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Lessons Learned from Hosting Workshops on Remote Control of Automated Systems

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Design and Evaluation of Collaborative Lab for Robotics Education

In recent years, remote laboratories have been used in engineering classes to overcome barriers such as equipment cost and limited lab time, and to provide authentic and self-paced learning experiences. With the rise of COVID-19, use of remote labs has increased. However, learning in isolation can be difficult. Collaborative remote labs can provide authentic and interactive learning experiences to address this challenge. This paper describes the design of team lab exercises using a Virtual Teach Pendant developed to teach robot programming. The lab exercise was evaluated by 52 undergraduate students enrolled in a Manufacturing Automation and Robotics course in spring 2020. All teams were able to complete the assigned task. Results suggest that the time needed to complete the task varied depending on familiarity with robot anatomy and team synergy. Students overall responded positively to the collaborative lab experience and the virtual teaching pendant. For example, two students commented that "being able to visually see the robot moving as the pendant was being used" and "hands on experience at the comfort of home" were most helpful. Suggestions for improvement include changing the angle of camera and the color of the objects, and incorporating a remote coding component.

Motivation

Hands-on experience is an essential part of manufacturing engineering education. However, the cost of industrial scale equipment, limited lab time, and large student population have hindered this desired experience. The idea of using remote labs (RL) was first proposed in 1991 by a researcher at Purdue University who created a remotely shared control systems lab [1]. Remote labs have received much attention as Internet technology has become mainstream. Remote labs can alleviate the challenges listed above [2-7]. Over the years, there have been a few attempts to review of RLs and suggest challenges/problems.

Chen [8] reviewed tools used to develop virtual and remote labs, such as LabView, Javascript, Flash, XML, and Web 2.0, and suggested a few open problems including how to incorporate Web 2.0 technology in developing lightweight, interactive, and responsive remote labs.

Teng et al.[9] reviewed, compared, and summarized observations about several virtual/remote labs and the technology used in their development over time. Advantages of virtual/remote labs include 24/7 access flexibility and learning at one's own pace. Virtual/remote labs are not intended to replace physical labs; rather, integrating physical labs with virtual and remote labs with a pedagogical component to support learning can create a rich learning environment and help achieve higher learning outcomes. Suggested potential research directions include understanding how to provide a personalized learning experience and how to create an environment that fosters collaborative learning.

Theo et al. [10] systematically reviewed remote laboratory (RL) work in science education with the intent of visualizing RL structure through HistCite and CiteSpace software. The findings revealed that RLs are a state-of-the-art subset of laboratory work and a new way of conducting laboratory work that has gained fairly wide research attention in engineering education over the past two decades. Suggested future work included employing RLs within the science and K–12 science education, and maximizing important features of RLs, such as long-time observation, real-time interactivity, anytime and anywhere access, and engagement. A RL system can be integrated with existing e-learning methods (such as online courses and mobile learning), which are important in distance education. Additionally, the development of feasible remote experiments across the science disciplines such as biology and chemistry should be considered in future work.

Recent work on VISIR (Virtual Instrument Systems in Reality), a remote lab developed by Blekinge Institute of Technology (BTH) in Sweden investigated its effects on teaching and learning, including how it aids student learning beyond the hands-on lab exercises experience [11]. VISIR was used in two different courses related to electric and electronic topics over three semesters and evaluated by 475 stidents. Results show that teachers' involvement plus their ability to brief students on VISIR's usefulness have a significant influence not only on students' performance but also on their perception of learning and satisfaction with the tool. In the analyzed cases, students with more learning needs seemed to benefit more from VISIR.

In summary, remote labs employ Internet and web development tools to provide authentic laboratory experiences to users over a distance. RLs allow self-paced, 24/7 authentic hands-on learning experiences for learners in engineering and science disciplines. As suggested by previous work, enhancing the learning experience by allowing multi-user collaboration is a future direction. Also, teacher or teaching assistant involvement during the introduction of a lab are essential to enhancing students' perceptions of RL and their performance in learning the subject.

