Feeder Setup Optimization in SMT Assembly

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Abstract

This paper describes an algorithm developed as a decision support system for SMT line operators and its purpose is to suggest changes in an existing feeder setup in order to improve the production performance. The proposed algorithm based on a relaxed model of the problem uses constraint programming approach and its performance is tested on production trial of one PCB type assembly.

Introduction

In the Surface Mount Technology (SMT) assembly process, usually the placement machines are—because of their high purchase cost—the limiting resource of the production. Therefore, the optimization of the operation of placement machines is necessary, and placement machine manufacturers deliver software for some kind of this optimization. Though, these tools are sometimes not able to fulfill all the needs of the SMT line operators.

In this work, we cooperated with a company where the SMT line is equipped with placement machines SiPlace HS50. The company uses SMT line computer optimizer developed by the machines manufacturer. The feeder setup by the line computer optimizer is implemented at the SMT line and a production test is carried out. Then, the SMT line operators analyze the quality of the assembly and make modifications in the setup to lower the number of defects in component placement. However, these interventions have negative effect on the workload balance and the assembly time increases. It is necessary to improve this setup. At the same time, the number of changes should be minimized because these changes can again worsen the quality of the assembly. The line computer optimizer is not suitable for this task because it returns different component allocations in every run of the optimization algorithm. Therefore we developed a new algorithm based on constraint programming (CP) approach (Jaffar & Maher 1994) and targeted to solve the problem.

Optimization of PCB assembly systems is a complex optimization problem even for the production of a single PCB type. It consists of two hierarchically related sub problems (Ammons *et al.* 1997). At the higher level, *allocation* of component types to machines is performed, and the *arrangement and sequencing* problem on each machine is solved at the lower level. The HS50 machines are, except the number of stations, of the same construction as the machines Fuji NP-132 in (Tirpak, Nelson, & Aswani 2000), where only the arrangement and sequencing problem is solved. On the other hand, the work described in our paper targets only the allocation of components, and the arrangement and sequencing problem is left for the line computer optimizer. Therefore, we are neither able to find nor prove the optimal solution of the problem. Despite of this fact, the results shown in this paper represent significant improvement of the production speed.

SMT Line Description

The SMT line consists of two machines Siemens SiPlace HS50 connected by two conveyors in parallel, as it is depicted in Figure 1. Each machine contains four revolver placement heads. Each head is equipped with 12 vacuum nozzles and a camera, and it has its own stationary feeder bank. The head is mounted on an overhead gantry that allows simultaneous movements in X-Y directions and also in Z direction for the component pick and placement.

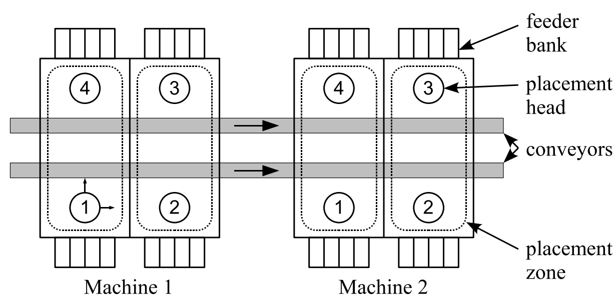

Figure 1: SMT Line with two machines HS50

The machine can be classified as a combination of dual-delivery placement machine and multi-station placement machine according to (Ayob 2005), and except the number of stations (placement heads), it is similar to Fuji NP-132 machine (Tirpak, Nelson, & Aswani 2000). The mounting space of the machine is divided into two placement zones. The placement zone is shared by a pair of placement heads that operate in dual-delivery mode, i.e. at one time only one head of the pair can move over the PCBs located in the placement zone.

The Setup Optimization Problem

When we define the Unique Component Set (UCS) as a set of components of the same type picked from the same feeder slot, the problem is specified as follows: for the existing feeder setup by SMT line operators, find the improved feeder setup w.r.t. workload balance while the number of changes in allocation should not exceed a given number. One pick and place *cycle* of the placement head consists of picking at most 12 components from the feeders, movement of the head to the mounting position, placing of all these components and return of the head to the feeder position. Since we did not have all the data required for computation of the time of the cycle, and so because we decided to solve only the assignment problem, the setup optimization problem was formulated as the number partitioning problem (NPP), and due to additional constraints, constraint programming approach was used instead of some algorithm for NPP.

