Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #48832

Educational Automated Manufacturing Cobot Work Cell in Conjunction with Machine Vision

Dr. Richard Y Chiou, Drexel University

Dr. Richard Chiou is Professor within the Engineering Technology Department at Drexel University College of Engineering, Philadelphia, USA. He received his Ph.D. degree in the G.W. Woodruff School of Mechanical Engineering at Georgia Institute of Technology.

Prof. Tzu-liang Bill Tseng, University of Texas at El Paso

Dr. Bill Tseng is a Professor and Chair of the Department of Industrial, Manufacturing, and Systems Engineering at UTEP. He is also a Director of the Research Institute for Manufacturing & Engineering Systems, the host institute of TMAC.

Dr. Md Fashiar Rahman, University of Texas at El Paso

Dr. Md Fashiar Rahman is an Assistant Professor of the Industrial, Manufacturing and Systems Engineering (IMSE) Department at The University of Texas at El Paso. He holds a Ph.D. degree in Computational Science Program. He has years of research experience in different projects in the field of image data mining, machine learning, deep learning, and computer simulation for industrial and healthcare applications. In addition, Dr. Rahman has taught various engineering courses in industrial and manufacturing engineering. His research area covers advanced quality technology, AI application in smart manufacturing, health care applications, computational intelligence/data analytics, and decision support systems.

Dr. Yalcin Ertekin, Drexel University

Yalcin Ertekin, Ph.D., CMfgE, CQE is a clinical professor in the College of Engineering, Department of Engineering Leadership and Society at Drexel University, Philadelphia, and serves as the Associate Department Head for Undergraduate Studies for the Engineering Technology program. He received his BS degree from Istanbul Technical University in Turkey, an MSc in Production Management from the University of Istanbul, an MS in Engineering Management, and an MS and Ph.D. in Mechanical Engineering from the University of Missouri-Rolla. Ertekin has also been a Certified Manufacturing Engineer (CMfgE), awarded by the Society of Manufacturing Engineers (SME) since 2001, and a Certified Quality Engineer (CQE) awarded by the American Society for Quality (ASQ) since 2004. In addition to positions in the automotive industry, Dr. Ertekin has held faculty positions at Western Kentucky University and Trine University. He later joined Drexel University's College of Engineering as an associate clinical professor and has been instrumental in course development and the assessment and improvement of the Engineering Technology (ET) curriculum, including integrated laboratories, project-based learning, and practicum-based assessment. Ertekin serves as the faculty advisor for the student chapter of the Society of Manufacturing Engineers (S058) and is a member of the College's Undergraduate Curriculum Committee. Involved in research, Ertekin has received funding from the National Science Foundation (NSF), private foundations, and industry. His research has focused on the improvement of manufacturing laboratories and curricula and the adoption of process simulation into machining and additive manufacturing practices. His areas of expertise are in CAD/CAM, manufacturing processes, machine and process design with CAE methods, additive and subtractive manufacturing, quality control and lean manufacturing.

Educational Automated Manufacturing Cobot Work Cell in Conjunction with Machine Vision

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 the 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. The ability to learn through direct interaction with modern industrial technologies is crucial for students aspiring to enter fields such as engineering and robotics. By engaging with a scaled-down version of a professional work environment, students gain insight into real-world applications and challenges, enhancing their technical skills and understanding of automated systems. This project not only bridges the gap between theoretical knowledge and practical application but also underscores the importance of safety, efficiency, and adaptability in modern manufacturing.

The market for automated manufacturing systems is somewhat of a niche market. The options that exist are limited to very expensive, large, or specialized. For example, the Amatrol Smart Factory Tabletop Mechatronics trainer offers many relevant systems to automated manufacturing. This unit can teach almost all modern automation techniques except for a vision system but the major downside to this unit is the large cost that increases with every optional system. This cost would not be feasible for a smaller department or a small company. In addition, these units tend to be highly complex and take up a significant amount of space [1].