Objectives

This paper focuses on the design and evaluation of a collaborative remote lab for learning robot programming using a virtual teaching pendant for a LabVolt 5150 articulated robot. The lab has been in place for three semesters. The remote lab setup and lab exercise were revised each semester based on students' comments and suggestions. The following sections describe the system setup, lab exercise, evaluation findings, and future directions.

Collaborative Remote System Design and Setup

The design allows students to control an articulated robot using a virtual teach pendant and to work collaboratively to accomplish tasks specified in a lab exercise. Figure 1 shows the collaborative remote lab architecture. The web page includes a real-time image of a remote articulated robot as shown via a webcam and a virtual teach pendant with the same layout as the physical pendant. Both webcam and teach pendant occupy an IP address. Students log in to the system via a web server (Apache) and can see and communicate with each other via a web conferencing platform (Zoom). Students' interactions with the virtual teach pendant are communicated to a robot controller connected to the web server. Therefore, virtual teach pendant commands result in actual robot movements, which are then displayed to the remote user via a webcam.

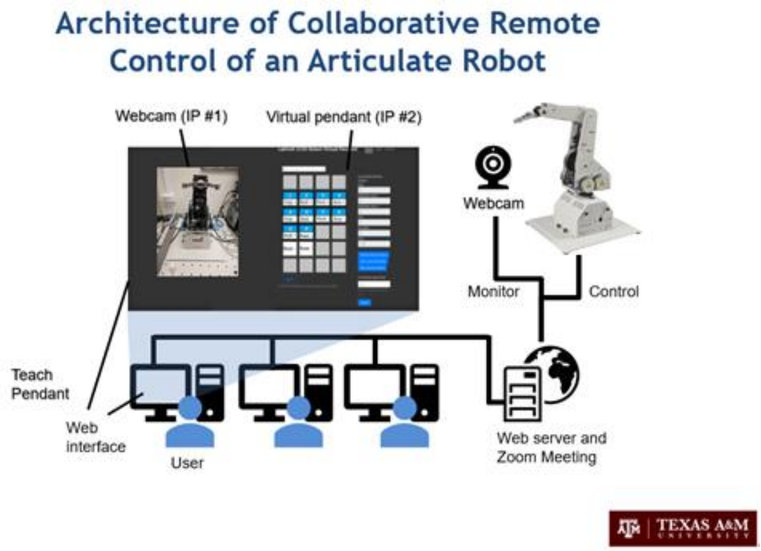


Figure 1. Collaborative Remote Lab Architecture.

The virtual teach pendant resembles the actual teach pendan used when controlling the robot locally. This allows students to transfer what they learned during the RL to the physical lab environment.

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 2 shows the flow of a typical user interaction with the LabVolt 5150 robot through the system.

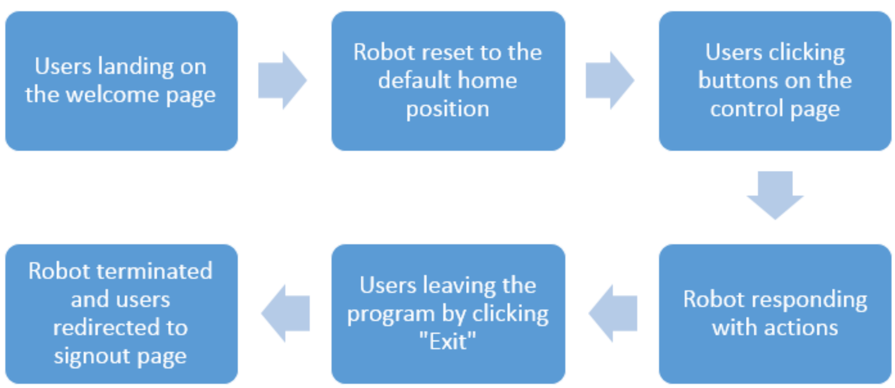


Figure 2. Process flowchart describing user interaction with system.

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 3) illustrates the dynamic between the web application and the background control unit.

