Enhancement of Online Robotics Learning Using Real-Time 3D Visualization Technology

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ABSTRACT

This paper discusses a real-time e-Lab Learning system based on the integration of 3D visualization technology with a remote robotic laboratory. With the emergence and development of the Internet field, online learning is proving to play a significant role in the upcoming era. In an effort to enhance Internet-based learning of robotics and keep up with the rapid progression of technology, a 3-Dimensional scheme of viewing the robotic laboratory has been introduced in addition to the remote controlling of the robots. The uniqueness of the project lies in making this process Internet-based, and remote robot operated and visualized in 3D. This 3D system approach provides the students with a more realistic feel of the 3D robotic laboratory even though they are working remotely. As a result, the 3D visualization technology has been tested as part of a laboratory in the MET 205 Robotics and Mechatronics class and has received positive feedback by most of the students. This type of research has introduced a new level of realism and visual communications to online laboratory learning in a remote classroom.

Keywords: Robotics, Online, polarization, e- Lab Learning, Internet, Evaluation, and 3D Visualization.

1. INTRODUCTION

Advances in computers and communication technology have changed traditional methods for learning and skills training. Today e-learning is becoming an increasing popular alternative to traditional programs. In modern learning and training systems, integrated learning scenarios where e-learning is linked with the world of work, play an important role. Distance-learning involving real-time connection between geographically separated entities holds enormous potential for education. The development of a Web-based laboratory enables participation in laboratory experiences by distance students. It is also motivated by the fact that presently, as never before, the demand for access to the laboratory facilities is growing rapidly in engineering and technology programs. Additionally, Web-based laboratories will provide the opportunity for students to explore the advanced technologies applied in implementing Internet-based technology solutions, so to prepare them for their future careers [1-9].

While online laboratories promote student centered-learning with a convenient scheduling, the limited visual feedback in the form of 2D images is far from adequate to perceive and understand the overall workings of the complex systems. Lack of depth perception and the limited visual and communications make it difficult for the cognitive information processing and cognitive understanding involved in the learning of such systems. Cognitive fatigue becomes more prominent as students are working with miniaturized equipment with a high degree of precision and accuracy. Isolation of distance learners from an instructor is a big hindrance in online laboratory learning. It requires not only the mastery of skills in operating and controlling the array of sophisticated equipment, but also the adequate levels of experience and knowledge. A great deal of mental effort is expended to convert the cluttered 2D images into 3D objects [10-17]. In the paper, the efficient approach for e-Lab Learning with the online 3D video streaming integrated with Internet-based real-time control of robots is developed. This involves finding the way of capturing the video stream and streaming it over the Internet by using the Web as both for teaching materials related to the experiments and mixed reality hardware and software.

2. FRAMEWORK

Image Capturing Mechanism

The Web-based real-time 3D visualization system for robotic laboratory learning is shown in Figure 1. Most stereoscopic video images are obtained by a dual-camera configuration where the left-eye and the right-eye view are recorded separately by two cameras taken a slightly different perspective. The chosen transport mechanism method provides server-to-client transport functionality suitable for real-time, delay sensitive data transmission. This system defines data transfers that allow the delivery of data in a manner scalable to large multicast networks. Data is received over the Internet into a designated client computer and then divided up into congruent horizontal bands for each of the two cameras and distributed to a variable number of computational nodes for image analysis. These analyzed images are then gathered to a single node, which combines them into a processed frame, and broadcast over the Internet to a remote display station.

The way polarized 3D glasses function is by creating the illusion of 3-dimensional images. This is performed by restricting the light that reaches each eye. However, in order for the polarized glasses to function properly, the two images must be projected superimposed onto the same screen through orthogonal polarizing filters. The polarized glasses also contain a pair of orthogonal polarizing filters each of which passes only the light that is similarly polarized and blocks the orthogonally polarized light. Thus, the 3-dimensional effect is created when each eye only sees its separately polarized image. In the system, passive 3D projection is chosen for displaying the received stereoscopic video. Owing to the big screen and lineless glasses, viewers can conveniently catch the strong 3D feeling in remote robotic operations.

