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An improved Shuffled Frog-leaping Algorithm to optimize component pick-and-place sequencing optimization problem

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A B S T R A C T

The component pick-and-place sequence is one of the key factors to affect the working efficiency of the surface mounting machine in the printed circuit board assembly. In this paper, an improved Shuffled Frog-leaping Algorithm was presented by improving the basic Shuffled Frog-leaping Algorithm (SFLA) with the strategy of letting all frogs taking part in memetic evolution and adding the self-variation behavior to the frog. The objective function of component pick-and-place sequence of the gantry multi-head component surface mounting machine was established. Parameters selection is critical for SFLA. In this study, Three-way ANOVA was used in parameters analyzing of the new improved SFLA. The parameters like memeplex numbers m, the frogs' number P and local evolution numbers i_{Part} were found having notable effects on the mounting time (time spent for components picking and placing), but the interactions among these parameters were not obvious. Multiple comparison procedures were adopted to determine the best parameter settings. In order to test the performance of the new algorithm, several experiments were carried out to compare the performance of improved SFLA with the basic SFLA and the genetic algorithm (GA) in solving the component pick-and-place sequence optimization problems. The experiment results indicate that improved SFLA can solve the optimization problem efficiently and outperforms SFLA and GA in terms of convergence accuracy, although more CPU time is undeniably needed.

1. Introduction

The traditional, manual, plug-in assembly method cannot meet the requirements of the printed circuit board (PCB) components installation which is characterized by miniaturization, micromation, chip-based, and high performance. The assembly costs, product quantity, volume, and reliability of the manual plug-in assembly method have reached their limit. Meanwhile the Surface Mount Technology (SMT) showed great vitality and was used widely in industrial applications. In SMT, the gantry multi-head component surface mounting machine is the most flexible one that can fit the widest range of components. Therefore, this kind of machine has the most extensive range of applications (Ashayeri, Ma, & Sotirov 2011; Ayob & Kendall, 2008; Kallio, Johnsson, & Nevalainen, 2012; Luo & Liu, 2013). The operation efficiency of the gantry component surface mounting machine has become one of the bottlenecks for the development of surface mounting equipment. The problem of operation efficiency is a typical surface mounting technical optimization problem with three sub-problems: the feeder slots location assignment, the component picking sequencing optimization, and the component placing sequencing optimization (Altinkemer, Kazaz, Köksalan, et al., 2000; Ho & Ji, 2003; Shayeri, Ma, & Sotirov, 2011; Wu, Ji, & Ho, 2009). These sub-problems are known to be NP-hard, with the characteristics of high dimension, discrete and nonlinear. The global optimal solution is not easy to obtain with the traditional method (Chang, Huang, & Ting, 2012; Torabi, Hamedi, & Ashayeri, 2013).

Many researchers have tried to solve these three sub-problems with various intelligent optimization algorithms. The multilayer neural networks were trained by Vainio et al. to approximate the assembly times of two different types of assembly machines based on several parameter combinations (Vainio, Maier, Knuutila, et al., 2010). Li and Tian (2008) solved the feeder location distribution problems with a genetic algorithm (GA) on the basis that the component pick-and-place sequence had been given. With a genetic algorithm (GA), Kulaka, Yilmazb, and Güntherb (2007) tried to solve the assignment of feeders to slots in the component magazine and the sequencing of the placement operations for collect-and-place machines. In his work, a revolver-type placement head was used to mount electronic components onto the board. Grunow, Güntherb, Schleusener, and Yilmaz (2004) presented a three-stage heuristic solution approach to solve operations

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planning for collect-and-place machines. Ho and Ji (2003) optimized the sequence of component placements and the arrangement of component types to feeders simultaneously with a Hybrid Genetic Algorithm (HGA) for a chip shooter machine, which produced more satisfactory results than what had been achieved prior to this point in time. Hong, Lee, Lee, et al. (2000) presented a method in which the feeder group was considered as one feeder and the component-cluster, with many various component models, as one model. Therefore the multi-heads problem was converted as a single head pick-and-place machine optimization problems. A biological immune algorithm was then adopted to solve this problem, and a better optimization solution was obtained when compared with the heuristic algorithm, which was adopted in an engineering project (Hong et al., 2000). Based on the analysis of these three sub-problems, a synthesized objective function was proposed by Chen and Lin (2007), and the particle swarm optimization (PSO) algorithm was adopted to solve the pick-and-place sequence optimization problem. Nozzles selection is an important sub-problem of the scheduling optimization problem of the surface mounting machine. The efficient greedy algorithms were used by Ráduly-Baka, Knuutila, Johnsson, and Nevalainen (2008) to solve the nozzles selection problem. Ráduly-Baka, Knuutila, Johnsson, and Nevalainen Olli (2010), Ráduly-Baka, Knuutila, Johnsson, and Nevalainen Olli (2011) also pointed out that the insertion of certain component types caused a delay in the movement of the component tape. The problem of assigning components to the sequencer was studied to minimize the tape construction delay. An integer programming formulation was created to describe the problem and an optimization algorithm was presented to minimize the component insertion time caused by the delay. The random restart hill climbing algorithm was used by Costa Filho, de Oliveira, and Costa (2010) to minimize the mounting time of components in a printed circuit board. Based on the extensive study of the different SMT optimization researches, Ayob and Kendall (2008) determined that all of the existing research had deficiencies. First, the characteristics and operational methods of the component placement machine were not clearly given, therefore the objective function was not clear; secondly, the moving distance of the heads or printed circuit board was often used as the mathematical expression of the object for formulating the objective function. They thought the type of component placement machines must be decided. However the mounting time, rather than the moving distance, should in fact be used for establishing the objective function in solving these kinds of optimization problems.