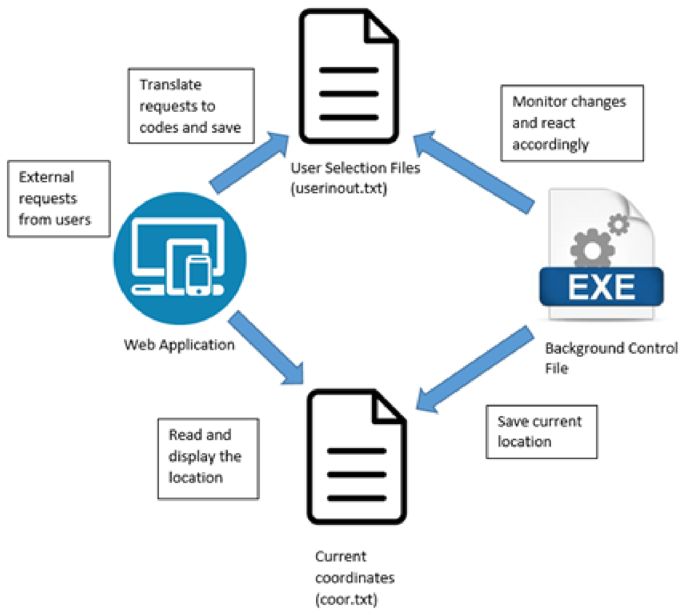
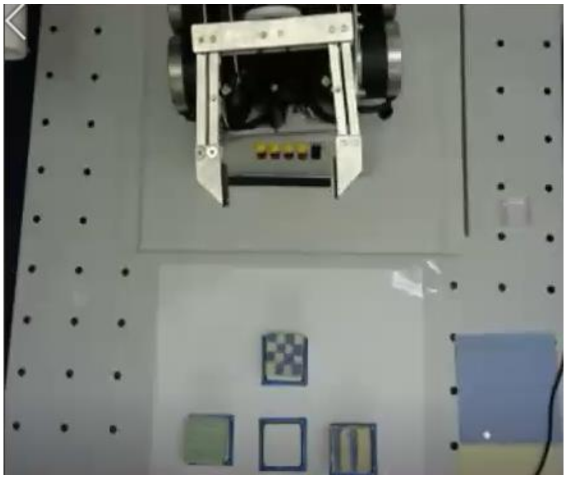


Figure 3. Illustration of relationship between system components.

Collaborative Environment Design

The collaborative environment design can be addressed from hardware and software perspectives.

Hardware. The setup has evolved over the last three semesters based on students' suggestions. Initally, a single camera was used to show the entire robotic system and its surroundings. Later, a second camera was added to provide information about the position of the gripper relative to the base of the robot. Most recently, a third camera was added to provide a top view of the entire robotic system and its environment, which facilitates motions such as grasping and stacking parts.. Figure 4 shows the layout of the robot workspace and Figure 5 shows the layout of the cameras that view the robotic system from front, top, and side angles.



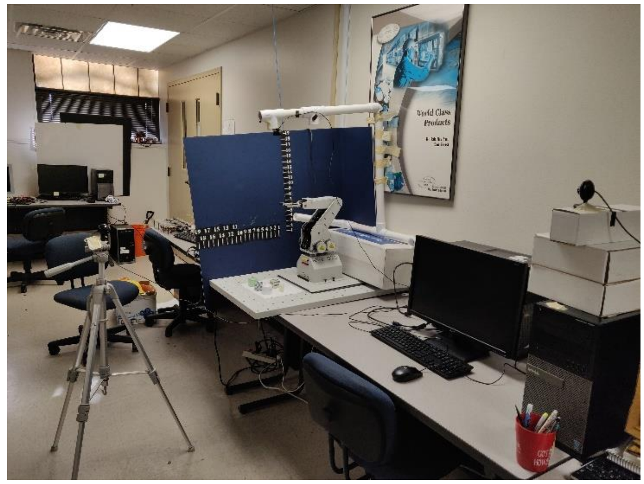
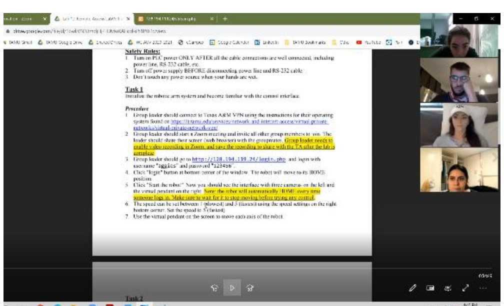


Figure 5. Layout of Robot Work Space.

