Manufacturing Letters 46 (2025) 152–155

Contents lists available at ScienceDirect

Manufacturing Letters

journal homepage: www.elsevier.com/locate/mfglet

Full Length Article

Educational automated manufacturing cobot work cell in conjunction with machine vision ☆

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ARTICLE INFO

Article history:
Received 22 July 2025
Received in revised form 23 October 2025
Accepted 1 November 2025
Available online 3 November 2025

Keywords:
Robotics
Cobot
Automation
Manufacturing process
Industry 4.0
Machine vision
Work cell
Quality
Education

ABSTRACT

This paper presents the design, construction, and programming of an automated collaborative robot (cobot) work cell in conjunction with machine vision, specifically tailored for educational purposes within STEM fields. The work cell integrates various manufacturing machinery on an educational level into a cohesive learning module, providing students with a practical understanding of the operations involved in a modern manufacturing work environment. The primary objective is to offer engineering students direct exposure to integrated equipment functionalities, including a conveyor belt for part transport, a machine vision system with a photoelectric sensor array for part detection and quality assurance, a 6-degree-of-freedom cobot, and a 3D printer, which is replaceable to facilitate easy transitions between different technologies. Additionally, the project is designed to be adaptable, accommodating ongoing technological advancements and thus expanding the range of topics and experiences available to students. This setup serves as a versatile educational tool, enhancing learning experience by bridging theoretical knowledge with hands-on practice in manufacturing processes.

1. Introduction

This project is designed to serve as a valuable resource for STEM students, providing them with a practical, hands-on understanding of manufacturing workcells and automation processes. Cobots are a form of robotic automation built to work safely alongside human workers in a shared, collaborative workspace [1]. In most applications, a collaborative robot is responsible for repetitive, menial tasks while a human worker completes more complex and thought-intensive tasks. The accuracy, uptime and repeatability of collaborative robots is designed to complement the intelligence and problem-solving skills of a human worker [2]. One of the most remarkable features of cobots is their sensitivity to safety. Since they can work in the same environment as humans, cobots are equipped with strong safety systems. Because of power and speed limits, torque sensors, and tactile sensors, they automatically stop or slow down upon contact with a human, thus minimizing the risk of collision. Cobots come into play especially in tasks involving ergonomic risks, such as heavy lifting and long-term repetitive operations [3–5]. Manufacturers have always been at the forefront of new technologies, striving to operate more efficiently and effectively. Now manufacturers are leading in the adoption and use of artificial intelligence [6]. In this context, automation and AI are impacting on workers and job profiles where repetitive or dangerous tasks are prevalent. From AI-assisted design tools to cobots and human–machine collaboration, the rise of engineering applications of artificial intelligence is reshaping how engineers work, learn, and lead projects [7,8].

Vision systems are one of the most critical elements of modern automation and robotization processes [9]. They have gained great recognition due to their significant capabilities in collecting and analyzing process data. The process of collecting and exchanging data between devices is the basic assumption of the concept of Industry 4.0, a concept characterized by integrating various systems based on recent achievements in many areas of science and technology, such as robotics, vision systems, machine learning, deep learning, and data processing [10]. The goal of this work was to design and develop an educational automated system interacting with a 3D printer. This system employed a collaborative robot together with a vision system, integrating algorithms to detect, identify, and accurately handle 3D printing parts [11]. The paper discusses the steps taken and apparatus used for performing cobot work cell design, assembly, and vision measurement of 3D

☆ This article is part of a special issue entitled: 'Manufacturing Education' published in Manufacturing Letters.

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https://doi.org/10.1016/j.mfglet.2025.11.001
2213-8463/

printing parts. It is concluded with experimental results, student learning experience, and evaluation regarding the project.

2. System design and architecture

The project provides the idea of adding lesson plans for courses such as embedded systems, allowing for additional teaching material for students outside of the lesson plans that may only deal with operating the work cell. Fig. 1 shows the system architecture, summarizing the flow diagram of the system. This system employed a cobot together with a vision system, integrating algorithms to detect, identify, and accurately handle 3D printing parts achieve this objective, the following sub-tasks were identified, including system requirements, cobot integration, vision system, and testing and validation.

The project uses UFACTORY Studio which is a graphical user application designed for controlling the robotic arm with ease. This application allows users to set parameters, move the robotic arm in live control mode, and create motion trajectories using a simple drag- and-drop interface with Blockly code blocks. The IFM Vision Assistant software is essential for configuring the parameters of the camera used in object inspection. This software facilitates the precise adjustment and calibration of the camera to ensure accurate and reliable object inspection, contributing to the overall effectiveness of the automated work cell.