Components allocated to one placement head correspond to a partition in the NPP. The set of all UCSs is denoted as $\mathcal{I}$, UCSs are indexed by i and the number of components in UCS$_i$ is n_i. Partitions are indexed by j and the set of all partitions is denoted as $\mathcal{J}$. The average number of cycles over all placement heads $\bar{c}$ is defined as $\bar{c} = \sum_i n_i/(n_h \cdot n_n)$, where $n_h = 8$ is the number of used placement heads, and $n_n = 12$ is the number of nozzles located on one placement head. The estimated number of cycles $\tilde{c}$ is then defined as $\tilde{c}_j = \lceil \bar{c} \rceil$ if $\bar{c} - \lfloor \bar{c} \rfloor > 0.5$, or else as $\tilde{c}_j = \lceil \bar{c} \rceil$ and $\tilde{c}_k = \lfloor \bar{c} \rfloor$ where j, k are heads of one pair.

Next, variable p_i denotes the placement head (i.e. partition) to which components of UCS$_i$ are allocated. Variable s_j is the number of components allocated to the head j and is defined by the constraint $s_j = \sum_{i|p_i=j} n_i$ for all $j \in \mathcal{J}$.

The number of components s_j is constrained by the number of cycles of the placement head by the relation $(\tilde{c}_j - 1) \cdot n_n < s_j \leq \tilde{c}_j \cdot n_n$ for all $j \in \mathcal{J}$.

The requirement of maximum allowed possible changes w.r.t. the existing setup is expressed by following constraints $(x_i = 0) \Rightarrow (p_i = a_i)$, $X \geq \sum_{i \in \mathcal{I}} x_i$, $x_{i|i \in \mathcal{U}} = 0$, where x_i is a binary variable with $x_i = 1$ meaning that the allocation of UCS$_i$ is changed, a_i denotes the original allocation of UCS$_i$, X is experimentally determined upper bound on the number of allowed changes, and $\mathcal{U} \subset \mathcal{I}$ is a set of UCSs that are not allowed to change allocation. The number of components allocated to one pair of heads (j, k) is required to be lower than experimentally determined upper bound, $\max_{j,k \in \mathcal{J}|pair}(s_j + s_k) < s_{UB}$.

The solutions to the problem specified by the previous constraints are generated by the CP system and then are filtered to find a solution satisfying also the constraint $\sum_{l \in nozzle} \lceil n_{jl}/\tilde{c}_j \rceil \leq n_n$ for all $j \in \mathcal{J}$, where n_{jl} is the number of components mounted by placement head j using nozzle type l.

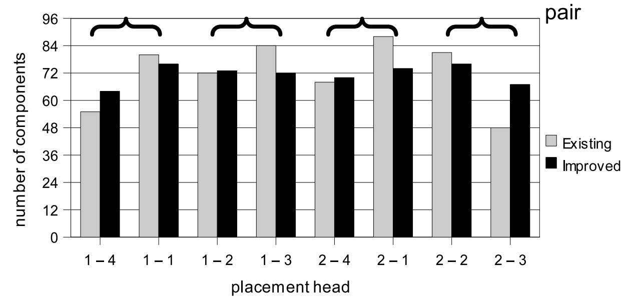

Figure 2: Component allocation for the existing and the improved feeder setup.

Experimental results

The experimental verification of the algorithm was realized for one PCB type. For both the existing feeder setup and the improved setup by our algorithm, in Figure 2 is depicted the number of components allocated to the placement head specified at the x-axis by label consisting of machine-head number code; also the pairs of heads are indicated. The y-axis grid corresponds to the 12-component cycles. The improved feeder setup was created by 11 changes in component allocation, and the difference of one cycle is obtained for all pairs of heads. Then, this feeder setup was used at the production trial, and maximum over all placement heads of the measured assembly time was reduced from 34.1 s with existing setup to 30.5 s with the improved setup.

Conclusion

The algorithm used in this feeder setup optimization is based on a simplified model of the problem, which is formulated as the number partitioning problem with additional constraint. When applied at production of one PCB type, the assembly time decreased by 10.5 %.

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