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Virtual Reality Robotics with Internet-of-Things for Student Learning on Industrial Robotics and Automation in Manufacturing

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Abstract

This paper explores the experience of implementing virtual reality (VR) laboratory activities with Internet-of-Things (IoT) for students to learn industrial robotics and automation in manufacturing. This work provides an innovative solution for optimizing learning effectiveness and improving educational outcomes through the development of VR models that can be used and integrated into the existing robotics laboratory. We explore methods of using ABB RobotStudio to allow students to program traditional industrial robots using the project-based learning approach. Key features of how they allow the user to move a virtual robot end effector and generate a tool path are described. A comparison between the conventional approach of robot programming using the teach pedant and the VR-based approach is then presented. The project provides students with opportunities to work with industrial robots. Students complete structured laboratory activities that introduce them to different aspects of applied robotics, including the design of end-effector tooling and fixtures for different tasks. The goal is to apply these VR simulators to train undergraduate engineering, engineering technology students, and professionals in robotics and automation education; and to offer experiential learning opportunities in 3D modeling, simulation, and visualization for robotics and automation. The students were given weekly robotics laboratory experiments in the course on robotics and mechatronics. VR robotics integrated with Internet-of-Things based mechatronics enables students to explore innovative approaches to integrate theoretical knowledge with practical applications, enhancing information retention, and promoting critical thinking.

1. Introduction

This paper presents the student learning result of a laboratory course on advanced robotics and mechatronics integrated with virtual reality (VR) and Internet-of-Things (IoT). Virtual reality industry is getting more recognition due to its application in various fields other than gaming such as education, medical, entertainment, military, fashion, healthcare, business, media, film, construction, sport, etc. Virtual reality in education has added another dimension for students to explore and understand the core concept of a certain work application. Virtual reality was widely used in education for topics such as virtual reality robotics where they learn about automation. This style of teaching is very appealing for young students who enjoy using the latest technology. Their experience of studying turns into playing with technology and learning at the same time and that is the key of improving their experience. This is also useful for students who are slow-learners and have a particular style of understanding such as creatives who find the learning process easier with colors, symbols and textures [1-5].

This virtual shop platform provides a safe environment to validate robotic program for any kinematic motion of the factory floor components, before it is downloaded into the physical controller. In addition to the safety features, virtual commissioning also saves cost from redundant components, programming error, and debugging time, before the shop is actually built [6-8]. In preparing students for their future career, simulation experience integrated hands-on training is an important part of their education. VR robotics simulation and weekly robotics laboratories are excellent teaching aids for providing students with opportunities to implement the theory they learn in class. Students begin their projects by identifying the main components of a given system and building robot and layout models. Students are asked to design using VR technology based on robot type, operating environment, etc. and verify by simulation [9-12]. The evidence of learning includes weekly laboratory report with description, analysis, experimental results, and summary.

2. Overview of the Course Development

The new course develops the advances of robotics and mechatronics applications and case studies involved with advanced automation concepts, including robotic workcell, process automation, IoT, computer vision, and VR robotics. The course learning outcomes include: 1. Learn extensive knowledge of digital manufacturing using industrial robots and other common mechatronic components; 2. Design the sensor monitoring and tooling with basic programmable logic controller (PLC) for robotic workcell and automation; 3. Understand fundamental digital image processing and machine vision concepts and their application to the fields of robotics and automation; 4. Perform basic RobotStudio virtual reality simulation and off-line programming robotics for automated work cells in manufacturing; and 5. Deal robotic real-time experiments associated with IoT. Table 1 provides an overview of lectures and laboratory series in the course.

