

Design and Experimental Evaluation of a High-Precision SCARA Robotic System for Underfill Dispensing in PCBA Assembly

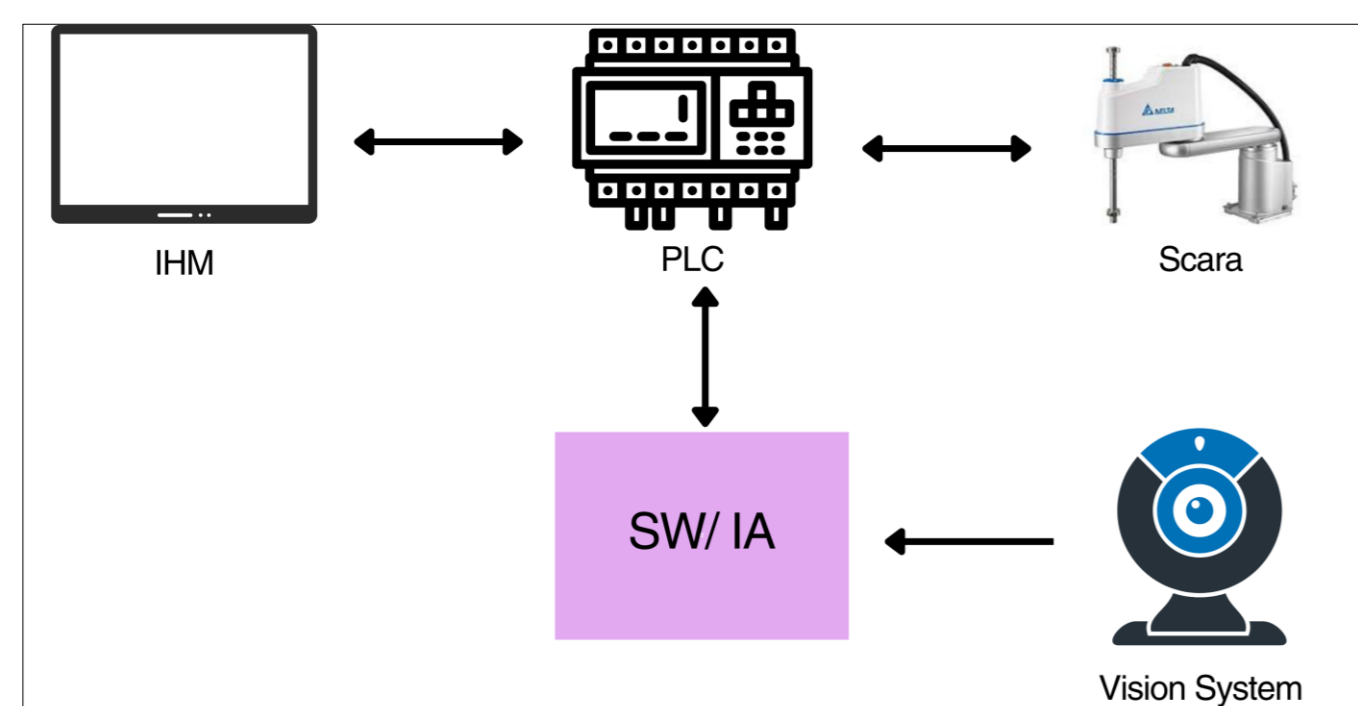
Jefferson da Costa¹, José Miranda Jr.¹, Thiago Alves¹, Yara Dutra¹, Josilene de Lima¹, Rivelino Nunes¹, Alfredo Salles Neto¹, Sharlene Meireles¹

¹Cal-Comp Institute for Research and Technological Innovation in the Amazon, Manaus, 69041-025, Brazil

INTRODUCTION & AIM

The increasing complexity of Printed Circuit Board Assembly (PCBA) processes has driven the adoption of automated solutions to improve quality, repeatability, and production efficiency. Manual underfill application presents significant limitations, including adhesive volume variability, ergonomic risks, and low process repeatability [1].

