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DEFECT DETECTION SYSTEM DEVELOPMENT SPECIFIC TO ELECTRONIC COMPONENT PLACEMENT

Andrei-Cătălin IOANA, Adela-Eliza DUMITRAȘCU

Abstract: *This paper presents the design of an innovative device for placing electronic components on printed circuit boards (PCBs), which integrates an intelligent real-time defect detection system. The proposed solution combines classic pick-and-place technologies with 3D scanning and artificial intelligence algorithms, aiming to automatically identify positioning, orientation, or missing component defects immediately after placement. Using artificial vision and machine learning methods, the system enables continuous process analysis, adjustment of placement parameters, and transmission of relevant information to operators in real time. The implementation of this concept leads to reduced waste, increased quality of finished products, and optimized production costs. The project aligns with Industry 4.0 principles, contributing to the development of intelligent, adaptive, and reliable production systems.*
Keywords: *Printed circuit boards, surface mount technology, intelligent defect detection system, operational efficiency, reliability, optimization of component placement, predictive maintenance.*

1. INTRODUCTION

The electronics industry is undergoing continuous transformation, driven by ever-increasing demands for quality, reliability, and efficiency in manufacturing processes.

In this context, surface mount technology (SMT) plays a key role in the production of printed circuit boards used in a wide range of industrial applications. Component placement accuracy and early detection are critical factors that directly influence performance and production costs.

Traditional inspection methods, performed after the placement process, can lead to significant losses of time and resources, especially in high-volume production. As a result, the integration of real-time inspection systems and artificial intelligence is becoming a strategic direction for the optimization of modern industrial processes [1].

This paper aims to develop an electronic component placement device that includes an intelligent defect detection system based on 3D scanning and machine learning algorithms. The solution aims to improve the quality of the production process, reduce defects, and increase operational efficiency, thus contributing to the implementation of Industry 4.0 concepts.

2. IMPACT OF THE PROPOSED SOLUTION ON THE SURFACE MOUNT TECHNOLOGY PRODUCTION PROCESS

The device for planting electronic components, which includes a device for detecting planting defects, represents an important innovation from several points of view [2], [3].

First, the proposed solution contributes to reducing production costs, due to the possibility of detecting defects in real time. By immediately identifying non-conformities that occur during the planting process, losses caused by defective boards are prevented, significantly reducing the costs associated with repairs and scrap. At the same time, costly investments required to implement additional inspections are avoided.

Secondly, the solution analyzed leads to increased efficiency an production speed.

Implementing inspection during the electronic component planting process eliminates additional verification steps, thus helping to speed up the production flow and reduce line downtime. Real-time defect detection allows for immediate correction without interrupting the process or removing products from the technological flow.

Another relevant aspect is the improvement of product quality and reliability. By integrating the defect detection system, the component placement process is performed with superior accuracy, reducing errors associated with incorrect alignment or insufficient bonding. This contributes to obtaining compliant and reliable end products that meet the functional and quality requirements of modern industrial applications.

Last but not least, the proposed solution allows for production processes optimization and advanced data analysis. The system has the ability to collect and store information about identified defects, providing support for adjusting machine parameters to improve process performance. In addition, the integration of a monitoring system allows for root cause analysis of reported defects supporting data-driven decision making and continuous improvement of the production process.

3. SMT COMPONENT PLACEMENT MACHINES

The component placement machine transforms a raw card into a fully functional PCB by precisely placing electronic components on the printed circuit board, as illustrated in Fig.1 Process of an SMT pick and place machine. This step is essential in the SMT (Surface Mount Technology) assembly process, as it is responsible for the precision and quality of the final product. The electronic components are fed into the placement machine either in the form of rolls (tape and reel) or in trays.

Small components, such as resistors, capacitors, or coils, are delivered in the form of rolls and positioned on feeders, which automatically feed the machine, allowing for fast and continuous placement. Large components, such as BGAs or connectors, are placed in trays, and drawer-type feeders allow for precise picking and placement on the PCB.

The planting process is carried out using planting heads, which use suction to lift and position each component on the circuit board. The PCBs are moved through the machine by a conveyor belt, which ensures that the movement is synchronized with the placement of the components. Automated optical inspection (AOI) systems check whether the components have been positioned correctly according to the board design, and the machine's software controller optimizes the placement sequence, detects any errors, and allows them to be corrected.