The system consists of an Ufactory Lite 6 robotic arm, an IFM O2D520 object inspection camera, an O6H301 object detection sensor, a conveyor belt, and a 3D printer. The Xarm 6 Lite can be programmed using ROS, Python, and RoboDK, facilitating instructional support and learning opportunities for students. The SV06′ s Polyetherimide-coated spring steel build plate, which self-releases the part when it cools, is crucial for preventing difficulties with cobot-assisted part removal. For these reasons, the Sovol SV06 printer was chosen, and it has performed as well as expected. IFM O2D520 Object Inspection Camera has been used in the project for inspecting the printed part. After inspection, camera sends digital input to cobot for performing further tasks. This camera uses IFM Vision Assistant software for setting parameters and logic.

3. Experimental setup and results

Based on the limits provided by ISO standard 15,066 guidelines, a protection cage that could be easily set up and taken down would be a cheap viable option to satisfy safety requirements. Fig. 2 demonstrates the layout of the work cell designed in SOLIDWORKS and the finished work cell. Inspection of the presence of features such as holes and other structural characteristics in molding and parts manufacturing is one of the quality control steps in industries.

Verification of the precise location of such features is necessary for meeting the design and functional requirements. The IFM O2D520 sensor, which provides object counting and localization capabilities, is efficient enough to detect the features and find their precise positions simultaneously. Based on this data, commands can be generated for downstream processes, enabling seamless integration into automated workflows. Fig. 3 shows the part inspection from the 2D machine vision camera. The whole process performs smoothly from printing the part to the final part inspected (Fig. 3 (a)) and picked by the cobot (Fig. 3 (b)).

4. Student project assessment and evaluation

The paper presents a senior design project that engages in educational activities to enhance student learning in smart manufacturing, including construction of an automated cobot work cell. The Team's performance was evaluated over three academic quarters (Fall, Winter, Spring) in the Senior Design course sequence. The assessment employed a ten-criterion Performance Evaluation Indicator (PEI) rubric aligned with Engineering Technology program outcomes. Each PEI was scored on a 0–5 Likert scale, where 5 represents excellent mastery. The 0–5 Likert scale will be converted into 0–100 points for faculty and industrial committee members to evaluate senior design project outcomes. The evaluation included oral and written components. As shown in Fig. 4 (a), the ten PEIs used in the assessment were: 1. Problem Definition and Need Analysis, 2. Project Planning and Management, 3. Design Process and Creativity, 4. Technical Approach and Engineering Methods, 5. Engineering System Modeling and Analysis, 6. Implementation and Testing, 7. Experimentation and Data Interpretation, 8. Teamwork and Communication, 9. Professional and Ethical Responsibility, and 10. Lifelong Learning and Contemporary Issues.

The Team's early evaluations revealed challenges in developing structured models and experimental procedures for their automated cobot and vision system. By Winter, the team had refined camera calibration, motion synchronization, and process documentation. In Spring, the group demonstrated a validated automated workflow integrating the cobot, conveyor, and vision sensor with real-time data feedback. The evaluators' consensus reflected significant growth in modeling sophistication and system

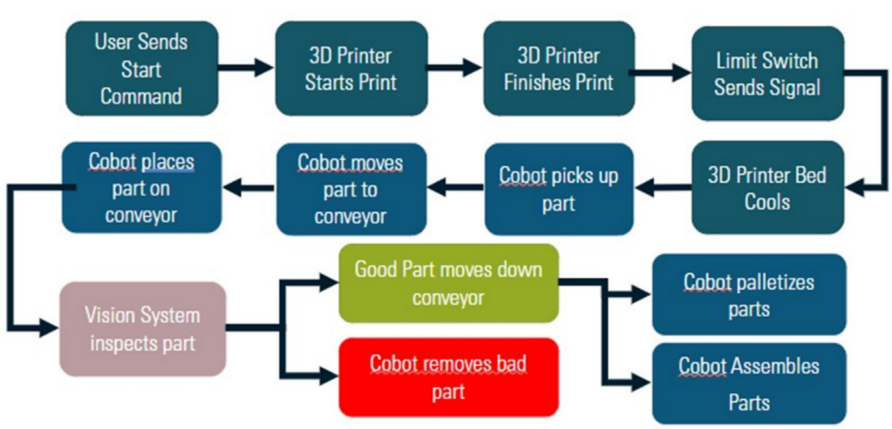

Fig. 1. System architecture.

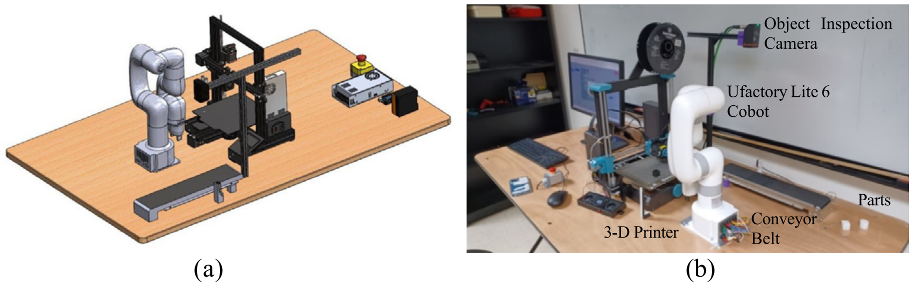

Fig. 2. (a) The layout of the designed work cell and (b) The finished work cell.

