Optimization of PCB component placements for the collect-and-place machines

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Abstract This paper presents two hybrid genetic algorithms (HGAs) to optimize the component placement operation for the collect-and-place machines in printed circuit board (PCB) assembly. The component placement problem is to optimize (i) the assignment of components to a movable revolver head or assembly tour, (ii) the sequence of component placements on a stationary PCB in each tour, and (iii) the arrangement of component types to stationary feeders simultaneously. The objective of the problem is to minimize the total traveling time spent by the revolver head for assembling all components on the PCB. The major difference between the HGAs is that the initial solutions are generated randomly in HGA1. The Clarke and Wright saving method, the nearest neighbor heuristic, and the neighborhood frequency heuristic are incorporated into HGA2 for the initialization procedure. A computational study is carried out to compare the algorithms with different population sizes. It is proved that the performance of HGA2 is superior to HGA1 in terms of the total assembly time.

Keywords Printed circuit board manufacturing · Collect-and-place machines · Genetic algorithms · Component grouping · Component sequencing · Feeder arrangement

1 Introduction

The printed circuit boards (PCBs) have been extensively applied in numerous contemporary electronic products such as personal computers, mobile phones, and audio-video equipment. This has placed an unprecedented demand for PCBs. Besides, customers’ changing needs, such as for smaller product size and more functions, are forcing surface mount technology (SMT) to replace the plated-through-hole technology. The PCB assembly process in the SMT environment consists of five major operations. First of all, solder paste is applied to where the electronic components will be placed on. Typically, it is applied in a screen print fashion. Then, it is followed by the placement operation. A high-speed placement machine (e.g., the chip shooter machine) is used to mount small components such as chip resistors on the PCB first. A flexible placement machine (e.g., the pick-and-place machine) is then adopted to mount large components such as integrated circuits on the PCB. After all the components have been assembled, the PCB is inspected whether there is any missing component or not. Subsequently, the PCB is conveyed through an oven, which causes the solder paste to reflow and form the solder joints. Finally, the PCB must be cleaned in order to remove the contaminants exposed during fabrication and assembly.

Among the assembly operations, the component placement one is generally the most time-consuming [28, 29, 34]. In addition, it is frequently a bottleneck of an assembly line [7, 8, 29], and determines the line’s cycle time [35]. Evidently, the throughput rate of a PCB manufacturing company or the company’s competitiveness can be increased if the component placement process is optimized. So, the focus of this paper is confined to the optimization of the component placement process. The objective is to minimize the placement time spent for assembling all electronic components to a board using an SMT placement machine.
In PCB assembly, there are several types of SMT placement machines. Each type of machines possesses its own peculiarities as well as operation. Among them, the three most popular types are the pick-and-place, chip shooter, and collect-and-place (CAP) machines. In the pick-and-place machine, components of the same type are stored in a single stationary feeder, whereas the PCB is secured on a fixed working table. During the placement operation, the assembly head travels to pick up one component at a time from a feeder, and then places it on the stationary board. The pick-and-place machine can achieve high accuracy. Moreover, it is suitable for operating with large components such as integrated circuits.

The second type of machine is the chip shooter machine. It possesses 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. Each assembly head has several nozzles of different sizes. A large nozzle is used to pick up and place large components. The major advantage of the chip shooter machine is its high speed because the pickup and placement operations are performed concurrently. However, it is only preferable for operating with small components such as chip resistors.

In the last two decades, the component placement problem has been studied thoroughly for both pick-and-place machine [2, 4, 10, 11, 16, 17, 19, 22–24, 28], and chip shooter machine [3, 6, 8, 9, 15, 18, 21, 23, 25–27, 29, 33–36]. Due to this reason, this paper studies the component placement problem for the CAP machine.

The CAP machine, as shown in Fig. 1, combines the advantages of the pick-and-place machine and those of the chip shooter machine. It can assure high placement accuracy and also achieve high placement speed. Furthermore, it is suitable for operating with a wide variety of components ranging from chip resistors to integrated circuits. This type of machines has multiple stationary feeders holding components, a stationary working table securing a PCB, and two or even more revolver heads with several vacuum nozzles (normally, 12). Each feeder of the machine can only hold components of the same type. In this paper, three basic assumptions are made. First of all, the CAP machine being studied consists of one revolver head in which there are 12 nozzles. Second, the head is always fully loaded with 12 components except for the final assembly tour. Third, each component type can only be assigned to a single feeder. The operation sequence of the CAP machine is that: The revolver head moves from its original location to a stationary feeder carrying components at the beginning. The first nozzle of the head picks up a component at a time, and then rotates one step. The second nozzle of the head picks up another component from the previous feeder if the next component is the same type with the previous one or moves to another feeder to pick up the next component if it is different from the previous one. The head repeats this pick-up operation until the head is fully loaded. After that, the head travels to the PCB, and places the components on it sequentially. This operation procedure is regarded as an assembly tour in which the placement sequence is the same as the pick-up sequence. In addition, the revolver head performs stepwise rotational movements only in one or forward direction while reverse rotation is not allowed. Another assembly tour is carried out until all components are placed on the board.

In order to minimize the assembly time for the CAP machine, three interrelated problems should be solved simultaneously. They include the assignment of components to assembly tours or which set of components is placed by the same assembly tour (i.e., the component grouping problem), the determination of component placement sequence (i.e., the component sequencing problem), and the arrangement of component types to feeders (i.e., the feeder arrangement problem). Since the traveling distance or assembly time is dependent on all these three problems, they are studied and solved in this paper.

This paper is organized as follows. Section 2 reviews the relevant literature concerning the component placement problem for the CAP machine. Section 3 describes two hybrid genetic algorithms for optimizing the component placement problem. Section 4 compares the performance of the algorithms, and studies the effect of population sizes on the solutions’ quality. Finally, Sect. 5 concludes the paper.

2 Literature review

To our best knowledge, there are only three publications in the international literature studying the component placement problem for the CAP machine. Altinkemer et al. [1] formulated a mathematical model for the component