In solving surface mounting problems, we found that there exists a direct relationship between the distribution of the location of components on the feeders and the position of the slots in the component surface mounting machine. Since there are 80 slots in both the front and the rear sides of some gantry multi-head component placement machines (such as JUKI2050M and JUKI2010F), the number of component types can meet the requirements of some PCB mounting. Thus, the components' location on the feeder can be predetermined. The surface mounting technical optimization problem can then be converted to the component pick-and-place sequencing optimization problem that was similar to the well-known vehicle-routing problem (Grunow et al., 2004). Therefore, in order to overcome the shortcomings of the existing studies, this research will use the surface mounting time as the object to establish the objective function (the mathematical model) of the component pick-and-place sequencing optimization. The Shuffled Frog-leaping Algorithm (SFLA) was improved and a new Shuffled Frog-leaping Algorithm is presented and applied in the pick-and-place sequencing optimization.

SFLA was initially proposed by Eusuff and Lansey (2003) and successfully applied to the water resource net distribution. Favorable results were achieved (Eusuff & Lansey, 2003; Eusuff, Lansey, & Pasha, 2006). The algorithm was also used to solve other significant challenges, such as the workshop dispatch problem (Alireza & Ali, 2008; Alireza, Mostafa, Hamed, et al., 2009), a lot-streaming flow shop scheduling problem (Pan, Wang, Gao, & Li, 2011), Jiles–Atherton (JA) model parameter determination (Naghizadeh, Vahidi, & Hosseinian, 2012), the resource-constrained project scheduling problem (Fang & Wang, 2012), the estimation of induction motor double-cage model parameters (Gomez-Gonzalez, Jurado, & Perez, 2012; Perez, Gomez-Gonzalez, & Jurado, 2013), the economic load dispatch problem (Roy, Roy, & Chakrabarti, 2013), the performance evaluation of radial distribution networks (Gomez-Gonzalez, Ruiz-Rodriguez, & Jurado, 2014), the 0/1 knapsack problem (Bhattacharjee & Sarmah, 2014), and the vehicle routing problems (Luo & Chen, 2014). This algorithm has been of considerable interest in recent years as a population-based technique for optimization. The most significant benefit of this algorithm is fast convergence with accurate results and easy implementation and tune (Naghizadeh et al., 2012). Because of the obvious advantages of SFLA, this algorithm was selected and studied to solve the pick-and-place sequencing optimization problem.

The remainder of the paper will discuss the following: Section 2 establishes the objective function of the pick-and-place scheduling problem for the gantry surface mounting machine; Section 3 describes the basic SFLA; Section 4 represents improved SFLA based on the improvement of the basic SFLA and the method is given; Section 5 compares the performances of improved SFLA, the basic SFLA and GA, and the parameters of improved SFLA are analyzed through experiments. The research results are presented in Section 6, which indicate that improved SFLA outperforms the basic SFLA and GA in terms of accuracy but more CPU time is indeed consumed. Future research works are also stated in this section.

2. Components mounting sequence description and the objective function

The structure of the gantry multi-head component surface mounting machine is illustrated in Fig. 1. The gantry robot with four heads moves between a feeder rack and the PCB. The feeders are mounted on the slots in the feeder rack. A PCB is transferred

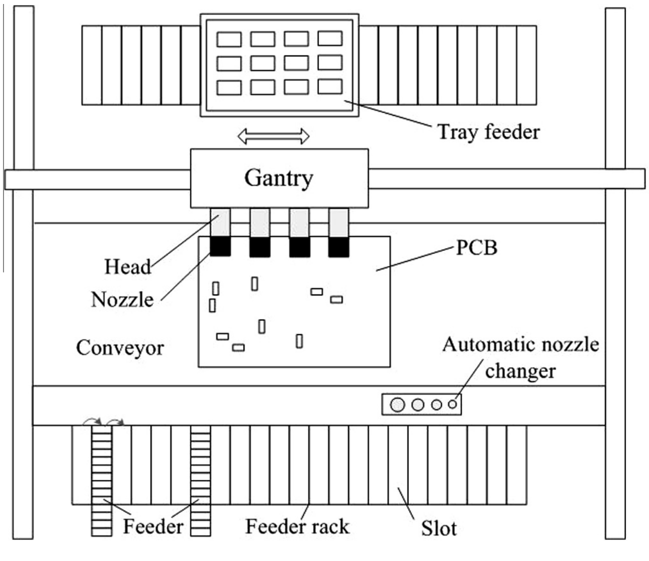

Fig. 1. The gantry multi-head component surface mounting machine.