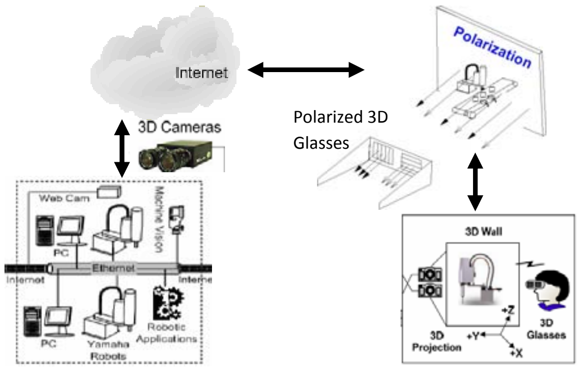


Figure 1: The framework of the online 3D visualization system

The 3D polarized setup for capturing mechanism is shown in the Figure 2. The hardware and software system consists of two Sony mini-DV Handycam Camcorders, i-Link firewire cables, video card with dual output cables, 2 DLP projectors, silver projection screen, twin sliding bar (6”), tripod, and WebcamXP Pro. The two camcorders are fixed on the twin camera bar which is then mounted on a tripod. The two cameras are placed in a parallel fashion. The distance between the two cameras and the distance between the cameras and the robot are tuned. The zoom level on both cameras must be minimal to ensure that the CCD level is not alternated during recording. The twin camera bar is designed to allow two cameras to be mounted side by side in a fixed horizontal position. The bar is designed to mount and remove each camera easily using two screw finger torn knobs. The bar also includes a bubble level to measure the tilt in the bar. It can easily be mounted on a tripod since it is equipped with a standard mounting hole.

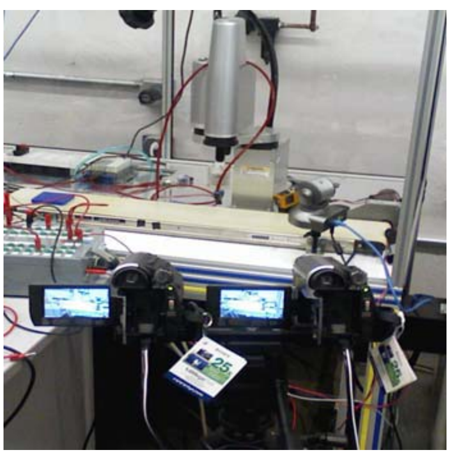


Figure 2: Capturing mechanism with a robotic station and twin camcorders

The Sony camcorders can transfer the data over an iLink firewire cable that is sufficiently fast for high quality streaming. The iLink interface also reduces the chances of having any delays in the transfer of the images from the camcorders to the WebcamXP server. However, a major requirement for this system to work is the ability for the computer to accept two firewire inputs from both cameras. Therefore, the computer should be equipped with a two-port firewire card. The goal of the project is to investigate how students perceive, process information, and develop cognitive learning under the proposed 3D tele-presence system, which is expected to impart cognitive advantages. It is hypothesized that the combined effects of visual feedback, the viewing angles, the number of multiple views, the field of view, and the format of auditory augmentation will enhance learning. The key importance is to render the remote systems as realistic as possible, hence the 3D cameras will be setup correctly to give a proper depth perception and to reduce the amount of distortion [18-20].

Displaying and Watching Polarized Video

In the case of a polarized video, the output has to be projected as two images (left and right) on a silver screen. By wearing a pair of polarized eye glasses, the user can see the image in 3D with a proper depth perception. In order for the dual output concept to work, a dual output video card is required. In this project, the “ATI Radeon HD 2400 Pro” video card was used with a dual output cable. The two cables are connected to two Mitsubishi XD490U XGA DLP ultraportable projectors that work on 2500:1 contrast ratio and very bright 3000 ANSI lumens. In this case, the ports and cables that are used are DVI ports and cables. The projectors also feature a color enhancer technology that intelligently produces true colors and smooth images for specific scene settings.

To help align the two projectors, an adjustable stacker unit is used. The stacker unit includes two custom adjustable filter holders for positioning pre-aligned linear polarizers. Polarized filters are installed on the stack unit and in front of each of the projects to create the polarized images effect necessary for the 3D vision. Those filters are essential for creating the 3D image and have to be placed in the correct viewing positions. Another important factor is the use of a silver screen instead of any ordinary screens. A silver screen is more reflective and brighter than ordinary screens. It is greatly recommended to be used when projecting polarized 3D images.

