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Development of Remote Virtual Teach Pendant for Robot Programming: Lessons Learned

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Abstract

A teach pendant is a commonly used and inexpensive method of programming industrial robots. However, the cost of robots and large class sizes are challenges that prohibit students from gaining sufficient practice in robot programming. There is an urgent need for engineers with robot programming in their skill set. This paper describes the development of a virtual pendant and web server that enables students to program a robot remotely. Students can define a path by specifying coordinates of points, then save the program and play it back at different speeds. The system has been evaluated by high school and undergraduate students at two- and four-year institutions. Survey results suggest that the virtual pendant is useful for learning robot programming; students would like to have more tools like this to help them learn; and the interface is user-friendly and easy to manipulate. Future directions include adding advanced programming functions (such as conditional and loop structures), installation of more webcams to provide different views of the robot position, development of a real-time 3D model to show the robot position within the work envelope, and providing haptic feedback.

Motivation

Robots have become significantly more powerful and intelligent with time, and are moving in to more service-oriented roles. Biggs and MacDonald have noted that with more widespread use, there is a need for easier-to-use and more flexible programming systems. In their review of manual and automatic programming systems, they note that manual systems require the user/programmer to create the robot program directly, by hand, while automatic systems generate a robot program as a result of interaction between the robot and the human. Lozano-Perez reviews requirements for and developments in robot programming systems, focusing on the areas of sensing, world modeling, motion specification, flow of control, and programming support [2]. Billard describes a common method for programming of robots—Robot Programming by Demonstration, also known as imitation learning [3]. Nicolescu and Mataric discuss natural methods for robot programming, including instructive demonstrations, generalization over multiple demonstrations and practice trials [4].

In the area of industrial robots, Pan et al. provide a comprehensive review of the recent research on programming methods for industrial robots, including online programming, offline programming, and programming using Augmented Reality (AR) [5]. Wang et al. propose an optimized path planning method for off-line programming of an industrial robot [6]. Sang Choi et al. present a lead-through method and device for industrial robots, which they found to be more efficient and intuitive for discrete point or continuous-path robot programs [7]. Maeda and Nakamura propose view-based teaching/playback as new method for robot programming [8]. This method aims to achieve greater robustness against changes of task conditions than conventional teaching/playback without losing general versatility. The method is composed of two parts: teaching phase and playback phase. The method was implemented and tested in a virtual environment with a limited sequence control robot. Zaeh and Vogl present a method for intuitive and efficient programming of industrial robots based on Augmented Reality [9]. Tool trajectories and target coordinates are interactively visualized and manipulated in the robot's environment by means of laser projection. Zieliński provides an object-oriented approach for robot programming [10]. Freund et al. discuss a process-oriented approach to efficient off-line programming of industrial robots, presenting two approaches: automatic trajectory generation and tech-in/playback programming using virtual reality techniques [11].

In industry, the most widely used method for robot programming is by using teach pendants [12]. A user uses the pendant to guide a robot along the path of completing a desired task. At the same time, at different points along the path, coordinates are recorded. After the task is complete, the recorded points can be played back at a slower speed to verify the accuracy of the program. An active focus of research is the development of soft teaching pendants as an alternative to traditional hardware teach pendant devices. Soft teaching pendants are potentially useful not only for industry applications, but also for robotics and industrial automation education. In educational institutions, due to equipment availability and lab time limitations, students often do not have sufficient opportunities for hands-on learning. Having the ability to remotely program a robot outside of scheduled lab times can allow more students the opportunity to gain experience using a teach pendant.

Kaluarachchi et al. present a soft pendant for a 6-axis Yaskawa Motoman HP3J robot [13]. Abbas et al. present the idea of an augmented reality based teaching pendant using a smart phone [14]. Jan et al. propose a smartphone-based control architecture for a teaching pendant, providing a user-friendly interactive control input method to the robot's operator [15]. This paper describes the development and evaluation of a Virtual Teach Pendant for a LabVolt 5150 Robot. The layout of the graphical user interface (GUI) is the same as the industry teach pendant while also providing the flexibility of remote control using a computer or a mobile device. A playback feature is included, allowing the user to record and play back the steps used to teach the robot. The virtual teach pendant allows increased access to equipment, facilitates self-paced learning, and provides the opportunity to experience remote control of a robot system. In addition, findings and lessons learned from evaluations of the system by high school students, two-year college students, and four-year college students are presented.