Another similar competitor is the Chungpa CPE-AT3680 Factory Automation Trainer. This unit is the closest to the unit that is to be built, as it has a small form factor and somewhat simple design. Just as there is not much data on the cost of this unit, there is not much documentation on this unit outside of technical specifications provided by the company Chungpa, based in Korea [2].

The options that exist now are either very high-level expensive units from reputable companies, or what appear to be cheaper units that lack proper documentation and have unknown quality. Educational institutions that would benefit from having a way to teach students these subjects on automation and robotics are statistically more likely to be in big cities, where space is a premium. This creates a perfect opportunity to create a more cost-effective solution that combines the benefits of both units, but at a much more reasonable cost. This paper aims to develop a cost effective and portable solution to allow teaching these topics with the help of an integrated cobot system that simulates industrial processes.

The design feasibility for the educational automated cobot work cell is based upon how well it can deliver for the project requirements, objectives, and goals. This led to determining both the 3D printer and cobot that have the functionality, performance, and estimated price that would produce successful integration into the work cell.

Ensuring a safe working environment stands as a pivotal pillar in this project's design ethos. Unlike their industrial robot counterparts, cobots are engineered to work in tandem with humans, and their characteristics emphasize that fact. Their slower traversal speed, smooth edges, and embedded sensor technologies ensure a safer working environment that minimizes the potential for injuries to human workers or damage to other machines [3]. In addition to the technical aspects, this project aims to teach prospective STEM (Science, Technology, Engineering, and Math) students about the various components of a typical automation process [4-13]. Through detailed guides, manuals, and video demonstrations, key information will be provided to make sure faculty and students understand the operation of a work cell while ensuring safety. In section 2, the design and architecture is discussed. Section 3 presents the experiments and results, which is followed by lesson plans and economics in section 4 and conclusion in section 5.

2. System Design and Architecture

System Architecture

In the proposed system, the 3D printer is tasked with the initial production of a part. Upon completion and cooling, the robotic arm retrieves the part from the printer plate and places it onto a conveyor belt driven by a single DC motor. The conveyor belt transports the part along its length where it encounters the object detection sensor. This sensor detects the presence of the part and triggers the machine vision camera to capture an image for inspection. On inspection, the camera sets one of its two output signals to HIGH, indicating whether the part is classified as 'good' or 'bad'. If the part is deemed 'good', the conveyor belt stops and the robotic arm transfers the part to a predefined location. Conversely, if the part is classified as 'bad', it is carried to the end of the conveyor belt where it is discarded. This sequence ensures that only parts meeting the quality standards are retained, enhancing the efficiency and reliability of the manufacturing process.

Figure 1 shows the System Architecture, summarizing the process explained above and Figure 2 is the logic diagram of the system. The I/O wiring diagram had a general overview of how the system's components would communicate, as well as circuits for the conveyor's motor (that needed to be stepped down to 12 V), the limit switch, and the cooling fans (that needed a constant 24 V). Additionally, by making a more detailed wiring diagram, we had the idea of adding that to 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. Being able to isolate and focus on specific aspects of the work cell will allow for more teaching opportunities on systems that are important but may not receive the attention they deserve.