To project the output from the PC as two images, each camera stream has to be projected separately onto the silver screen. Each camera stream will be displayed on an internet browser that will be projected on a separate projector. On the screen, the two images have to be overlapping and the adjustments have to be performed manually by tuning the adjustable dual stacker unit and dragging and dropping the two images on the browsers. In this way, the parallax and the separation levels will be adjusted as to obtain the best 3D image quality. After that, a pair of polarized glasses should be worn to see the 3D effects.

Custom-built Website for 3D Online e-Learning

The Javascript code that is embedded into the HTML file calls the Mootools library. Mootools is an open-source licensed compact, modular, object-oriented javascript framework designed for the intermediate to advanced Javascript developer. It allows writing powerful, flexible, and cross-browser code with its elegant, well-documented, and coherent API. Using the Mootools Core Builder and More Builder, it is possible to create a javascript library that is useful for a certain programmer. Mootools in this case is used to provide the feature of dragging and dropping the video image on the screen of the browser.

Figure 3 shows the online 3D vision system in Client 1 integrated with Internet-based robotics laboratory in Client 2. The following steps are described how the server/client procedure works for the video streams:

1. Browser asks the Drexel Webserver for the HTML file and other resources necessary for the Webpage, 2. Drexel Webserver sends back the HTML, CSS and Javascript files and the browser downloads them, 3. The browser uses the CSS file to identify the settings for the video display, 4. The browser connects to the WebcamXP Webserver to ask for the video stream. The HTML file contains information about through which URL and port number the browser has to connect to the server, 5. The WebcamXP server asks for authentication from the user on the browser, 6. The user authenticates the transfer of data, 7. Data containing the streamed video starts flowing into the browser with no buffering on any side. The Javascript code together with Mootools, keep refreshing the page to get new images for the video, and 8. Mootools allows the user to drag and drop the video on the screen.

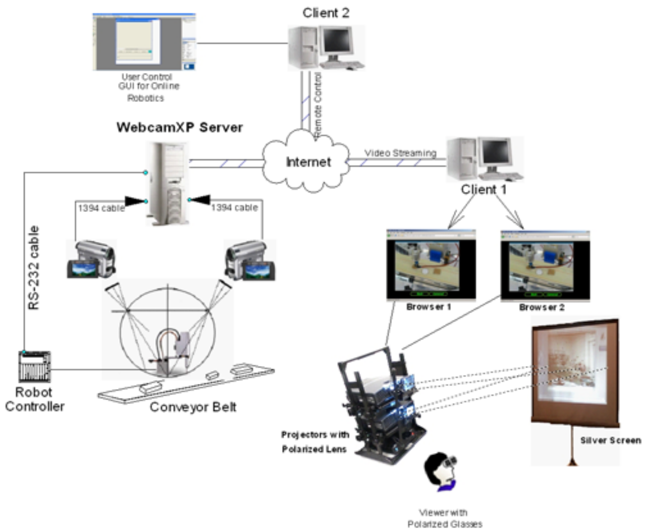


Figure 3: Real-time polarization application

Streaming the Polarized Video in Client 1

Figure 4 shows the methodology in the system for developing application software modules and the interface for streaming video through the Internet. Streaming polarized video does not exactly mean streaming the video in its polarized form. The process is performed by streaming the videos from the two camera sources in real-time. In order to achieve the minimal delay, the buffers at the server and the client sides have to be almost completely eliminated. After extensive research, practical software that was able to achieve this goal was found. WebcamXP is a camera management and streaming software for private and professional use [21].

The video streaming capabilities described for the client (the user's view's point) are supplied by servers. To supply HTTP (Hyper-Text Transfer Protocol) - based materials, an HTTP server is needed. HTTP server video coding capabilities can be supplied on a variety of software platforms including UNIX, WebcamXP, and Windows Media streams (ASF) - local video files (AVI/WMV/MP4/MOV/...).

Since the stereo video encoding scheme is based on twin cameras, WebcamXP is the best choice for transporting the stereoscopic video streams. It offers unique features and unequaled ease of use to allow a user to broadcast and manage multiple video sources on the same computer. It is the tool to secure files and to manage users' accesses at Drexel's Webserver. It also supports FTP/FTPS and HTTP/HTTPS Post - motion detector (optical or acoustic) with many possible ways to handle alerts (local recording, ftp, http post, launch external applications).