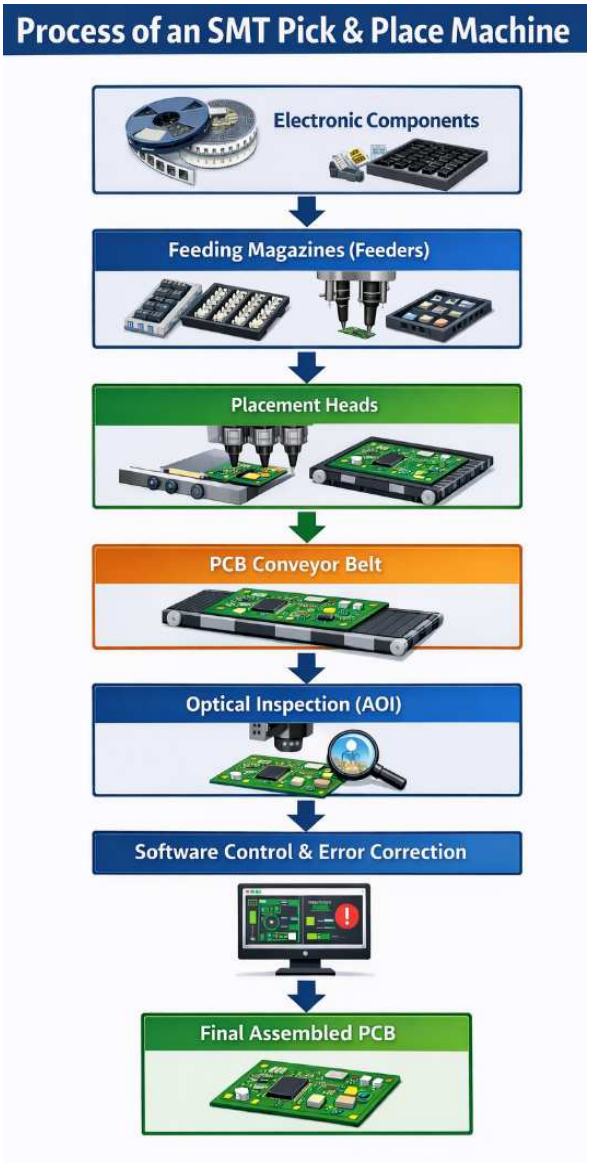


Fig. 1. Process of an SMT pick and place machine.

Currently, there are three main types of placement machines. Manual machines require operator intervention and are used for small-volume production or prototypes. Semi-automatic machines allow the operator to load the PCB and components, while the actual placement is automated, providing a balance between precision and flexibility. Full automatic machines are used in mass production, offering high placement speed, high precision and high production capacity.

The main components of a pick and place machine include placement heads, which suck up and place components on the PCB; the conveyor belt, which ensures the synchronized movement of the boards through the machine: feeders, which store the rolls or trays with components and the software controller, which optimizes the process and manages errors.

Existing placement machines include the Europlacer II-N1 multifunctional SMT machine, the Europlacer ATOM 2 SMT machine, the KAYO A6L SMT machine and the KAYO A4 and A2 SMT machines, which allow components to be placed directly on the table [3].

4. BRAINSTORMING TO DEVELOP THE CONCEPT

The theme of the brainstorming session was the development of a device for planting components on a printed circuit board (PCB), which would include a 3D scanning module for detecting defects that occur during the planting process. Following the meeting, several ideas were identified to improve the performance and reliability of the device: automatic verification of component recognition to avoid placing the wrong parts, and automatic alerts in case of repeated errors. It was also proposed to analyze and report defects to optimize the production process, automatically adjust the speed and pressure of planting depending on the type of PCB, and monitor the wear of suction nozzles using special sensor. Other suggestions included creating a modular design for easy integration with existing machines, developing a user-friendly interface that displays errors and recommends solutions and implementing real-time auto-adjustment to correct component position before soldering. Machine learning systems for optimizing component placement, multi-technology inspection combining artificial vision with laser scanners or X-ray sensors for detecting visible and hidden defects, and predictive maintenance with sensors that monitor the condition of machine components and notify operators before problems arise were also prosed.