Development

Figure 1 provides an overview of the system. After logging in, the user can press symbols representing each joint of the robot (Figure 2). Based on these inputs, a series of coordinates are sent to a robot controller, which moves the robot to the corresponding locations (point-to-point programming). The user can monitor the movements of the robot through a webcam or IP cam.

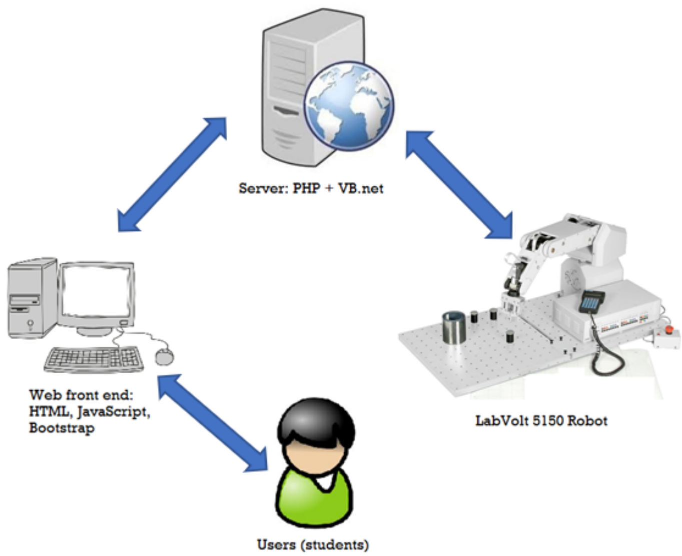

Figure 1. Overview of Virtual Teach Pendant system

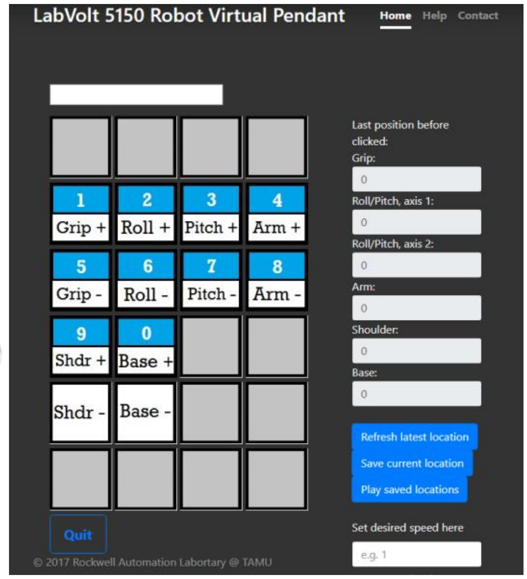

Figure 2. Virtual Teach Pendant user interface

Process Flow Chart

The LabVolt 5150 Robot Virtual Teach Pendant system consists of the following components: web UI (user login system + main function), background executable file, and the robot. Figure 3 illustrates a typical user interaction with the LabVolt 5150 robot through the system.

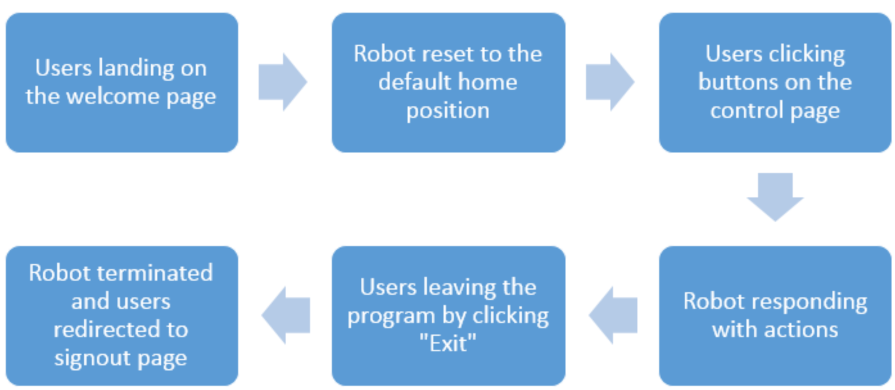

Figure 3. Process flow chart describing user interaction with system.