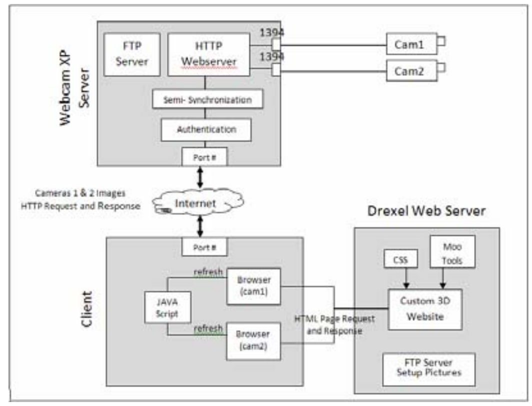


Figure 4: Real-time transport method for data transmission

As shown in Figure 5, WebcamXP allows a user to share the data coming from the connected camera to the Internet or Intranet users. When this broadcasting feature is enabled, the internal webserver of WebcamXP would be enabled. This allows users who know the server's IP address or Website URL to navigate to a custom-designed page and observe the streaming representation of the cameras that are connected to the server. In order to configure the Webserver, the server's host name and port should be specified. The broadcast is accessed through this name and port. Broadcasting in WebcamXP is performed over HTTP. A user can access the connected cameras through any type of browser (Microsoft Internet Explorer or Mozilla Firefox) that imports from WebcamXP's Webserver. It has to be noted though that authentication can be applied so that the user would be prompted to enter a password whenever he/she tries to connect to any of the cameras. The first figure below displays how WebcamXP works. Two video sources can be recognized corresponding to the left and right cameras. After including all the settings, the Webserver can be enabled.

Figure 5: WebcamXP for broadcasting video streams

Now that WebcamXP is broadcasting the two video streams, it is up to the users to determine how to display those streams. For this reason, it was decided to design a custom Website for this type of application. The Website would provide the students with some knowledge regarding how the whole system works in addition to accessing the two video streams. Each of the cameras has its own link on the Website which can be displayed in a separate browser. Moreover, each of the camera videos can be dragged and dropped over the screen to simplify the procedure of overlapping the video streams for the purposes of creating the 3D effects.

As shown in Figure 6, The Website itself was created using Microsoft Frontpage and some custom HTML code. For the pages that include the video streams, additional CSS and Javascript codes are required. The Website was uploaded to Drexel University's Webserver so that it would be available to all the students. It was specifically uploaded to the instructor's FTP server space.

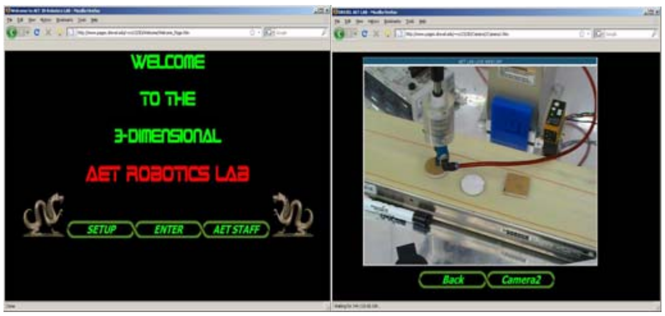


Figure 6: Web home page and a camera video stream in Client 1

Remote Robotic Control in Client 2

For our purposes, the robot online has to be operated using software that can be remotely controlled. This objective is primarily accomplished by the use of Yamaha VIP programming. Yamaha VIP Windows is applied as assistant software for a multi-axis robot controller and robots. To allow remote operation, the Yamaha YK220X Scara robot facilitates the remote robotic control. The Yamaha VIP Windows is the software that remotely operates the robot arm as well as runs the robotic programs. It executes instructions via Ethernet connected to the robot controller which facilitates the inputs and outputs for the robotic operations.