Figure 6. Layout of Robotic System and Camera Setup

Software. Since the beginning of the COVID-19 pandemic, Zoom meeting software has become a university-wide platform for online instruction. Zoom allows users to share their computer screens as well as see one another. For this collaborative lab exercise, three students worked together using Zoom. Team members could communicate and share ideas about how to accomplish the tasks in the lab exercises. Below are screen shots of students remotely manipulating the robot to accomplish the tasks described in the lab exercise. Figure 6 shows the e-copy of the lab exercise that students are following. Figure 7 shows the RL robot in motion. The left portion is the images of three webcam looks at three different angles of the robot; the middle portio is the virtual teach pendant; and the right portion of the window is the images of the team members.



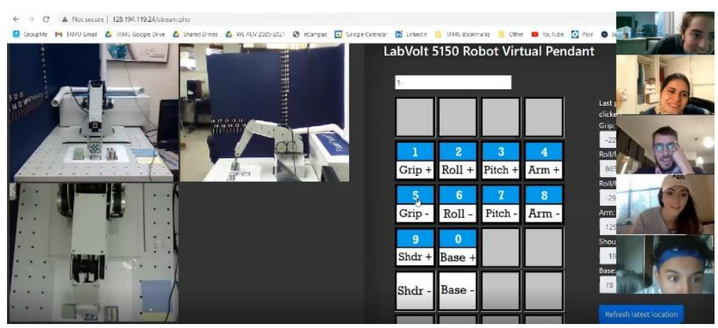


Figure 6. Students Reviewing Lab Exercise on Shared Screen.

Figure 7. Robot in Motion.

Collaborative Lab Exercises

The lab exercises are designed to (1) require three students to work as a team. One serves as the driver to operate the robot; the others provide advice in real-time as the driver manipulates to robot to accomplish an assembly task, and (2) allow students to investigate the basic properties of an articulated robot such as joints, limits, and work envelope.

Procedures. The team captain initiates a Zoom meeting and then shares their computer screen with the team members. The team captain drives the robot while other members help determine the robot position and how to move the robot to the desired location.

Tasks. Below are sample questions from the lab exercise.

- Identify the joints of the robot and explore their limits as well as the work envelope of the robot
- Calculate the resolution of the Base and Roll joints.
- Program the robot to stack Cube A on top of cube B.

These tasks help students to become familiar with the virtual teach pendant interface and how to control each joint by exploring the limits of each joint and calculating the control resolution and work envelope of the robot. Afterwards, they complete a simple stacking operation.

Evaluation

The remote lab for robot proramming has been evaluated by undergraduate students for three semesters. The idea of collaborative RL was initiated in Fall 2020 due to COVID-19 pandemic needs. Most courses were converted to online and in-person lab instructions became very challenging due to the need to maintain social distance. The collaborative remote lab was evaluated by 52 upper-level undergraduate. The goals were to determine to what extend did the collaborative remote lab help students to learn more about basic robot anatomy, links and joints, and how to use a teach pendant to move a robot. Students also provided their opinions about various aspects of the collaborative remote lab, such as user friendness, features, objectives, emphasis on important information, use of multimedia, and relevance to their education

Ratings

All students provided ratings and comments using an opinion survey using a 7 point Likert scale (1=strongly disagree; 7=strongly agree). Figure 8 shows students' ranking regading the lab exercise ranging from robot joints, limits, work envelope, and working as a team. Resruls suggests that students liked all aspects of the lab exercise, especially the understanding of joint limits with the rating of 5.46 on a 7-point scale.