Design Diagram

In order to communicate with the robot through a web UI, two main components are required: a web application, developed using a mix of JavaScript, CSS, HTML and PHP, and a background executable file, which is written in Visual Basic. The web application displays all available options and saves users' selections into a text file. The background executable file (also known as the actual control unit) runs simultaneously and in parallel with the web application. It monitors user inputs and sends instructions to the robot as soon as it captures changes from the user input file. The LabVolt 5150 comes with a Dynamic Link Library (DLL) to allow external programs to communicate with the robot. Currently, the robot takes one input at a time. Once the robot moves, the background program records the relative coordinates and saves them to a coordinate file for display to the user. The diagram below (Figure 4) illustrates the dynamic between the web application and the background control unit.

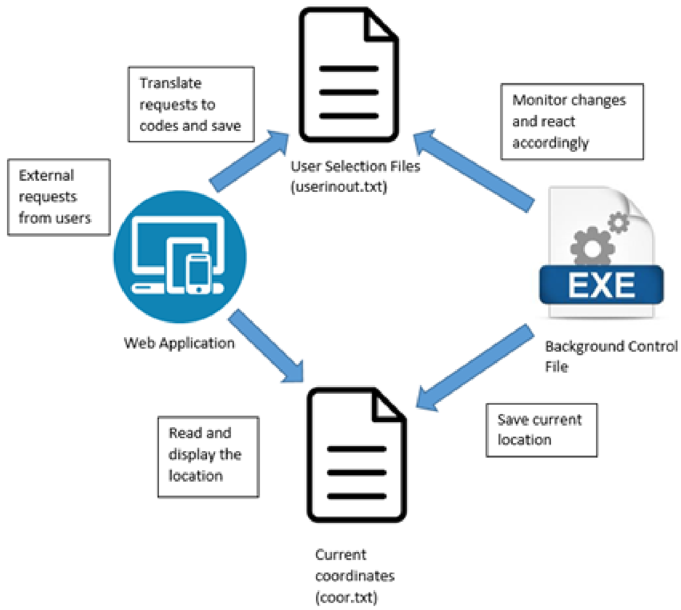

Figure 4. Illustration of relationship between system components.

System Layout

Figure 5 is a screenshot of the web page from the user's perspective. On the left side is video from two cameras streamed through YouTube. The upper video is from a camera positioned at the front of the robot, and the lower video is a view from the side. On the right is the Virtual Teach Pendant interface. The Virtual Teach Pendant is used to control each joint of the robot and thereby move the robot to a desired location within its travel path to accomplish a task.