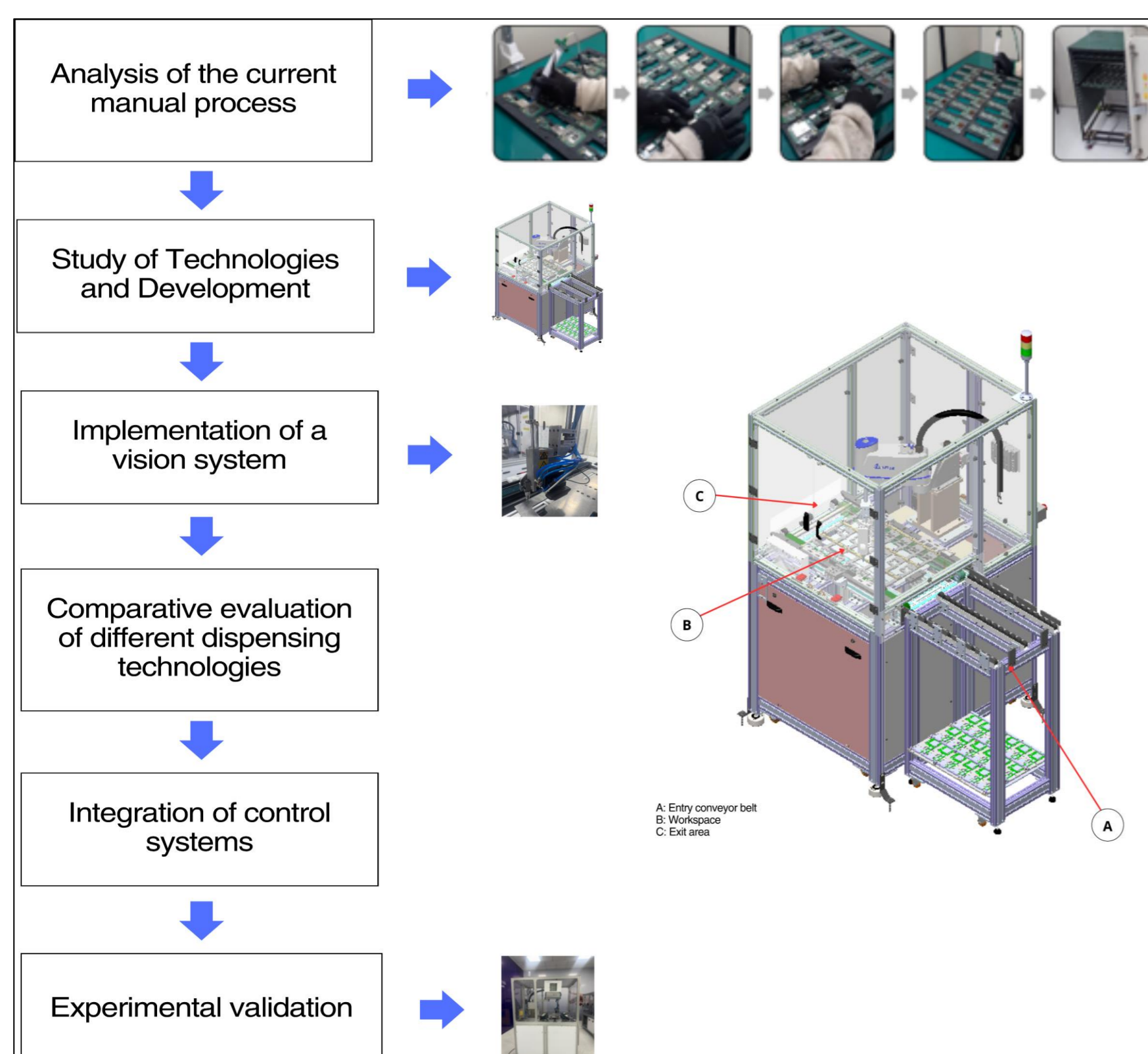
This work aims to design and experimentally validate an automated underfill dispensing system for N950U PCBAs based on a SCARA robotic manipulator integrated with high-precision dispensing, vision-assisted positioning, and inspection [2]. The objective is to study and compare different dispensing technologies, define optimal process parameters, and improve process stability, productivity, and industrial efficiency.



METHOD

The methodology is based on Design Science Research (DSR) combined with Design of Experiments (DOE) and validation through an offline prototype. The process includes: (i) analysis of the manual process and identification of critical variables; (ii) Development of an automated solution using a SCARA robot with dynamic compensation on the Z-axis and study of technologies; (iii) comparative evaluation of different dispensing technologies, including needle geometries and applicator types; (iv) implementation of a vision system for positioning and post-process inspection; (v) integration with industrial control systems (PLC and HMI); and (vi) experimental validation through controlled tests.

The vision system performs color-based detection to evaluate adhesive presence by identifying green pixel concentration [3], classifying PCBAs as OK or NG and enabling automatic decision-making integrated with the PLC.