5. DEVELOPMENT OF THE PRESENTED CONCEPT

Idea number 1 presents increased precision, thus the exact placement of components is essential for the correct functioning of PCBs. Automatic position verification reduces errors and ensures consistent quality. In addition to these two arguments, there is also a reduction in defects achieved through rapid detection of positioning errors, which prevents soldering defects and saves time in the repair process [4].

Idea number 2 eliminates human error thanks to automatic recognition that ensures the correct placement of each component, saving time and avoiding costly errors.

Idea number 3 argues for rapid problem identification and improved reliability; this idea can determine whether a defect occurs frequently and can help continuously improve the production process.

Idea 4 is based on data-driven analysis; data is collected and analyzed in real time, helping teams identify root causes and resolve them quickly.

Idea 5 is based on adaptability to various types of PCBs and reducing the risk of defects. PCBs vary in size and material and automatic adjustments allow better control of the process, while automatic adjustment minimizes the risk of human error and ensures consistent performance [5].

Idea 6 prevents mechanical defects that can occur as a result of wear and tear and helps improve efficiency by reducing equipment downtime.

Idea 7 helps detect and correct certain defects resulting from positioning and reduces

the number of defective boards that reach the final testing stage [6].

Idea 8 is the basis for continuous improvement and production optimization. Machine learning can learn from past errors and anticipate future defects, adjusting the process to prevent them from occurring. This system helps create a faster and more efficient planting process based on historical data.

Idea 9 is the basis for identifying hidden defects and reducing invisible defects. Artificial vision combined with advanced technologies allows the identification of defects that are not visible to the naked eye, helping to check internal soldering or BGA components that cannot be inspected optically.

Idea 10 is based on reducing downtime and preventing equipment failures. Continuous monitoring of equipment status allows maintenance to be scheduled before equipment fails by proactively replacing worn components.

Idea 11 helps develop a flexible, low-cost design. A modular design allows the machine to be easily adapted to the needs of a varied or changing production line.

Idea 12 is based on reducing human error and increasing operator efficiency. An intuitive interface allows operators to quickly understand errors and apply the correct solutions, minimizing the risk of errors in the planting process.

These arguments support the ideas and present them as viable solutions for improving quality, efficiency and costs of the electronic component planting process.

6. MULTI-CRITERIA ANALYSIS

To carrying out the multi-criteria analysis, the specifications of three equipment solutions for SMD component placement, used in today's electronics industry, were analyzed and compared. The models considered are:

- option (a) - the Europlacer ii-N1 multifunctional pick and place SMT machine, recognized for its flexibility and high industrial performance;
- option (b) - KAYO A6L, an SMT component placement machine geared towards medium-scale production, with an advantageous cost-performance ratio;
- option (c) - the device/ machine designed within the current project, developed to meet the specific requirements of the application under analysis.

The multi-criteria analysis is carried out in two main stages. The first stage consists of establishing a clear and well-defined viewpoint of the analysis team, through which the relevant properties, attributes, and characteristics of the object under evaluation are identified, individualized, and defined.

The next stage is the determination of the weight of each criterion, achieved by calculating weighting coefficients established according to the three-value Latin grid. For this purpose, a square matrix is constructed, having the same criteria on both rows and columns, within which each criterion is compared with all the others. The assignment of values is performed as follows: if the criterion on the row is more important than the one on the column, a value of 1 is assigned; if they are of equal importance, a value of 0.5 is assigned; and if it is less important, a value of 0 is assigned. For calculating the weighting coefficients (Yi), the practical Frisco formula, also known as an empirical formula, is used.[7]

$$\gamma_i = \frac{p + \Delta p + m + 0{,}5}{-\Delta p' + \frac{Issue}{2}}, \qquad (1)$$

where:

- p represents the sum of points obtained by the element taken into account.
- Δp represent the difference between the score of the element taken into account and that of the last level.
- m represents the number of criteria surpassed.
- *Issue* represent the position of criterion
- $\Delta p'$ represents the difference between the score of the element taken into account and that considered first in the analysis (Table 1).

The evaluation criteria were established with the aim of making an objective and relevant comparison between the three variants. Thus, the analysis took into account the planting speed, expressed in components per hour

(criterion V), which directly influences the productivity of the production line, as well as the placement accuracy (criterion PP), which is essential for ensuring assembly quality and reducing defects.