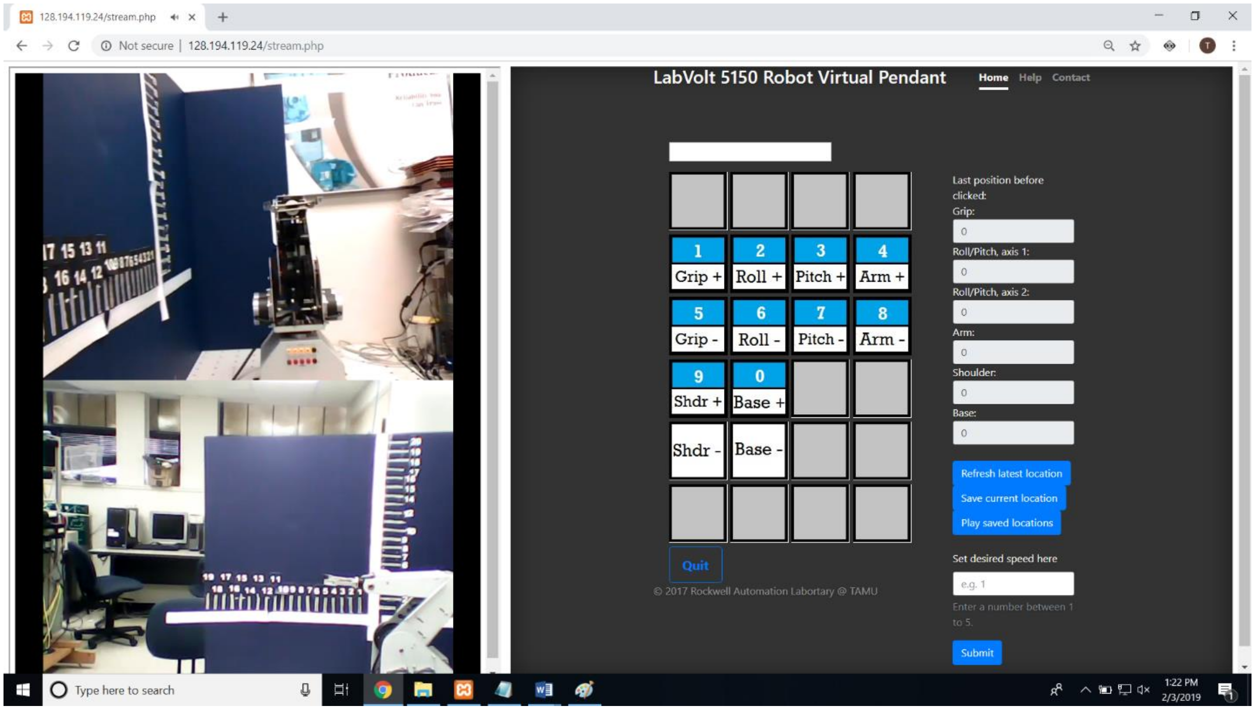

Figure 5. Overall web page layout of the LabVolts 5150 Robot Teach Pendant.

Evaluation

The Virtual Teach Pendant has been evaluated by 19 two-year college students, 29 four-year college students, and 24 high school students. The goals were to determine:

- Did the VTP help students to learn more about basic robot antomy, links and joint, how to use pendant to move robot around.
- Student opinions about various aspects of the VTP, such as user friendness, features, objective, emphasis on important information, use of multimedia, and relevance to their education
- Student comments

All students provided ratings and comments using an opinion survey. In addition, the two-year college students completed a pre- and post-test.

Pre-and Post-tests

<u>Participants</u>. Participants in the pre- and post-testing were 19 two-year college students enrolled in an Industrial Automation and Robotics course, during a lab session in which they were learning how to program a robot to accomplish a pick and place task.

<u>Materials</u>. Students' knowledge of articulated robot anatomy, manipulating robots, and programming a robot using a virtual teaching pendant (VTP) was assessed. Figure 6 shows sample test questions:

The robot Home position is described as ______________________?

a. perch position c. pick position

b. starting position d. place position

The robot Perch position ______________.

a. allows product to enter a point to be picked without colliding with the robot shoulder
b. allows product to enter a point to be picked without colliding with the EOAT
c. allows product to enter a point to be picked without colliding with the robot base
d. allows the robot to return to the Home position after each product pick

Figure 6. Sample pre- and post-test questions

Pre and Post-Test Data Analysis and Results

The pre and post test data were analyzed to see if there was statistically significant score improvement between tests. Two stages of analysis were performed on the data sets. In stage I, Shapiro-Wilk's test was used to test the normality of the data set. If the data set follows a normal distribution, then a t-test can be used to do the paired data comparison. However, if the data set fails the normality test, a Wilcoxon Ranks test should be used to perform paired data comparison. The null hypothesis H_o for stage I is that there is no difference between the distribution of the data set and a normal distribution. The null hypothesis H_o for stage II is that there is no difference between the two sample sets. Two different tests were conducted; ***Test 1*** (before using VTP), and ***Test 2*** (after using VTP).

The analysis results revealed that the null hypothesis was rejected for average test score and standard deviation of test score. This suggests that using the VTP causes significant improvement in learning. Table 1 summarizes the test statistics, critical value and conclusions for each test, where the null hypothesis is $\mu_d = 0$, sample size for VTP is 19, and the α value is 0.05. The average score before and after VTP was 65.0 and 80.5.

T1 vs T2

Shapiro-Wilk Normality Test:

Shapiro-Wilk's W = 0.9593
Probability = 0.5810
P>0.01 Do not reject Null Hypothesis

Table I: t test of mean and f test of variance for Virtual Teach Pendant

	Test statistic	Critical value	Conclusion
Before VTP vs. After VTP (t-Test)	4.2876	2.1098	Reject Null Hypothesis
Before VTP vs. After VTP (F-Test)	2.3262	2.2719	Reject Null Hypothesis

Opinion Survey

<u>High School Students.</u> The work was presented during AP Computer Science and Technology classes at a high school in Texas. Figures 6 and 7 are photos of the presentation and classroom.

Concepts such as different types of robot configureations, applications, robot anatomy, and work envelope were presented. The Virtual Tech Pendant was used to illustrate the work envelope of the LabVolt 5050 robot. Volunteers moved the robot to find out the answers.