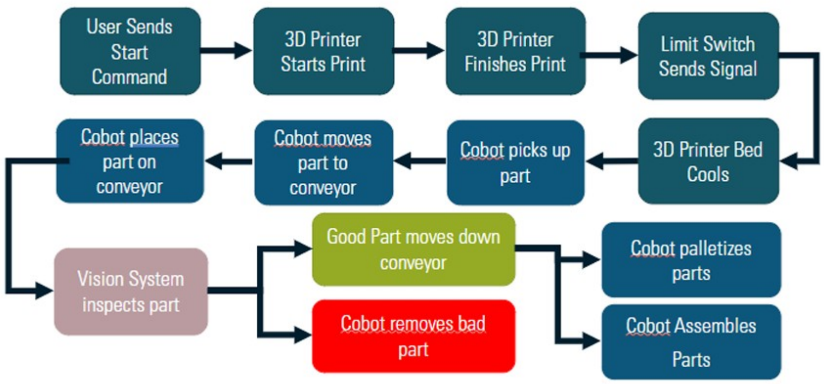


Figure 1. System Architecture

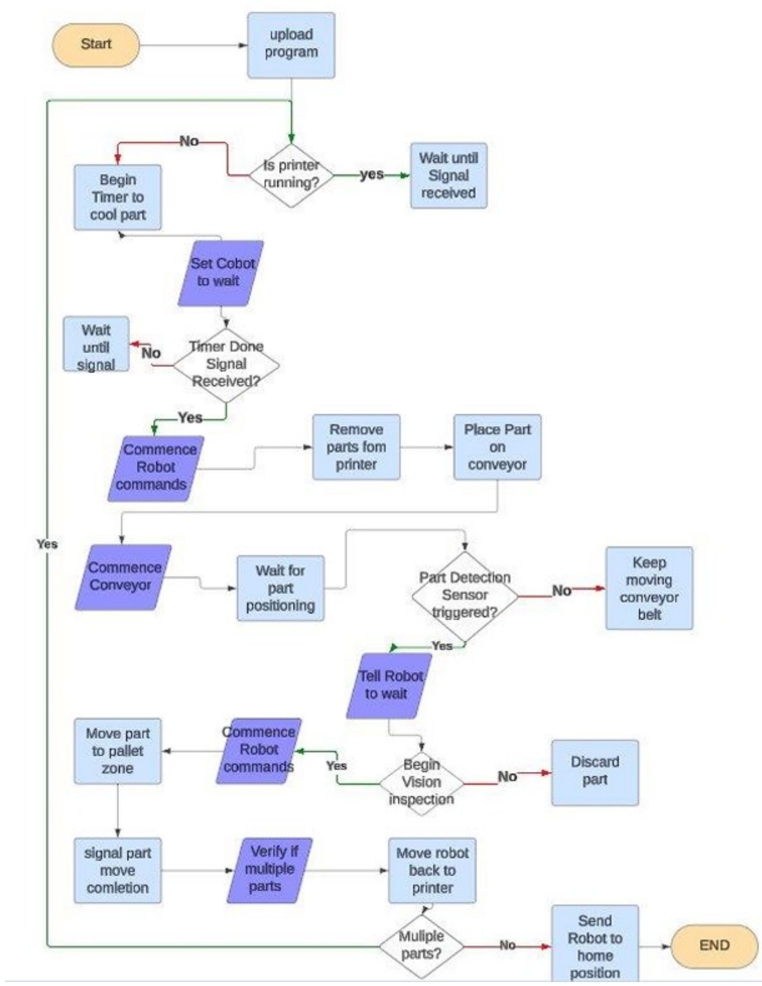


Figure 2. Logic Diagram

3. Software Development

UFactory Studio

The project uses UFACTORY Studio (Figure 3) 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. It is specifically designed to enable motion planning for the robotic arm without requiring programming skills.

