub-problems in order to obtain good solutions in a reasonable amount of time.

The chip shooter machine is the most commonly used due to its high speed. The machine, as shown in Fig. 1, consists of a movable X-Y table carrying a PCB, a movable feeder carrier with several feeders holding components and a rotary turret with multiple assembly heads (usually 10 or 12). Each assembly head has several (normally five) nozzles with different sizes. A large nozzle is used to pick up and place large components. The operation sequence of the chip shooter machine is that: As the first board of a batch enters the machine, the first nozzle of the turret picks up a component from a feeder. Then the turret indexes one step and the next nozzle picks up the second component. After that the turret indexes again to pick up the next component, and so on. In the same moment, the PCB is moved to the placement location waiting for the first component to be placed on the board. When the sixth component is being picked up if the turret has 10 heads, the first component is being placed on

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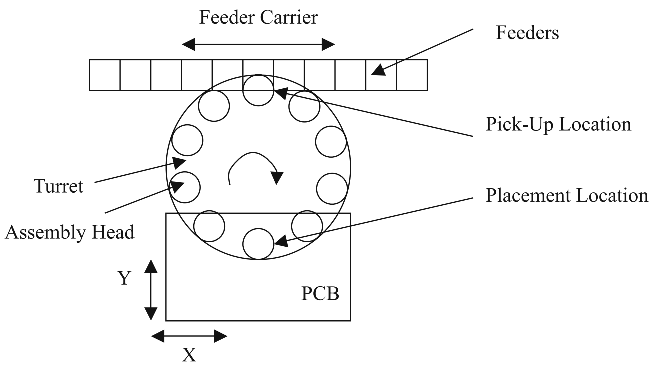

Fig. 1. The schematic diagram of the chip shooter machine

the board at the same time. These operations continue such as the turret indexes one step, the feeder carrier moves to the location containing the next pick-up component, and the X-Y table moves to the next placement location. In the assembly of the last five components, there is no need to pick up components for the board being assembled. However, the nozzles of the turret can pick up the first five components for the next board to be assembled if necessary. For the first few components assembled in a batch of PCBs, there are only pick-up movements and no placement movement. For the last few components of the same batch, there are only placement movements and no pick-up movement. Therefore, if the PCB's quantity in a batch is very large, these boundary effects can be neglected [3].

2 Literature review

There are a number of researches concerning the optimisation of the component sequencing problem, the feeder arrangement problem, and the component retrieval problem for the chip shooter machines. However, many of them focused on the individual problems for the machine. Some researchers [4, 5] studied the component sequencing problem only, whereas some researchers [6–8] worked on the feeder arrangement problem alone. Similarly, Crama et al. [9] also investigated the component retrieval problem merely for a chip shooter machine.

Besides, many researchers solved the problems separately for the chip shooter machines. Bard et al. [10] used an iterative two-step approach to determine the component placement sequence, the feeder arrangement, and the component retrieval plan. Although three problems were considered, they were solved separately. Sohn and Park [11] formulated the component sequencing and the feeder arrangement problems as a nonlinear programming model while using the one-head case as an approximation to the multi-head case. A heuristic approach was developed to solve the problems sequentially. Yeo et al. [12] developed a rule-based frame system to generate the feeder arrangement first, followed by the component placement sequence for a chip shooter machine. Crama et al. [2] proposed a solution procedure based on a hierarchical decomposition of the planning problems for a chip shooter machine. They solved the feeder arrangement problem heuristically first, and then solved the problems of component sequencing and the component retrieval using the constructive heuristics and the local search methods. Ellis et al. [13] developed a heuristic approach to determine the component placement sequence first, and then the feeder arrangement for a chip shooter machine.

Leu et al. [3], Moyer and Gupta [14], and Ho and Ji [15] studied and solved the component sequencing and the feeder arrangement problems simultaneously for a chip shooter machine. However, none of them have mentioned the component retrieval problem. Therefore, in this paper, a hybrid genetic algorithm is presented to solve the combined problem of the three sub-problems simultaneously for the machine.

3 Hybrid genetic algorithm

The success of genetic algorithms (GAs) in solving a wide variety of complex optimisation problems [16] and the advantages of GAs such as simplicity, easy operation and great flexibility have prompted us to apply GA to solve the combined problem. As mentioned in Sect. 1, the problem we face in this paper can be regarded as the combination of three hard optimisation problems. So, a simple GA may not perform well in this situation. The GA developed in this paper is therefore hybridised with several heuristics in order to improve the solution further. However, it was found that none of the researchers have studied the three sub-problems for the chip shooter machine using a hybrid GA (HGA). The flowchart of the HGA for the combined problem is illustrated in Fig. 2. The algorithm is so called because three heuristics are incorporated in it. First, the nearest neighbor heuristic (NNH) is applied for generating the first link, which is the sequence of component placements, in the initial population. Second, a heuristic called the iterated swap procedure (ISP) [15] is applied to improve the first link. Third, the 2-opt local search heuristic is adopted to improve the second link, which is the feeder arrangement. Actually, the principle of the ISP is very similar to that of the 2-opt local search heuristic, except that some instead of all 2 swaps are examined. The computational effort will be high if the 2-opt local search is performed on the first link because the number of components is quite large, normally several hundred.

Besides, the roulette wheel selection operation is adopted in the HGA to select chromosomes to perform the genetic operations, which include one crossover and two mutations. They are the modified order crossover [15], the heuristic mutation [16] and the inversion mutation [16]. Generally, GAs developed especially for the PCB assembly problems are not limited to using one crossover and one mutation. Due to the complexity of the problems, several genetic operations will be adopted [3].

In the following sub-sections, the way of representing a chromosome for the combined problem of the three sub-problems for a chip shooter machine is explained first, followed by the discussion of the component retrieval plan. After that, the fitness function for calculating the total placement time of a chromosome is presented.