Table 1

Determining the weight of each criterion

Criterion	Option A	Option B	Option C
	Score	Score	Score
V	15.54	12.09	15.71
PP	1.65	1.88	2.88
T	2.11	2.35	1.645
CA	15	7.5	16
CO	15	6	13.5
F	45	27	45
U	22.4	22.4	22.4
C	24.9	32	24.9
Total	141.6	111.22	142.14

Another important criterion is the type and number of components supported (criterion T), which reflects the flexibility of the equipment and its ability to respond to the diversity of SMD components used in modern production.

The acquisition cost (CA criterion), which has a direct impact on the initial investment, and the operating and maintenance costs (CO criterion), which is relevant for assessing long-term expenses, were also analyzed. The reliability and durability of the equipment (F criterion) were considered essential criteria for the continuity of the production process and the reduction of downtime. Last but not least, the analysis included the ease of use and quality of the included software (U criterion), which influences operator training time and operational efficiency, as well as compatibility with other equipment in the production line (C criterion), necessary for easy integration into an existing technological flow.

Based on these criteria, a rigorous comparative evaluation of the three variants can be performed, highlighting the advantages and limitations of each solution in relation to industry requirements and the objectives of the analyzed project.

It can be seen that the best option for a component placement machine is the machine concept proposed in this project, with 142.14 points. In second place is the "Europlacer ii-N1 multifunctional pick and place SMT machine" with a score of 141.6 and in third place is the "Kayo A6L SMT component placement machine". Therefore, this concept is remarkably close to the performance of industrial-grade equipment that can plant up to 80000 components per minute.

7. CONCLUSIONS

This paper has presented the development and evaluation of an innovative electronic component placement device that integrates real-time defect detection based on 3D scanning and artificial intelligence. By combining classic pick-and-place technology with advanced inspection and data analysis capabilities, the proposed solution directly addresses key challenges in modern SMT production, such as defect prevention, process optimization, and cost reduction.

The analysis highlighted the significant impact of integrating intelligent inspection during the planting process, leading to improved placement accuracy, reduced waste, and increased production efficiency. The brainstorming and concept development stages demonstrated that features such as automatic component recognition, adaptive process control, machine learning-based optimization, and predictive maintenance can substantially enhance the reliability and flexibility of the equipment.

Furthermore, the multi-criteria analysis confirmed the competitiveness of the proposed concept when compared to established industrial solutions. With the highest overall score, the developed machine concept proves to be a viable and efficient alternative, offering performance levels close to those of high-end commercial equipment, while maintaining improved adaptability and cost efficiency.

Overall, the proposed solution aligns with Industry 4.0 principles by enabling data-driven decision making, continuous improvement, and intelligent automation. Its implementation can contribute to the development of smarter, more reliable, and more sustainable electronic manufacturing processes, particularly in

demanding sectors such as the naval and aeronautical industries.

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Dezvoltarea sistemului de detectare a defectelor specific pentru plantarea componentelor electronice

Rezumat: Această lucrare prezintă conceperea unui dispozitiv inovator de plantare a componentelor electronice pe plăci de circuit imprimat (PCB), care integrează un sistem inteligent de detectare a defectelor în timp real. Soluția propusă combină tehnologiile clasice de tip pick-and-place cu scanarea 3D și algoritmi de inteligență artificială, având ca scop identificarea automată a defectelor de poziționare, orientare sau lipsă a componentelor imediat după plantare. Prin utilizarea metodelor de viziune artificială și învățare automată, sistemul permite analiza continuă a procesului, ajustarea parametrilor de plantare și transmiterea informațiilor relevante către operatori în timp real. Implementarea acestui concept conduce la reducerea rebuturilor, creșterea calității produselor finite și optimizarea costurilor de producție. Proiectul se aliniază principiilor Industriei 4.0, contribuind la dezvoltarea unor sisteme de producție inteligente, adaptive și fiabile.

Andrei-Cătălin IOANA, PhD student, Transilvania University of Brașov, Department of Manufacturing Engineering, E-mail: andrei.ioana@unitbv.ro, +40 268 421 318, 5 Mihai Viteazul Street, Brașov, Romania.

Adela-Eliza DUMITRAȘCU, Prof.habil.eng., Transilvania University of Brașov, Department of Manufacturing Engineering, E-mail: dumitrascu_a@unitbv.ro, +40 268 421 318, 5 Mihai Viteazul Street, Brașov, Romania.