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Invited Review

A survey of surface mount device placement machine optimisation: Machine classification

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Abstract

The optimisation of a printed circuit board assembly line is mainly influenced by the constraints of the surface mount device (SMD) placement machine and the characteristics of the production environment. This paper surveys the characteristics of the various machine technologies and classifies them into five categories (dual-delivery, multi-station, turret-type, multi-head and sequential pick-and-place), based on their specifications and operational methods. Using this classification, we associate the machine technologies with heuristic methods and discuss the scheduling issues of each category of machine. We see the main contribution of this work as providing a classification for SMD placement machines and to survey the heuristics that have been used on different machines. We hope that this will guide other researchers so that they can subsequently use the classification or heuristics, or even design new heuristics that are more appropriate to the machine under consideration.

Keywords: Scheduling; Printed circuit board assembly; Component placement sequencing; Feeder setup; Heuristic

1. Introduction

SMT (surface mount technology) assembly lines usually involve solder paste, component placement and solder reflow operations (a soldering process to adhere components to the printed circuit board (PCB)) (Tirpak, 2000). An SMD (surface mount device) placement machine is very expensive (US$300,000 to US$1,000,000) and yet SMT lines are typically designed such that the SMD placement machine is the limiting resource or "bottleneck" which is the key issue for assembly line optimisation (Csaszar et al., 2000a; Moyer and Gupta, 1997; Tirpak et al., 2000).

Typically, the placement operation begins by loading the PCB into the SMD placement machine (e.g. via a conveyer system). Next, a "fiducial marks" operation is performed to identify the exact position and orientation of the PCB inside the

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SMD placement machine. The "fiducial marks" are special points (typically 2–4 points) that are usually located at the corners of the board (Magyar et al., 1999). Then, the components are assembled onto the PCBs guided by the optimisation software that has been installed in the SMD placement machine. Finally, once completed (or partially completed, e.g. due to component runs out or job completion), the PCB is transferred out of the SMD placement machine. Before undergoing a solder reflow operation, the components are secured onto the PCB by using adhesive or solder paste (Leu et al., 1993).

Owing to the lack of standardisation among SMD placement machines, the optimisation of the pick-and-place operations in a PCBA (printed circuit board assembly) line is mainly influenced by the constraints of the SMD placement machine and the characteristics of the production environment (Duman and Or, 2004; Leipälä and Nevalainen, 1989; Shih et al., 1996). Crama et al. (2002), Jeevan et al. (2002) and Sun et al. (2005) also agree that the technological characteristics of the placement machine influences the nature of some of the planning problems to be solved and the formulation of the associated models. As a result, little consensus exists as to what a suitable model should be for the characteristics of a given machine, and the formulations proposed by different authors tend to be difficult to compare.

Electronic components (possibly hundreds or thousands) are assembled onto a PCB using an SMD placement machine. Optimisation of the feeder setup and component pick-and-place sequence, are important factors, which influence the efficiency of SMD placement machines. Faced with mounting hundreds of electronic components, of different shapes and sizes, finding an optimal travelling route for the robot arm of the SMD placement machine is a challenging optimisation problem (Su and Fu, 1998). In general, the component pick-and-place sequencing problem is modelled as a travelling salesman problem (TSP), which is a strongly NP-hard (Garey and Johnson, 1979; Truss, 1999) problem. Hence, this problem is also a strongly NP-Hard optimisation problem and most practical instances are difficult to solve to optimality in a reasonable time (Ellis et al., 2001; De Souza and Lijun, 1995). Indeed, the general PCB assembly problem is at least as complex as the TSP, which is known to be NP-complete (Nelson and Wille, 1995).

The complexity of concurrent machine operations also causes difficulties in formulating a realistic mathematical programming model (De Souza and Lijun, 1995). Many technical constraints also have to be considered (De Souza and Lijun, 1995). These include:

(a) The head(s), feeder carrier(s) and PCB table(s) usually move independently and at different speeds. Indeed, the speed changes when different sized components have to be placed.
(b) Smaller size components are usually placed before larger sized components since the larger components that have already been placed may be displaced when the placement heads and the PCB table increase their speed in order to place smaller components.
(c) Since the head(s), feeder carrier(s) and PCB table(s) move concurrently, the movement should be considered simultaneously in order to improve the throughput of the machine.

Due to the problem size, it is not realistic to use mathematical programming approaches. Alternatively, the problem has to be generalised or simplified (Moyer and Gupta, 1996a). For example, Ahmadi (1993), Ball and Magazine (1988), Bard et al. (1994), Chiu et al. (1991), Crama et al. (1996, 1997), Gavish and Seidmann (1988), Leipälä and Nevalainen (1989) and Van Laarhoven and Zijm (1993) have abstracted the problem by isolating it into subproblems. A heuristic approach which finds a near-optimal solution in an acceptable time is, therefore, more appropriate in solving the problem (De Souza and Lijun, 1995).