Table 1: Overview of lectures and laboratory series

Week	Topic	Labs
1	Introduction to modern manufacturing	Robotics Lab Tour
2	Programmable Logic Controller (PLC)	Lab 1 Basics – Remote PLC I
3	PLC for process automation and material handling	Lab 2 Basics – Remote PLC II
4	Single-station manufacturing cells Robotic workcell automation	Lab 3 PLC integrated With Robotics
5	Multi-station manufacturing cells	Lab 4 Workcell SCARA w 1-D robots
6	Machine vision inspection principle	Lab 5 Workcell ABB w. robots Auto mode
7	Robotic inspection technologies Machine vision	Lab 6 Basics – Machine Vision
8	Product design and CAD/CAM Virtual Reality Robotics	Lab 7 Vision for Smart Robotic Control
9	Virtual Reality Robotics for modeling	Lab 8 ABB RobotStudio Introduction
10	Virtual Reality Robotics for process planning simulation	Lab 9 ABB RobotStudio Simulation

Teaching advanced robotics and mechatronics presents the general challenges of teaching an application rather than a discipline. In that case we could rely heavily on successful practice and then develop principles to explain those successes with implementation of robotics for automation in manufacturing. Hence, without too much exaggeration, there is either theory or much reliable practice to teach. It Is important to incorporate emerging and IoT practices concepts. The students are able to handle specific problems concerning robotics and mechatronic. The class is evaluated through weekly reports and two exams in order to assess the level of the student understanding of the course materials. The course is broken down into ten laboratory modules. Brief details of these modules are described below.

3. Advanced Robotics & Mechatronics Laboratory

As shown in Figure 1, the Advanced Robotics & Mechatronics (ARM) Laboratory has been developed and offered for teaching weekly laboratory experiments. The laboratory course provides the students with a comprehensive knowledge of IoT based robotics and automation using industrial robots and other common machinery. Laboratory assignments include important technological issues and provide hands-on design experience with Internet-based technologies. The specific Internet-based technologies chosen include computers, networks, robotics, automated inspection and vision systems, PLCs, sensors, automated assembly systems, and automated material handling. Various laboratory assignments are used to reinforce lecture information and to give hands-on design experience on Internet-based robotics and mechatronics. All the devices such as robots, Web-cameras, and programmable logic controllers (PLC) are connected to the Ethernet.

Figure 1. Advanced Robotics and Mechatronics (ARM) Laboratory

The controller of the robot (RCX40) can be connected to the Internet directly. The software used for communication is VIP for Windows developed by Yamaha Co. Ltd. The experimental setup includes the following items: ROCKWELL RSLogix 5000, Yamaha SCARA robot, RCX40 robot controller with optional on-board Ethernet card, and ABB robot IRB 120. The system also consists of power supplies, DC motors, fans, buzzers, limit switches, relays, lights, etc. During the laboratory procedures, the students programmed, debugged, uploaded, and tested the robotic systems over the Internet. Students implemented internet applications to remotely operate the robot in the form of an information interface. The final two weeks are allocated to the specifically designed online RobotStudio simulation.

4. IoT_based Robotics Workstation

In the PLC laboratory experiments, students learn the basics of using the ROCKWELL Automation "RSLogix 5000" Enterprise series ladder logic software. Students become familiar with Internet based Computer Integrated Manufacturing (CIM) or Internet-of-Things (IoT).

Students learn how to set up simple ladder logic programs, and how to run the Allen Bradley PLC to automate robots and a conveyor belt or any actuators with sensor feedback for applications in a robotic workcell. RSLogix 5000 is a powerful industrial software package which is similar to many other industrial ladder logic programs in use today. Becoming comfortable in the use of RSLogix 5000 will be a valuable addition to technical skills. Students will have a good working knowledge of the basics of ladder logic programming. Students are expected to learn the concepts presented in this experiment and to be able to utilize the RSLogix 5000 programmable software. The PLC code is compiled and run in the RSLogix 5000 software. RSLogix 5000, through its simulation configuration creates the necessary communication protocol to the virtual PLC by creating the connection between its symbol table and the input and output ports of the PLC [13-15].