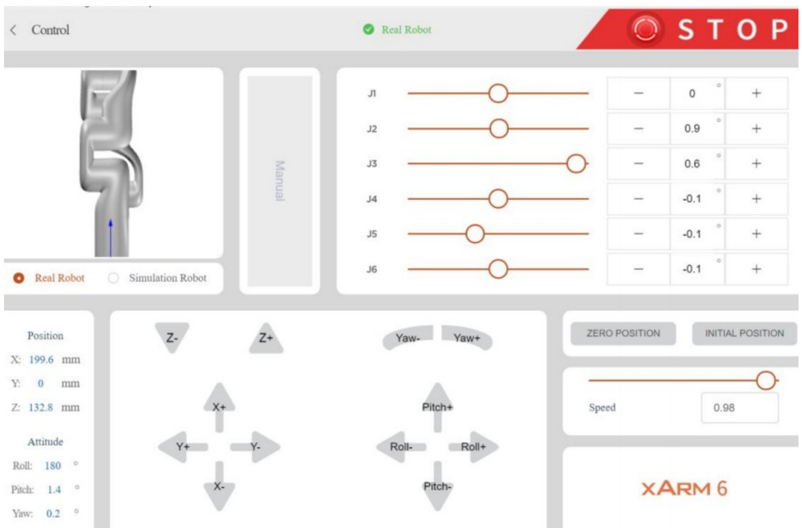


Figure 3. UFACTORY Studio

IFM Vision Assistant Software

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 manufacturing work cell.

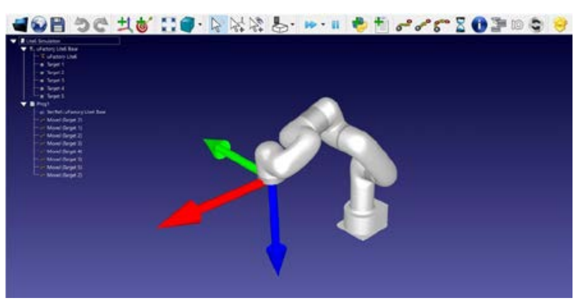


Figure 4. RoboDK Simulation

Apart from these, RoboDK (Figure 4) was also utilized to simulate the motion of the Xarm 6 Lite, as well as to develop preliminary programs. RoboDK allows the user to simulate the motion of robots and to also add in items in the surroundings for the robot to interact with.

4. Hardware Development

The system consists of an Ufactory Lite 6 robotic arm, an O2D520 object inspection camera, O6H301 object detection sensor, conveyor belt and a 3D printer. Figure 5 shows all the hardware used in the system along with the flow of data across the system.

Figure 5. Hardware

Furthermore, most of the components are powered through the robot by using a voltage regulator for stepping down to desired supply which also acts as the resistor required for implementing the digital output that is in the form of NPN with an open collector (OC).

UFactory Lite 6 Cobot

To select the appropriate hardware for this project, a decision matrix has been created (Figure 6) comparing the cobots. Budget constraints limit the options, but ultimately, UFactory offers the best value per dollar. UFactory provides reliable customer support—an important factor given some issues with getting quick information. The Xarm 6 Lite can be programmed using ROS, Python, and Robo DK, facilitating community support and learning opportunities for students. It is also more cost-effective.

Cobot Selection Matrix											
		Option Name and Cost									
		Option A		Option B		Option C		Option D		Option E	
		Elephant Robotics myCobot 280		Elephant Robotics myCobot 320		Ufactory xArm 5		Ufactory Lite 6		Ufactory xArm 6	
		$799		$2,699		$5,494		$3,639		$8,594	
Criteria Category	Weight (%)	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost	40	5	200	4	160	2	80	3	120	1	40
Max Motion	10	2	20	3	30	5	50	4	40	5	50
Compatibility	10	2	20	2	20	5	50	5	50	5	50
Max Payload	10	2	20	3	30	4	40	3	30	5	50
Speed	10	3	30	3	30	4	40	4	40	4	40
Build Quality	15	1	15	1	15	4	60	4	60	5	75
Size	5	1	5	2	10	2	10	3	15	2	10
Total Score (Out of 500)		310		295		330		355		315	
Proceed to next round		NO		NO		YES		YES		NO	

Figure 6. Decision Matrix used to compare different Cobots

3D Printer Selection Matrix									
		Option Name and Cost							
		Option A		Option B		Option C		Option D	
		Creality Ender 3 Pro		Elegoo Neptune 3 Pro		Sovol SV06		Anycubic Kobra Neo	
		$139-189		$199-300		$259		$139-250	
Criteria Category	Weight (%)	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost	30	5	150	4	120	3	90	4	120
Max Print Size	10	5	50	5	50	5	50	5	50
Compatibility	10	5	50	4	40	5	50	4	40
User Friendliness	10	3	30	3	30	5	50	3	30
Speed	10	4	40	4	40	4	40	5	50
Build Quality	20	3	60	3	60	4	80	4	80
Add-in's	10	1	10	2	20	4	40	2	20
Total Score (Out of 500)		390		360		400		390	
Proceed to next round		YES		NO		YES		NO	