Figure 6. Presentation and Remote Robot.

Figure 7. Picture with teacher and students.

Due to time constraints, only the opinion survey was administered. The mean responses to the survey questions are shown in Figure 8. Student ratings were positive for all items (n = 24, min 5.43, max 6.08), especially on the question of "more tools like this to help them to learn"—perhaps because only a few were able to use the Virtual Teach Pendant (VTP).

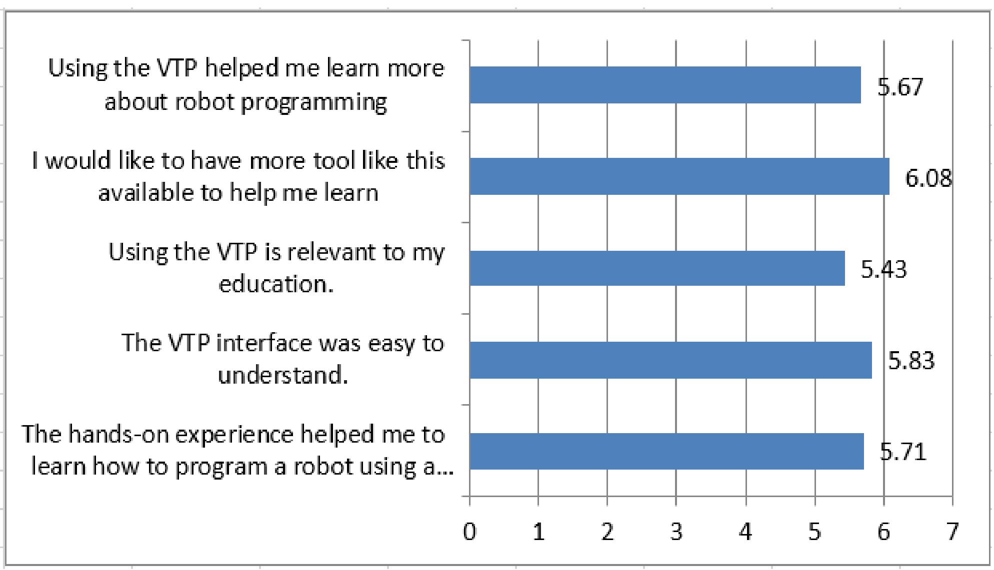

Figure 8. Opinion survey of high school stuents to Virtual Teach Pendant.

<u>Two-Year Students</u>. Figure 9 shows opinion survey results for the two-year college students. Their responses were also positive (n = 19, mix. 5.74, max 6.31). Again, the item of "would like more tools like this" ranks highest.

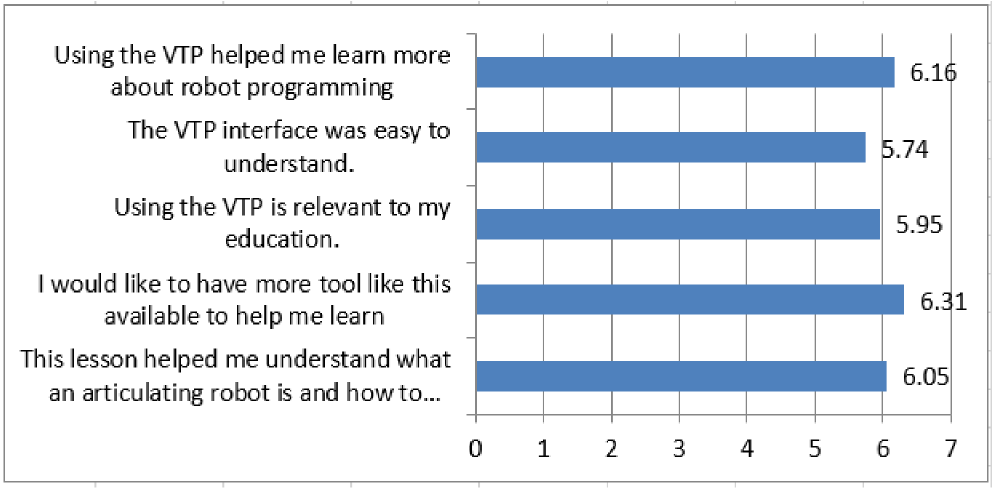

Figure 9. VTP Opinion survey results - two-year college students.