The Rockwell Automation PLC DeviceNet is a communication link to connect the Internet with industrial devices (such as limit switches, photoelectric sensors, valve manifolds, motor starters, push buttons, bar code readers, variable frequency panel displays, and operator interfaces) to a network. The framework supports student learning and the instruction of IoT in the program curriculum. The commercially available Internet based sensors can directly communicate with user PCs over Internet. The framework is organized as a communication cycle with four learning modules: Sensor network/inspection, diagnostic systems for advanced technologies in IoT for manufacturing [16-18].

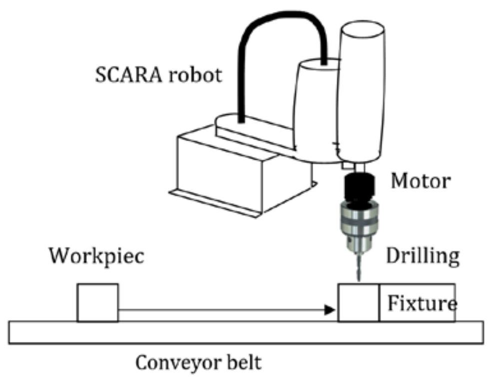


Figure 2. A simulated robotic drilling workcell with PLC

As shown in Figures 2 and 3, one of the weekly laboratory experiments is to write a PLC ladder diagram integrated with a robotic text-based program so that it functions as a robotic drilling workcell. It is required that the program performs the same sequence of operations after the SCARA robot moves from a position to another position for a drilling operation with the following commands, including IF...THEN…ELSE, AND, OR, WAIT, etc. Students need to write a program to turn on a conveyor belt and carry a workpiece for the robotic drilling operation system shown in the figure (assumed). The following is an example of sequence of operations, including a. The start button is closed, the conveyor (or lamp) starts to move, carry a workpiece, and stop it in a fixture (in front of the photoelectric switch sensor), activating the photoelectric sensor, b. Open the air and clamp the workpiece for 10 seconds, c. The robot moves to the location above the workpiece, d. The motor rotates, e. The robot comes back to the original location, and f. Steps 1-5 are repeated 5 times.

SCARA Robot	PLC Ladder Diagram

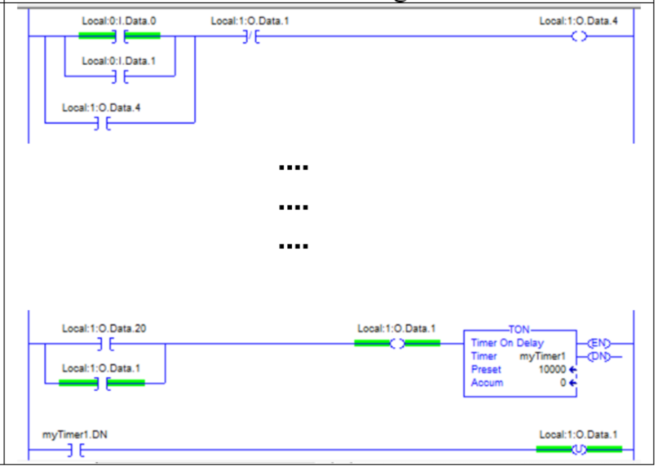
SPEED 10
*L:
DO(20)=0
MOVE P, P0
IF DI(20)=1 THEN
MOVE P, P1
DELAY 20000
MOVE P, P2
DELAY 20000
MOVE P, P1
DELAY 20000
MOVE P, P0
DO(20)=1
ENDIF
GOTO *L
	

Figure 3. Robot program and programmable ladder logic (Allen-Bradley PLC)

For Yamaha robot controller programming (RCX40), students check the program and program the motion defined by the commands between PLC and robot controller. Students make a new program in RSLogix 5000 and perform the following operation with the following interfacing: 1. Inputs to receive the signal from sensors and 2. Outputs to communicate with the robot controller. Students will turn on the conveyor belt when the program starts and no part is in front of the photo sensor. By turning off the conveyor belt whenever the part triggers the photo sensor, the students can tell how the robot controller performs the movement. Students learn the introduction of the PLC techniques to manufacturing in the first three weeks. Specially designed laboratory experiments have been developed for the course as a part of this practicum. Students will learn how to perform the Allen Bradley PLC with robot controller. In addition, students are required to perform experiments utilizing the RSLogix 5000 programmable software for robotics and automation.