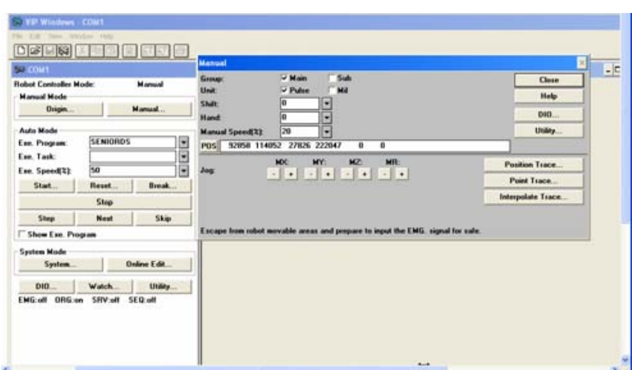


Figure 7: Remote robotic operation by Yamaha VIP Windows software in Client 2

The system integration enables the computer to automatically perform the sequence of tasks outlined by a user when the students start the equipment from a remote site. It can also be used to create and edit programs, teach points, define parameters, and shift and/or run data directory used with robot controller. As shown in Figure 7, the Yamaha VIP Windows software for robotic operations enables information exchange between the various levels of the control architecture.

3. RESULTS

Online Laboratory Learning Experiments

The new online 3D polarized vision setup was ready to be tested as part of one of the laboratories for the robotics class in MET 205 Robotics and Mechatronics offered at Drexel University in the Winter of 2009, as shown in Figure 8. The system was setup in one of the Goodwin College classrooms and the students were asked to perform the following real-time robotic experiments while looking at the 3D video that is streaming from the laboratories: 1. Running and testing the motion of the robot on the different axes, and 2. Each group will teach a set of 4 points by manually jogging the robot.

The students used the polarized glasses to see the 3D video that was projected on the silver screen in the classroom. As for controlling the robot, the students used the Yamaha VIP software to create and edit programs, point, parameter, shift and/or hand data directory used with robot controller. For example, for a pick and place program, students check for a part at position 1 or position 2 and check for a robot to pick the part and drop it at position 3. WebcamXP has the ability of adjusting the bandwidth of streaming according to the available bandwidth on the client side. Based on the tests performed within Goodwin College, each camera stream utilizes an average of 750 kb/s out of the estimated 80 Mb/s available bandwidth. With these results, an average streaming delay of less than half a second is achieved. Thus, with sufficient available bandwidth on the client side, the developed 3D system can be considered to be appropriate for rich real-time online robotic education.

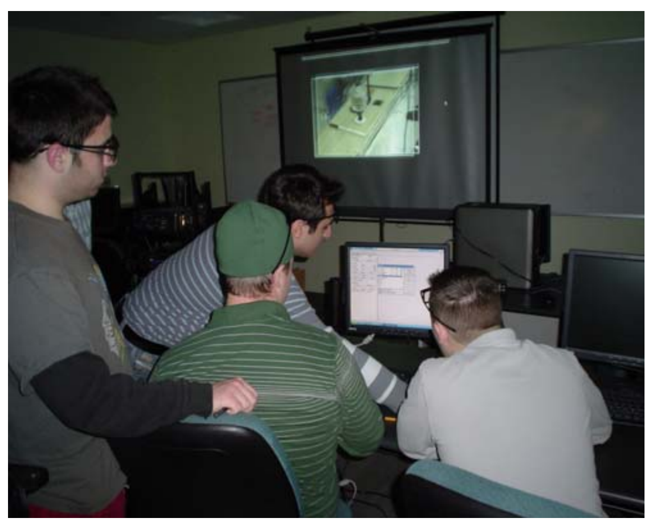


Figure 8: Students watching and controlling a 3D real-time robot

The robotic online experiments measured three questions: (1) cognitive fatigue in remote operation; (2) information processing under different modalities; (3) how students feel about online laboratories. Students were sitting remotely from the robot and asked to use the two viewing windows on a PC for visual communications. They were asked to command the robot to move onto the pick point, then to the place point. Robot end-effector was to be positioned directly over the points in order to measure: (1) the positioning accuracy; (2) the time to complete the task; and (3) the cognitive fatigue on a 1 to 5 scale. The exact coordinates of the points were recorded prior to the experiments, and the students were asked to record their robot's positions for each point. The experiments demanded constant visual attention from the operators. Students have been using a teach pendant in the previous experiments, hence they are accustomed to the workings of the teach pendant in VIP software. They used the same viewing windows on a PC, but with a computer-based robot control interface. The students received the customized questionnaire before/after the experiments for pre-course and post-course evaluations.