Figure 7. Decision Matrix used to compare different 3D Printers

Sovol SV06 3D Printer

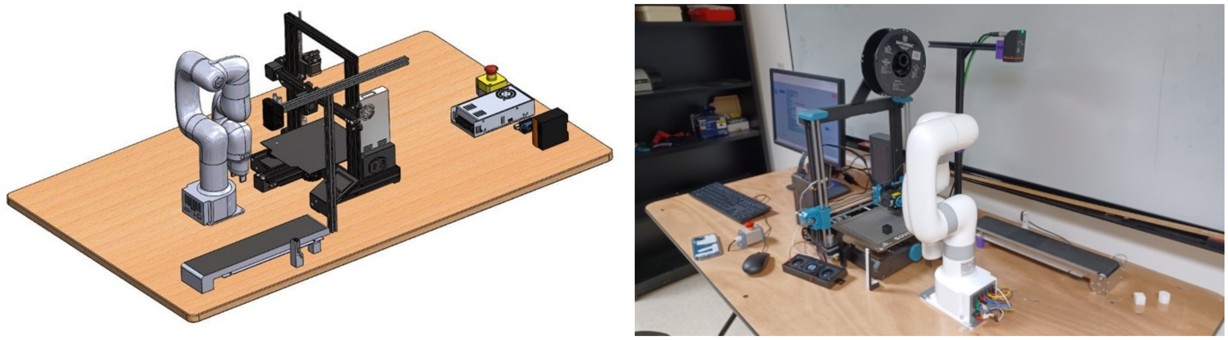
A decision matrix (Figure 7) is also created for the 3D printer. In evaluating the four choices in the decision matrix, it was determined that two contenders fit system needs the most: the Ender 3 Pro and the Sovol SV06. The Ender 3 Pro, a very common hobby-grade printer, is highly inexpensive and benefits from a large aftermarket parts supply and open-source software. The Sovol SV06, although more expensive, offers additional features that enhance automation and longevity. Also, the SV06's PEI-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 Camera

IFM O2D520 Object Inspection Camera has been used in the project for inspecting the printed part. After inspection, camera sends digital input to robot for performing further tasks. This camera uses IFM Vision Assistant software for setting parameters and logic.

5. Experimental Setup and Results

Figure 8 demonstrates the layout of the work cell designed in SOLIDWORKS and the finished work cell. All the wiring and other connections are safely set up under the platform for safety and presentation. Based on the limits provided by ISO standard 15066 guidelines, a protection cage that could be easily set up and taken down would be a cheap viable option to satisfy safety requirements.



(a) (b)

Figure 8. (a) the layout of the designed work cell and (b) the finished work cell.

Cooling time of the part on the printer is critical to the timing of lab activities. Since we would like lab activities to be completed during the typical class period (one and a half hours), it is imperative that each process be trouble free and simple enough for the user to complete in a short window. For this reason, we evaluated the system to find any areas where time could be saved to ensure if any errors come up that the lab activity can still be completed in a reasonable amount of time. However, after some tests of letting the print bed cool down naturally, we noted that it took, on average, nine minutes for the print bed to go from 60ºC to 40ºC. When added to the time it took to print our base cube, half the class time would be spent on those two processes. To reduce that time, we decided to reconsider adding small fans to help speed up the cooling process. To begin, we had to determine the best place to position the fans. We originally thought about placing them on the back of the print bed opposite the cobot and ran some tests. We recorded average cooling times of 3 minutes, much lower than the bed naturally cooling. After running tests from this position, we noted that, while the cooling times were about 20 seconds longer than our original tests, it was still much quicker than natural cooling (Figure 9). As such, we added fans to the side of the print bed so that the work cell could be as efficient as possible.