5. Machine Vision integrated with Robotics

The computer vision techniques have been used to provide product data which assists decision-making of the production systems. An automated vision system has also been used to inspect defects on printed circuit boards using reference comparison approach. This automated visual inspection system was considered to be efficient for defect detection and defect classification. In the automatic assembly process, the machine vision system is also feasible to inspect the characteristics, size, shape, orientation, and defects of the product models. This inspection assists the automatic assembly system to distinguish the models and respond to those models correctly. The vision system basically based on image classification. First, the object image is captured using camera. Next, the search area of the image is specified to set the environment for image processing. In the image processing step, the classification is identified by comparing the significant features of the captured image to those of the standard image [19-21].

As shown in Figure 4, the In-Sight 8000 models deliver high- performance vision tools, faster communication speeds, and high resolution in a small package that is ideal for integrating into small spaces where machine space is a premium. In-Sight 8000 series vision systems are conveniently setup with the In-Sight Explorer software. In-Sight Explorer combines the guided step by step setup of Easy Builder with the additional power and flexibility of the spreadsheet for greater control and customizing of application data. Also included is the new scripting function which uses standard JavaScript to simplify data- intensive tasks like geometric analysis of hundreds of points, parsing and comparison of text or ID code results, or complex final result.

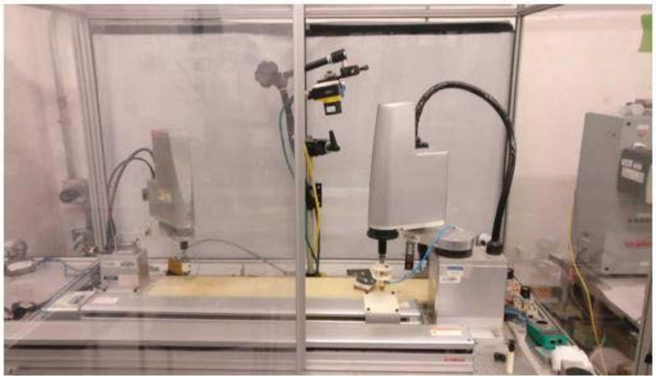


Figure 4. Experimental setup

The InspectEdge tool tracks an edge of a part to inspect for defects and flaw experiment. Two assembly models (square and circle) are placed into the corresponding 1D Robots in their respective positions. The parts are moved along the conveyor belt, the robot shall respond to the output of the vision controller and put the right part into correct position on 1D robot. The vision system is integrated to identify the geometry and the orientation of the part on the conveyer belt. The experimental setup is shown in Figure 5. The Camera sensor is connected using the Ethernet cable to the Software. On establishing the connection, the sensor ID appears on the screen. The entire process of setting up the image processing and recognition window is done in offline mode. The setup is easy and running down the application steps. This applies the settings to the live feed coming in from the camera. It is seen that the circles are accepted (indicated by green) and the squares are rejected (indicated by red).