The structure of this paper is as follows. In the next section we describe the characteristics of various SMD placement machines and their operational methods, and also discuss some of the optimisation issues that arise. In Section 3, we classify the SMD placement machines into five categories, based on their specifications and operational methods. In Section 4, we survey each of the machine classifications described in Section 3, with respect to the heuristic methods that have been used on these machines. Section 5 concludes the paper.

This work represents a significant extension to our previous survey (Ayob et al., 2002). We hope that researchers find it a useful resource in being able to classify various SMD machines and also provide access to the literature as to the heuristics that are available.

2. Surface mount device placement machines

In the early 1980s, the first pick-and-place SMD placement machine, with only one placement head, was introduced (Bentzen, 2000). Nowadays, there are many types of SMD placement machines available, such as sequential pick-and-place, rotary disk turret, concurrent pick-and-place, etc. (Grotzinger, 1992; Gastel, 2002; Khoo and Loh, 2000). As different SMD Placement machines have different characteristics and constraints this, inevitably, influences the production process (Burke et al., 2001; Wang et al., 1999).

To date, SMD placement machines have been classified into a few categories. For example, Moyer and Gupta (1996a,b, 1997) defined three types of typical SMD placement machines, these being single compliance robot for assembly (SCARA), cartesian/gantry and high speed chip shooter. SCARA machines are usually pick-and-place machines, which have three joints that permit greater flexibility within the work area. Generally, SCARA machines are recommended for high mix, low volume assemblies as well as for odd shape components (Moyer and Gupta, 1998). The cartesian/gantry SMD placement machine has better throughput compared to SCARA. However, Moyer and Gupta (1996a,b, 1997) do not discuss the machine specification and operation. The high speed chip shooter SMD placement machine has a turret head that rotates between fixed pickup and fixed placement locations. However, these mechanical attributes do not generally affect the optimisation problems that have to be addressed.

There was also an attempt to classify the placement machines based on basic operational methods, these being concurrent and sequential, by McGinnis et al. (1992), or fixed pick-and-place point (FPP) and dynamic pick-and-place point (DPP) by Wang et al. (1998). Just having two categories, however, is not broad enough to allow the formulation of optimisation problems, which can be applied to many different machine types. Recently, Magyar et al. (1999) classified the placement machines into three categories, these being insertion, pick-and-place and rotary turret machines; whereas Bentzen (2000) classifications were turret head, pick-and-place and pick-and-place with rotary head; and Jeevan et al. (2002) classified them as multi-head, high speed chip shooter machine and robotic arm placement machine. However, they do not explicitly discuss the machine characteristics and the operational methods. Again, these three categories are too broad. Therefore, this work proposes five categories of machines based on their specifications and operational methods; these being dual-delivery, multi-station, turret-type, multi-head and sequential pick-and-place SMD placement machines. This grouping aims to guide future researchers in this field to have a better understanding of the various SMD placement machine specifications and operational methods, and subsequently use them to apply, or even design, heuristics which are more appropriate to the machine characteristics and the operational methods.

A typical SMD placement machine usually has a feeder carrier (or feeder magazine), PCB table, head, pipette (or spindles) and a tool magazine (tool bank). The feeder carrier, PCB table and head can either be stationary or moveable, depending on the specification of the machine. The feeder carrier is mounted on one, two, three, or four sides of the machine and holds several feeder banks. The feeder bank consists of several feeder slots where the component feeders are located. The component feeders are used to provide the machine with a continuous supply of components. Several kinds of component feeders are available to handle the various types of component packaging; tape, sticks and trays (or waffle). Fig. 1 shows an example of an SMD placement machine (pictured at the Dima factory).

A typical component feeder consists of either tape reel feeders or vibratory ski slope feeders; or both (Ahmadi et al., 1988; Jeevan et al., 2002). The positioning of the feeder reels or vibratory ski slope feeders, in the feeder carrier, is an optimisation problem in itself. The component feeders might have different widths and several slots may

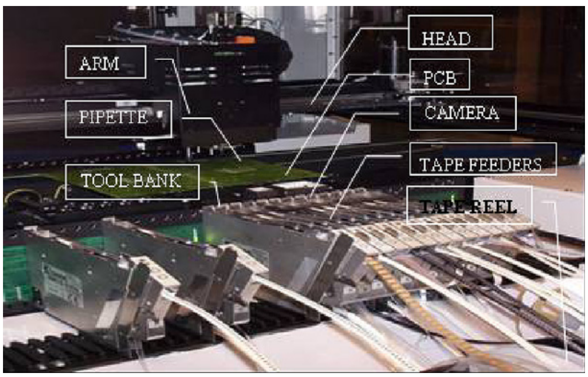

Fig. 1. An example of an SMD placement machine (Dima HP-10).