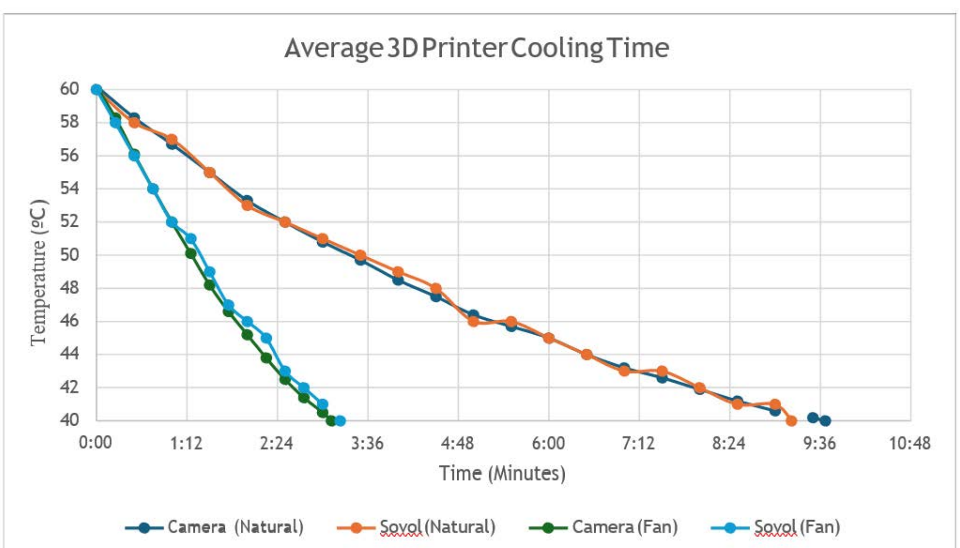
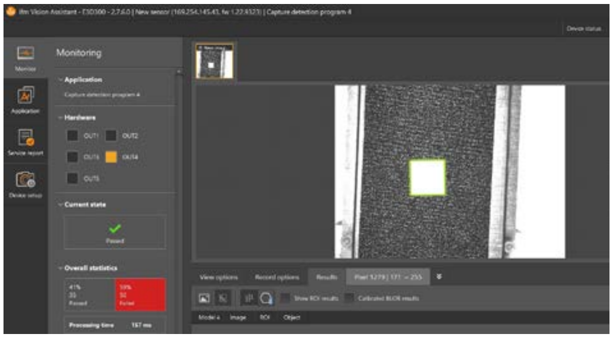
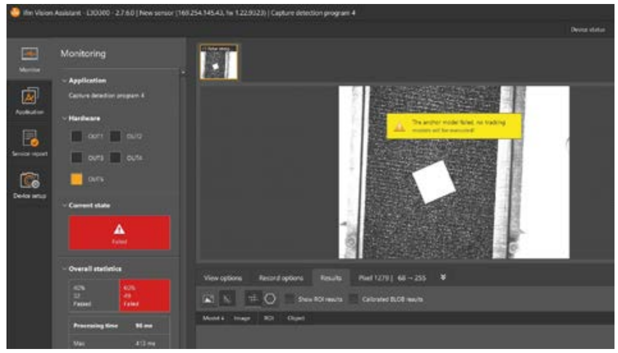


Figure 9. Average Cooling Time of the 3D Printer Bed

The whole process from printing the part to the final part dropping task performs smoothly. Figure 10 shows the part inspection from the 2D machine vision camera.