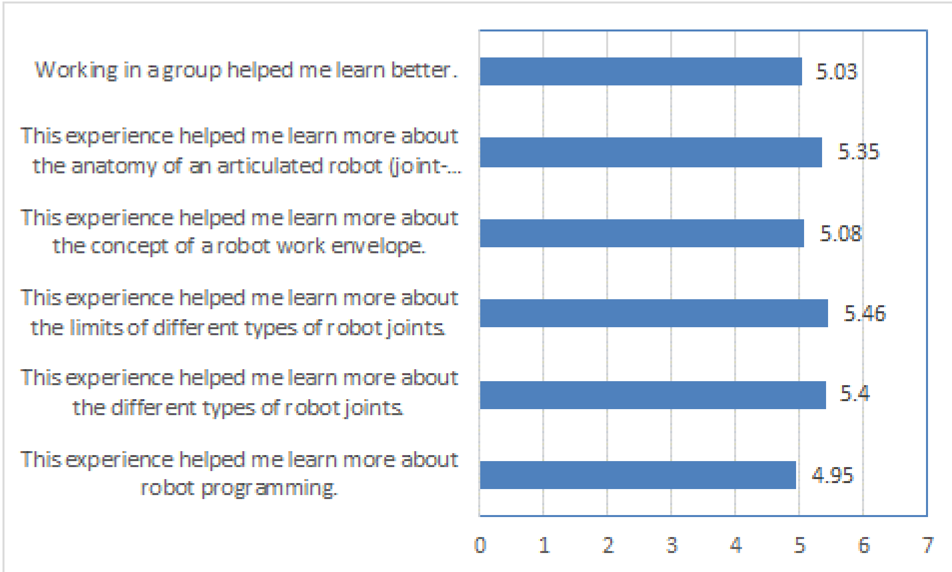


Figure 8. Opinion survey of undergraduate students about Collaborative Remote Lab.

Student Comments

In students' responses to the question "The most helpful thing about this project has been:" commonly mentioned themes were that the hands-on, teamwork, and visual experience were helpful to learning, and self-paced learning. Below are some sample responses:

- Was being able to see how each joint differed in the way it moved the robot. Although there were three rotating joints, they all produced a vastly different range of motion.
- It helped me visualize how an operator views and controls a robot using an ip address. Also, helped me understand the importance of knowing the work envelope of a robot and its limitations.
- The most helpful thing about this experience was being able to manually control the robot arm. It allowed me to learn via trial and error.
- Hands on experience and working in teams.

In students' responses to the question "This project could be improved by:" common themes were (1) more time and everyone can control the robot; (2) more cameras, wider angle, or high resolution; and (3) a more complicated task. Sample comments are below:

- If every group member had a chance to control the robot; Everybody got to control the robot
- This experience could be improved if we were given more time to control the robot
- It was kind of challenging to do it remotely, the robot and the pendant had some input lag so it wouldve been easier in person but since covid has affected this semester, we had to do it remotely
- better resolution on the cameras and wider angles;The camera angles could be better, but other than that the experience was good

- Every team was given a different task and each task combined achieved one goal; through a visual display such as the projector, if one team fails the other teams are able to give insight how they can achieve the failed task

Conclusion and Future Directions

In this paper, we have described the design and development of a collaborative remote lab to teach students about robot anatomy, joints, limits, control resolution, work envelope, and programming a robot using teach pendant. The design incorporates a mix of JavaScript, CSS, HTML and PHP, and a background executable file, which is written in Visual Basic. The web based communication platorm was Zoom Meetings. Evaluation results suggest that the collaborative remote lab was effective for robotics education in the pandemic environment. Future directions include 1) expand the system to allow online reservation of equipment time; 2) design lab exercises for more complex tasks that require team work; 3) continue assessing the effectivenesss of the collaborative RL; 4) add advanced programming functions (such as conditional and loop structures); 5) install more webcams that allow students to zoom, pan and tilt to provide different views of the robot position; 6) develop a real-time 3D model to show the robot position within the work envelope; and 7) provide haptic feedback.

Acknowledgements

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