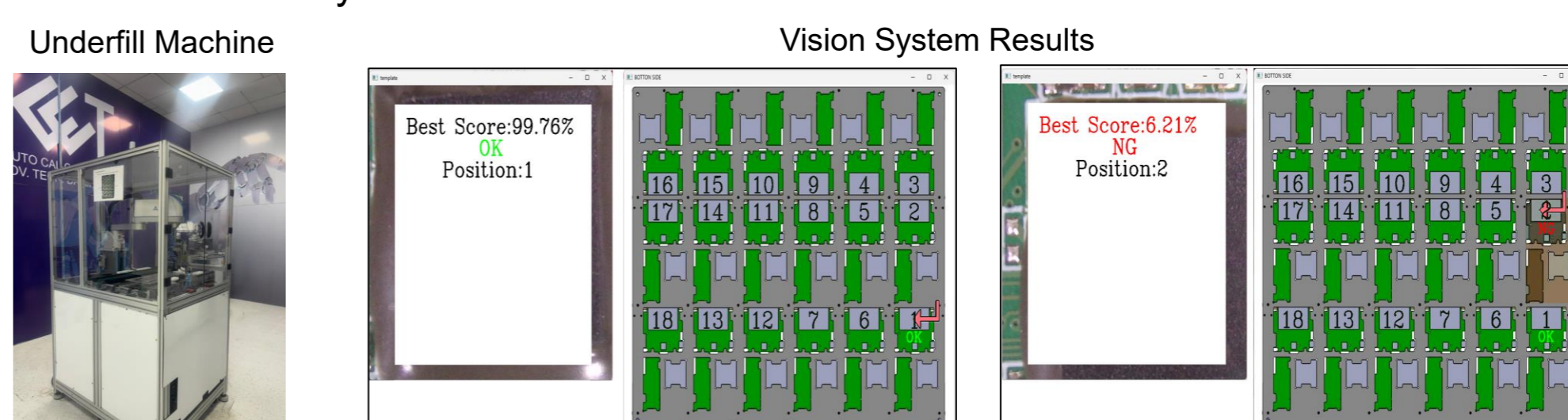


RESULTS & DISCUSSION

Experimental results showed that dispensing performance depends on needle geometry and applicator type. The 23G stainless steel needle achieved the fastest cycle time (~7.7 s/PCBA) but presented adhesive accumulation and risk of contact with components. Larger-diameter needles reduced residue but increased cycle time (up to ~21.6 s/PCBA) due to Z-axis compensation.

Comparative analysis indicated that the Nordson Unity IC30 Plus offers lower cycle time and simpler implementation, while auger-based systems provide higher volumetric precision at the cost of increased complexity.

A vision-based inspection system was implemented to validate adhesive application using HSV color detection. By quantifying green pixel presence (threshold: 0.97), the system classifies PCBAs as OK or NG, enabling real-time verification and integration with the PLC. The combined system improved process consistency, reduced application variability, and enabled detection of insufficient underfill. The solution supports a production capacity of up to 2,400 PCBAs per day with an average cycle time of ~2.5 minutes per carrier, confirming its industrial feasibility.



Comparison of Needles and Dispensing Technologies

Category	Technology	Specification	Cycle Time (s/PCBA)	Advantages	Limitations	Discussion	Picture
Needle	Stainless Steel Needle (23G)	ID: 0.33 mm	~7.7 s	High precision; acceptable adhesive volume; fast cycle time	Adhesive accumulation; risk of contact with IC; requires frequent cleaning	Best performance in speed, but operational instability due to residue buildup makes it less viable for continuous production	
Needle	Aluminum Needle	ID: 1.0 mm	~22 s	High flow rate; low clogging risk; easy maintenance	Low precision; risk of overflow; discontinuity in application	Suitable for high-flow applications, but lacks control for small components	
Needle	Conical Plastic Tip (18G)	ID: 0.84 mm	~21.6 s	Reduced residue; less contact with component	Increased cycle time; requires Z-axis compensation	Improved process stability but at the cost of productivity (cycle time increase ~64%)	
Applicator	Nordson Unity IC30 Plus	Multi-needle compatible	~20-22 s	Lower cost; simple setup; faster implementation; available in process	Sensitive to parameter tuning; lower volumetric precision	Best trade-off for industrial deployment with optimization	
Applicator	Nordson EFD 794 (Auger)	Precision dispensing system	~25-30 s	High volumetric precision; stable flow; high repeatability	Higher cost; complex maintenance; longer setup time	Recommended for high-precision applications where quality is critical	

CONCLUSION

The proposed system demonstrates the feasibility of replacing manual underfill application with a robotic solution integrating SCARA dispensing and vision-based inspection. The approach improves repeatability, reduces variability, and enhances process reliability, supporting the transition toward Industry 4.0 through increased standardization, traceability, and automation.

FUTURE WORK / REFERENCES

As an evolution of this work, we intend to:

- Expanding the solution to other PCBA models, enabling further process automation and predictive quality control.

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