(a) Good Part (Pass)



(b) Bad Part (Fail)

Figure 10. Camera Inspection Output

6. Lesson Plans and Economics

Lesson Plans/ Educational Opportunity

In addition to being able to program the robot for set-up, there is a need to have set processes in place for troubleshooting, maintenance and receiving further support. A solution to address this concern was through implementing not only lesson plans but also instruction manuals for the instructor, teaching assistants, and the A major part of creating the lesson plans is understanding the perspective of not only the students but also the teachers. On gathering data and surveying faculty and students from an educational department, potential lesson plan topics have been created, such as:

- Simple square part inspection and sorting
- Simple cylindrical part inspection and sorting
- Inspecting a part with complex geometry (multiple features)
- Palletizing finished parts
- Programming the robot using ROS and Python
- Programming the vision system
- Go/No-go decision program

The goal with the lesson plan topics is to provide a variety of potential applications that can be done using the work cell. This intends to align this project plans with courses provided such as Advanced Robotics, Measurement Techniques, Computer Numerical Control, and Embedded Systems.

Cost/ Economics/ Budget

For the design, the primary goal was ensuring that the work cell is financially accessible, ensuring that the products selected were of quality as well, since that will mitigate the future costs for repair, maintenance, and replacement. The project maintains a maximum budget of $10,000 and is built in under $6,500 without maintenance.

7. Conclusion

Overall, the project progressed well and resulted in a functioning work cell that can do everything one sets out for it to accomplish, despite the changes to design. This project is able to provide a solution for teaching automation concepts in a cost-effective manner, while also aiming to inspire and engage more students in STEM fields. The emphasis on safety, along with the creation of detailed guides and manuals, ensures that the work cell designed can be effectively operated by students and faculty while maintaining a secure learning environment. This project on constructing a work cell, a functional platform, for students to gain hands-on experience with both robotics and 3D printing technologies. Students will gain a plethora of knowledge through simulations of automation processes and smart manufacturing, preparing them for their future careers in the rapidly growing automation industry.

8. 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.

9. References

[1] Amatrol, ”Portable Mechatronics Training,” https://amatrol.com/product/mechatronic-training-system/.

[2] Chungpa EMT, ”Factory Automation Trainer CPE-AT3680,” https://chungpaemt.tradekorea.com/company.do.

[3] enVista, ”Collaborative Robots vs. Industrial Robots,” https://envistacorp.com/blog/collaborative-robots-or-industrial-robots/.

[4] Aaron Kane, Michael Racek, Japheth Eloi, Hunter Walker. Drexel University College of Engineering. MET 423 - Senior Project Design III, June 2024.

[5] Creality, ”Ender 3 Pro 3D Printer,” https://www.creality.com/products/ender-3-pro-3d-printer.

[6] Sovol, ”Sovol SV06 3D Printer,” https://www.sovol3d.com/products/sovol-sv06-

ace?srsltid=AfmBOorzJoqHJApTs7PD69sdqjUJUofkB_6wfXiwR

KGyOVl0J0w810gY.

[7] Elephant Robotics, ”myCobot320 Pi,” https://shop.elephantrobotics.com/products/mycobot-pro-raspberry-pi.

[8] IFM, ”IFM O2D520 Object Recognition Sensor,” IFM. ”IFM O2D520

Object Recognition Sensor. https://www.manua.ls/ifm/o2d520/manual

[9] Amatrol, ”Smart Factory Tabletop Mechatronics,” https://tech-

labs.com/products/amatrol%E2%80%99s-smart-factory-tabletop-mechatronics-

system.

[10] International Organization for Standardization. (2016). Robots and robotic devices — Collaborative robots (ISO Standard No. 15066:2016(E)).

[11] International Organization for Standardization. (2023). Additive manufacturing of plastics — Envi- ronment, health, and safety — Test method for determination of particle and chemical emission rates from desktop material extrusion 3D printer (ISO Draft International Standard No. 27548:2023(E)).

[12] Mohd Javaid, and Abid Haleem, ”Significant applications of Cobots in the field of manufacturing,” Cognitive Robotics Volume 2, 2022.

[13] Claudio Taesi, and Francesco Aggogeri, ”COBOT Applications—Recent Advances and Challenges,” Robotics 2023; DOI:10.3390/robotics12030079, June 2023.