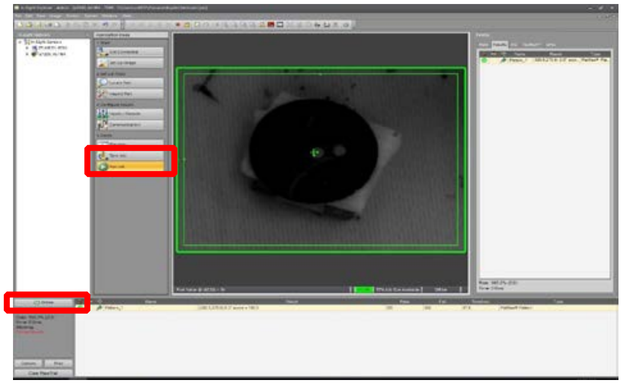


Figure 5. Region of interest circles marked green

The SCARA YK 250 robot is used for the experiment. In our case, students have the BELT program loaded. The speed of the conveyor belt can be varied. For various speeds, students can see how well the machine vision camera detects desired objects and how efficiently the robot picks and places the identified objects. Students are required to write a program so that the SCARA robot picks an object from a certain location on the conveyor belt and then places it in another location of the belt. The conveyor stops while the robot picks and places. After that, the program halts the robot. The robot picks and places operation integrating machine vision camera is completed successfully for the two shapes circles and square. Students program the robot to pick the circle from the point where the camera detects the part and the square is picked off from the location of a photoelectric sensor which stops the conveyer belt on detecting an object.

6. Virtual Reality Robotics

Robotic simulation has been gradually adopted by the manufacturing industry. Its initial use was to aid in design of the physical layout of the shop floor to prevent any type of interference. Next, robotic simulation can add the feature to model the kinematics of the industrial robots, so that students are able to plan and optimize the robots' motions in a virtual environment. This virtual shop platform provides a safe environment to validate robotic program for any kinematic motion of the factory floor components, before it is downloaded into the physical controller. In addition to the safety features, virtual commissioning also saves cost from redundant components, programming error, and debugging time, before the shop is actually built [22-28]. Recent years, with the improvement in high speed computing especially of high resolution graphics and the user interaction devices, the technology of virtual reality has been widely used. VR has emerged as a useful and important tool in today’s society. A VR system creates an environment, which enables human to interact with anything or anyone on a virtual level. In fact, this technology has emerged twenty years ago. Now, VR has been widely applied in the medical field, manufacturing, education, military, gaming, entertainment, commerce, and architecture.

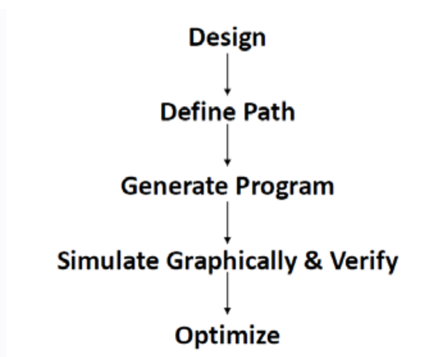


Figure 6. Steps in using RobotStudio

As shown in Figure 6, the features of RobotStudio are split into Basic and Premium functionality. The Basic functionality includes the necessary features to start up an ABB IRB120 industrial robot on the shop floor, and to do simple text-based programming. The same functionality is also available for virtual controllers running on a PC. The Basic functionality also includes the ability to open existing stations and Pack & Go files, run a simulation and watch the result in the graphical

3D view. In addition, students can import the ABB range of industrial robots, run them on the virtual controller and jog them around. The Go Offline feature will let students create a virtual replica of their connected real robot controller system. The Premium functionality includes productivity features for efficient commissioning and programming. Tabular editing of RAPID data, and a comparison tool for viewing program differences are examples of Premium functionality. Program debugging is enabled by the RAPID Watch window, RAPID breakpoints, and the Signal Analyzer. Using the Screen Maker, students can create custom user screens for the Flex Pendant. In addition, offline programming, simulation and 3D functions are all part of the Premium package.