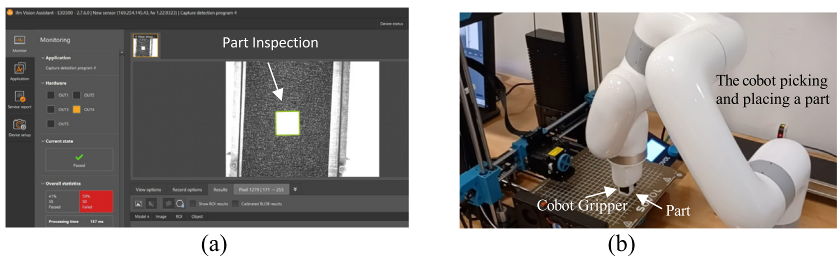

Fig. 3. (a) Camera inspection output and (b) Robotic pick-and-place.

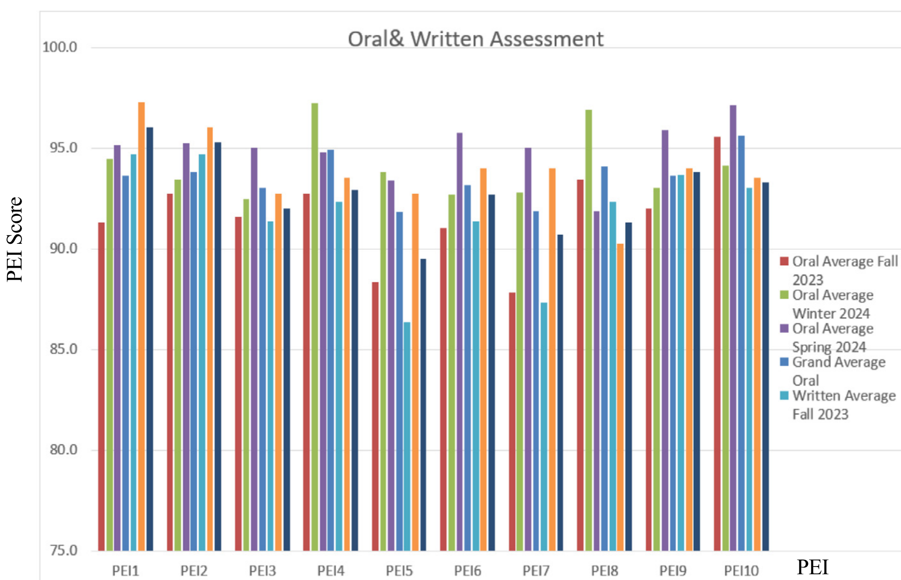

Fig. 4. The Team's oral and written assessment from Fall 23 to Spring 24.

verification. While this summary highlights PEI 5 and PEI 7, overall performance across all PEIs showed a positive upward trend. Average PEI scores improved from approximately 3.9 in Fall to 4.6 in Spring, indicating a steady strengthening of technical, analytical, and professional competencies throughout the project.

- PEI 5 (System Modeling and Analysis): 3.81 → 4.84 (+1.03).
- PEI 7 (Experimentation and Data Interpretation): 3.69 → 4.69 (+1.00).

These results confirm consistent progress in both analytical and experimental domains, supported by qualitative comments emphasizing improved project structure, data-driven decision-making, and documentation quality.

5. Conclusion

The development of the educational automated manufacturing cobot work cell successfully demonstrated how collaborative robotics and machine vision can be integrated into an accessible, hands-on learning platform. The system achieved its intended goals—enabling safe, reliable operation of a 6-DOF cobot, vision-based inspection, and automated part transfer using a conveyor and 3D printer interface. Beyond its technical success, the project provided a scalable and cost-effective instructional resource for teaching key concepts in robotics, machine vision, and smart manufacturing.

Student assessment results revealed measurable growth in system modeling, experimentation, and data interpretation, reflecting the effectiveness of project-based, interdisciplinary learning in Engineering Technology education. Through iterative design and testing, students developed deeper understanding of automation integration, control logic, and safety compliance while improving teamwork and communication competencies aligned with Performance Evaluation Indicators (PEIs). The project serves as a model for integrating Industry 4.0 technologies—robotics, vision systems, and additive manufacturing—into undergraduate STEM curricula. Future work will focus on expanding networked data exchange between subsystems, incorporating AI-based defect detection, and enhancing real-time monitoring capabilities to further align educational experiences with emerging smart manufacturing practices.

CRediT authorship contribution statement

Richard Y. Chiou: Investigation. **Tzu-Liang (Bill) Tseng:** Investigation. **Md Fashiar Rahman:** Investigation. **Yalcin Ertekin:** Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This work has been supported by the US Department of Education under the joint MSEIP Program with the University of Texas at El Paso, PR/Award No.: P120A220044. The authors wish to express sincere gratitude for their financial support.

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