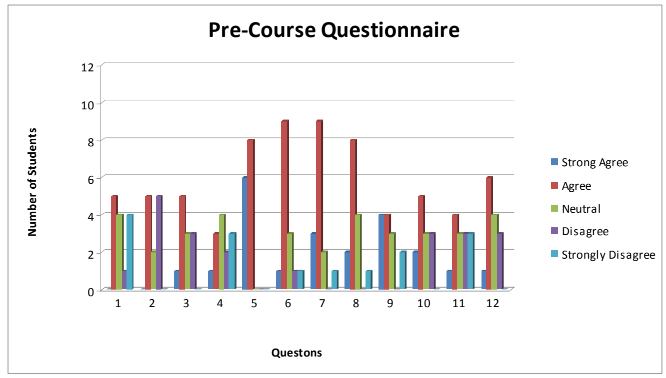
Evaluations

On the scale from 1 to 5, where 1 indicates "strongly disagree" and 5 indicates "strongly agree" please evaluate the following statements:

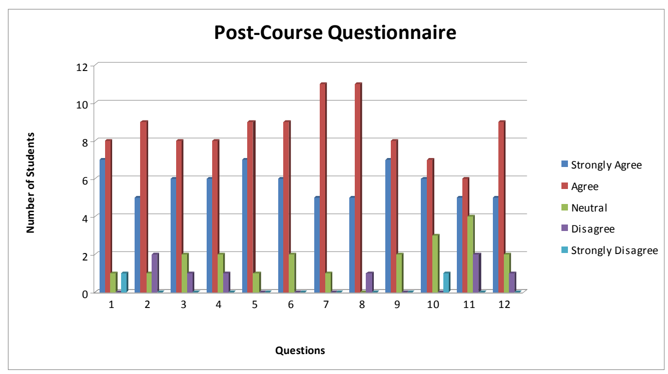
1. I understand the meaning and nature of online lab courses, as opposed to the conventional lab courses.
2. How do you perceive online lab experience with conventional lab experience?
3. How do you compare online lab and conventional lab courses in terms of learning effectiveness?
4. I have the knowledge in robotics and network technologies that enable the remote operation of equipment over the Internet.
5. I understand the importance of remote robotic operations using advanced technologies.
6. I understand technology is related to online laboratory learning.
7. I perceive lab instructions, lab manuals, and other lab materials are very important for online lab courses.
8. I perceive technology influences online laboratory learning in different ways.
9. The online lab facility provides adequate means of information (visual, auditory, textual) in terms of operating the robot remotely. However, it can be further improved by incorporating more advanced systems, and consequently, students will enhance their learning.
10. One critical shortcoming in learning the online lab is the lack of instructor's presence. I perceive the shortcoming can be overcome by incorporating new technologies, such as intelligent tutoring system.
11. Assume that you have to take this course online, and conduct all lab exercises over the Internet. Do you think you would learn equally well as in the classroom setting?
12. Online laboratory experience using remotely operated robots is important in terms of acquiring skills and knowledge that will help prepare my future.

<Pre and Post Course Questionnaire >

The finals results of the questionnaires are shown as the histograms in Figure 9. The questionnaire results have shown a significant increase in the students' acclaim of the new 3D system. The research into enhancing the real-time 3D display system has proven that it is possible to improve the quality of learning in Robotics classes. The evaluation results have displayed a significant increase in the students' understanding of robotics. The experiment included teaching the RCX40 robot different points on the conveyor belt. Using this new 3D system, the students were able to easily point out the objects on the conveyor belt and teach the points. Thanks to the 3D visualization, the students were able to better perceive the depth of the robot image. This proves that the system that has been built contributes greatly to the goal of enhancing online learning.



(a)



(b)

Figure 9: Evaluation results of online student learning enhancement, (a) Pre-Course questionaire and (b) Post-Course questionaire

4. CONCLUSION

The new 3-Dimensional scheme of viewing the robotic laboratory has been introduced in addition to the remote controlling of the robots. The 3D display system can project both stereoscopic 3D video and standard 2D video (in either stacked mode or as two separate projectors). This new 3D system approach has provided the students with a chance to experience an online robotics laboratory in a more realistic fashion. An evaluation of the polarized technologies has been performed which has portrayed the students' preference of the polarized technology. As a result, the polarized 3D visualization technology had been tested as part of a laboratory in the MET 205 Robotics and Mechatronics class and the evaluations have displayed positive results.

5. ACKNOWLEDGEMENTS

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