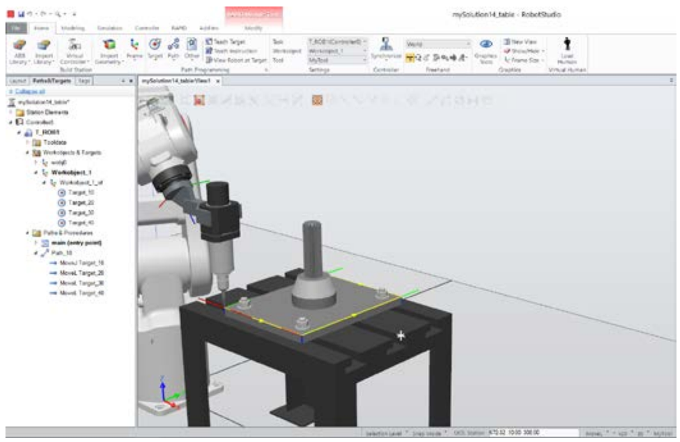


Figure 7. ABB robot and the table as the workobject

As shown in Figure 7, the experiment taught how to simulate ABB robot operations using RobotStudio. The freehand tab was used to jog the robot joints. The import library was used to import a tool to attach to the robot. A table was imported for the tool to operate on. Targets were set on the four corners of the table. A path was created between the four corners and. A path can be taught instructions by manually jogging joints. When the path between the four corners was defined, the robot was made to move along the path. This was simulated at different speeds of 200, 400, 600, 800, and 1000 mm/s and the cycle time to go along the path was recorded. The cycle time decreased as speed increased. This decrease was the steepest from 200 to 400 mm/s and kept getting less and less steep.

The experiment demonstrated how RobotStudio can be used to mimic the function of ABB robots while being offline. The creation of paths using the freehand tab and targets showed the different ways of teaching commands to the robot. The generation of RAPID using RobotStudio was taught where speed and zones could be modified and simulations could be run at different speeds as shown in Figure 8. The experiment showed the wide-ranging applications of RobotStudio in understanding automation without having access to a robot. To program an industrial robot, the programmer can describe its movement by using a teach pendant. This on-line teach method allows the programmer to interact with the robot, manually jogging the end effector to specific locations, recording the location changes in time, and assigning corresponding non-motion instructions.

```
MODULE Module1
        CONST robtarget Target_10:=[[0,0,0],[0,0,1,0],[0,0,0,0],[9E+09,9E+09,9E+09,9E+09,9E+09,9E+09]];
    CONST robtarget Target_20:=[[200,0,0],[0,0,1,0],[-1,0,-1,0],[9E+09,9E+09,9E+09,9E+09,9E+09,9E+09]];
    CONST robtarget Target_30:=[[200,250,0],[0,0,1,0],[0,-1,0,0],[9E+09,9E+09,9E+09,9E+09,9E+09,9E+09]];
    CONST robtarget Target_40:=[[0,250,0],[0,0,1,0],[0,-1,0,0],[9E+09,9E+09,9E+09,9E+09,9E+09,9E+09]];
!***********************************************************
```

...

```
    PROC main()
        !Add your code here
        Path_10;
    ENDPROC
    PROC Path_10()
        MoveJ Target_10,v200,z0,MyTool\WObj:=Workobject_1;
        MoveL Target_20,v200,z0,MyTool\WObj:=Workobject_1;
        MoveL Target_30,v200,z0,MyTool\WObj:=Workobject_1;
        MoveL Target_40,v200,z0,MyTool\WObj:=Workobject_1;
        MoveL Target_10,v200,z0,MyTool\WObj:=Workobject_1;
    ENDPROC
```

Figure 8. RAPID program generated

7. Student Learning Outcomes and Analysis

The final assessment of how this idea fared was completed by twelve students in a section with surveys in Table 2 based on six criteria listed below:

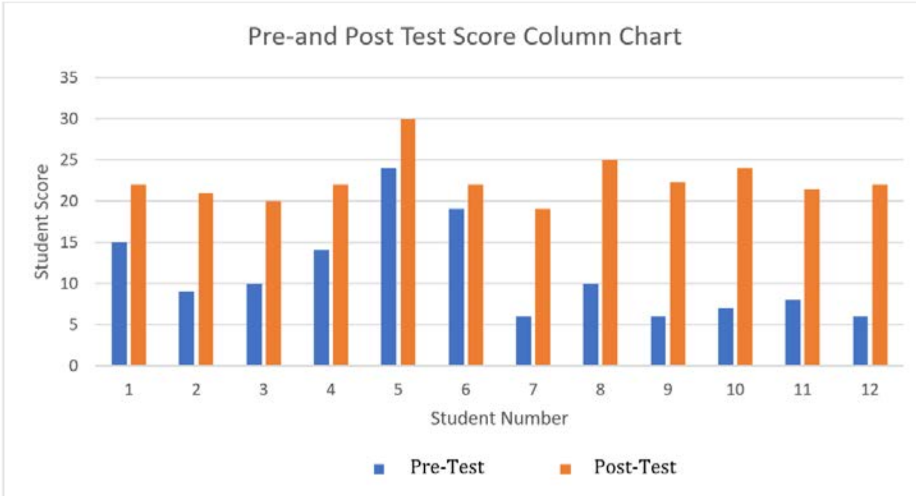
Table 2. Student surveys on learning advanced robotics and mechatronics

S No.	SURVEY QUESTIONS	Pre-Course RATING (Out of 5)	Post-Course RATING (Out of 5)
Q1	Rate your understanding of the meaning and nature of the advanced robotics lab course		
Q2	How will you rate your understanding of programmable logic controller (PLC)?		
Q3	How well do you know robotics workcell?		
Q4	How well do you know RobotStudio?		
Q5	How will you rate virtual reality VR in RobotStudio enhancing your understanding of robotics?		
Q6	How well do you know machine vision?		

The students rate these questions a score out of 5 based on their understanding before and after taking this course. The total score for each before and after is 30 points. This survey data was used to analyze how 3D modelling and VR helps students understand more about industrial robotics application.

Student Understanding Score: Sum of all the ratings given by an individual student for the survey. This is a measure of how well each student knows about all the topics.

Class Understanding Score: Sum of all the ratings given by all the students to a particular criterion. This is a measure of how well the class knows about a topic.



Pre-Test: Mean = 11.17, SD = 5.75 and Post-Test: Mean = 22.56, SD = 2.82

Figure 9. Results pertaining to pre-test and post-test

Analysis of the data: As per the data and graph presented in above Figure 9, a good increase in student's understanding can be seen by using IoT, PLC, vision, and VR simulation in advanced robotics and mechatronics. The mean class understanding of the topics before the course during the MW section was (Mean = 11.17, SD = 5.75) and the class understanding after the class is (Mean = 22.56, SD = 2.82), which is a significant increase of 11.38 (38%). Similarly, based on the individual student score, students found that it was easy to understand and learn from the course related to the concepts of industrial robotics and automation after the class.

Overall, the student feedback received from the surveys was positive with regard to the learning outcomes involving advanced robotics and mechatronics. Most of students appreciated the laboratory learning experience including machine vision, PLC integrated with robotics, virtual reality robotics, etc. They also suggested the future project topics to be included, such as more RobotStudio, machine learning, AI, ANN, advanced machine vision, etc. The students only suggested more hands-on practice during the laboratory experiments to improve the learning experience.

8. Conclusion

In conclusion, this laboratory course provides valuable insights and hands-on experience in advances of robotics and automation. The laboratory focused on understanding the robotic Workcell for automation and industrial control, as well as the process automation using PLC, digital I/Os, and machine vision. Interfacing two robots with their respective controllers was also explored, enabling students to gain proficiency in coordinating and communicating between robots. By incorporating VR into robotics education, this interactive method of learning brings about benefits to both engineering and technology students. The ability to model and simulate presents the tools and incentive for students to come up with creative and innovative solutions. This style of teaching can be appealing for the younger generation and motivating for slow learners, thus optimizing its effectiveness and improving the overall educational outcome. Overall, this laboratory course facilitates a comprehensive learning experience and fosters a deeper understanding of IoT based robotic workcell and their programming capabilities.

9. Acknowledgement

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