Undergraduate Students. The VTP was also used in an upper-level undergraduate class on Manufacturing Automation and Robotics course at a university in Texas as part of a lab exercise. Survey participants (n = 29) had positive responses to VTP (Figure 10). Again, the item of "would like more tools like this to help me to learn" rated highest.

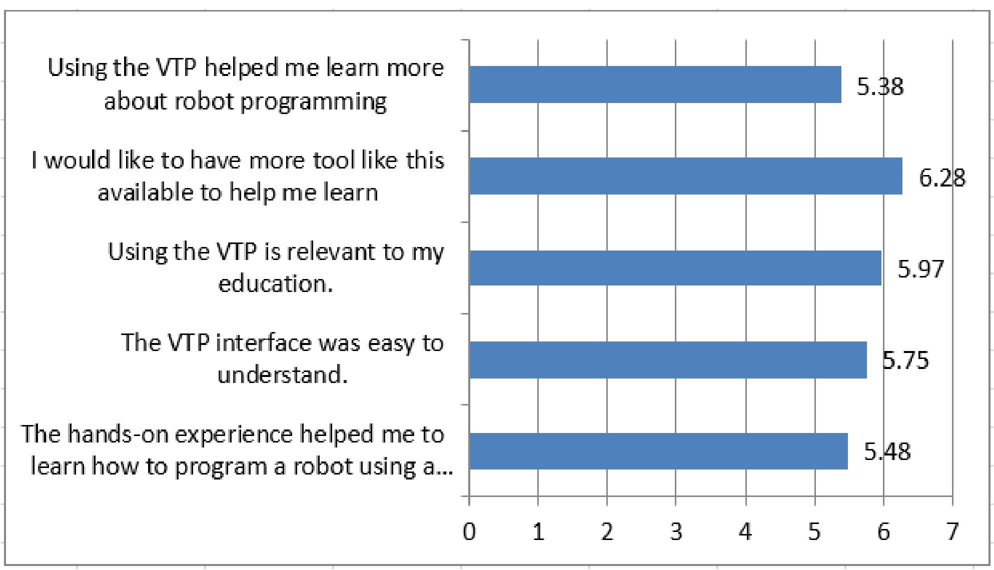

Figure 10. Opinion survey of undergraduate students to Virtual Teach Pendant.

Student Comments

In students' responses to the question "The most helpful thing about this project has been:" a common theme was that the hands-on, visual experience was helpful to learning. Below are some sample responses:

- It helped me experience controlling a robot from a remote location.
- It had an easy user interface.

- It allowed us to understand the different movements that a robot can make.
- Remotely viewing the robot that was being controlled made for a better challenge and forced the user to think about the task in order to accomplish it.
- That we were actually using the robot without having to hook it up or physically have it.
- Seeing the robot joints that we covered in class in action.
- Watching the degrees of freedom live
- I was able to utilize the web development program to control the robot in the Texas A&M Lab. This showed me how the IP Address was used to connect over servers to control the robot on another server.
- That it had a live feed on how the robot was moving.
- The easy interface was very helpful in learning how to use the VTP

In students' responses to the question "This project could be improved by:" common themes were 1) the camera feed needed to be faster; 2) the camera needed to be positioned better relative to the object to be picked up; and 3) it would be helpful to be able to refer to a diagram or labels to be able to remember angles and positions. Sample comments are below:

- A diagram of the robot with rotation angles on it would have eliminated some of the experimentation.
- The camera could be positioned better to see the position of the robot in reference to the cube.
- If it was labeled a little better. As in Grip:open and Grip: closed. I got a little confused every now and then.
- N/A! I think it was great. Maybe more on programming!
- The camera showing the robot had better real time feedback.
- more complex task
- The lag on the video made the robot more difficult to control.
- The cube was colored and there were multiple camera angles
- If there was no delay between the controls and the video.
- More programming was involved

Conclusion and Future Directions

The evaluation responses suggest that Virtual Teach Pendant is effective for Industrial Automation and Robotics education. Future directions include incorporate on-line reservation of the equipment time; design more lab exercises that utilize the VTP; continue assessing the effectivenesss of the VTP at all education levels from high school to college; add advanced programming functions (such as conditional and loop structures), install more webcams to provide different views of the robot position; develop a real-time 3D model to show the robot position within the work envelope, and provide haptic feedback.

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