Real-time Stereoscopic 3D for E-Robotics Learning

Richard Y. Chiou[*1], Yongjin (James) Kwon[2], and Tzu-Liang (Bill) Tseng[3], Robin Kizirian[1], and Yueh-Ting Yang[1]

[1]Engineering Technology, Drexel University, Philadelphia, PA 19104, USA
[2]Division of Industrial & Information Systems Engineering, Ajou University, South Korea
[3]Department of Industrial Engineering, The University of Texas at El Paso, USA

ABSTRACT

Following the design and testing of a successful 3-Dimensional surveillance system, this 3D scheme has been implemented into online robotics learning at Drexel University. A real-time application, utilizing robot controllers, programmable logic controllers and sensors, has been developed in the "MET 205 Robotics and Mechatronics" class to provide the students with a better robotic education. The integration of the 3D system allows the students to precisely program the robot and execute functions remotely. Upon the students' recommendation, polarization has been chosen to be the main platform behind the 3D robotic system. Stereoscopic calculations are carried out for calibration purposes to display the images with the highest possible comfort-level and 3D effect. The calculations are further validated by comparing the results with students' evaluations. Due to the Internet-based feature, multiple clients have the opportunity to perform the online automation development. In the future, students, in different universities, will be able to cross-control robotic components of different types around the world. With the development of this 3D E-Robotics interface, automation resources and robotic learning can be shared and enriched regardless of location.

Keywords: E-Robotics, Online, Polarization, Quality, PLC, E-Lab Learning

1. INTRODUCTION

E-Robotics is the modern term for combining E-Learning techniques with the traditional Robotics learning programs. It emphasizes the controlling and programming of robotic components over the Internet without having to be physically next to them. This scheme is part of an E-Industry that has been widely developing with the popularity of the Internet over the world [1-7]. However, E-Robotics suffers from the lack of realism which makes it hard to progress. The inability to accurately locate points and teach the robots imposes difficulties on engineers or even students who are involved in this type of industry. As such, a new display system has been established and calibrated to offer the robot programmers with the best field of view to pursue their jobs.

A few years ago, the word "3D" was used to reflect an illusionary technology that transformed images to resemble those from real-life [8]. Stereoscopy was still developing and its applications could be hardly found in people's everyday lives. Today, 3D technology is becoming publicly available and accepted by different societies. It can be found in the media world in addition to professional applications. In the entertainment world, 3D movies and multimedia have created a realistic virtual environment for the audiences, dazzling them with the power of such technology. In the field of online education, 3D stereoscopy has also obtained positive feedback by allowing the educators and learners to get involved in a new educational atmosphere [9]. This environment combines the traditional classwork duties with a rich Internet-based learning experience that can benefit the students even though they are working remotely. At Drexel University, this stereoscopic 3D technology has been adopted, optimized for the best 3D effects, and used for E-Robotics teaching. The optimization parameters have been based on objective calculations of a 3D metric known as "Stereo Base" and subjective evaluation outcomes from the students. The result has been the development of an online real-time 3D Robotics laboratory that has received encouraging statements from the student, allowing them to access the Robotics laboratory from any location at any time.

As a supplementary effort to enhance the online Robotics program, programmable logic controllers (PLC) have been integrated into the laboratory experiments. PLCs are widely used in manufacturing facilities as the primary controller of the shop floor [10]. They take inputs from individual robot controllers, sensors, and human machine interfaces. After processing the inputs, they generate output signals according to the compiled program in the controller to control all external components in a real-time manner [11-12]. Providing the students with the chance to use the 3D display system to control and program robots and logic controllers allows them to improve their knowledge in the automation field and tackle its issues in the future.

This paper discusses the usage of stereoscopic 3D technology for robotics education applications. Section 2 provides a general background of the 3D system that has been developed at Drexel University. The enhancements to the 3D system using new robotic software and 3D quality calibration methods are shown in Section 3. Section 4 describes a real-time remote-laboratory application, involving PLC integration, performed by students. The paper is concluded in Section 5 and future 3D robotic cell applications are presented in Section 6.

2. PREVIOUS WORK

The developed system at Drexel University uses the polarization technology to develop the 3D experience for the students. A dual-camera configuration at the robotic side defines the image capturing mechanism. The images from the two cameras are streamed in a synchronized fashion through a software-based video server over the Internet. On the client side, the students are able to capture the two camera image streams remotely and display them in their web browsers. With the help of two projectors, polarizing filters, a silver screen and polarizing glasses, the students are able to experience a rich 3D Robotics laboratory without having to be present in the classroom [13].

Figure 1 shows the Internet-based 3D Robotics educational system. Two client PCs are necessary to run this system. The first PC is used to feed the projectors with the dual video streams. The second PC is used to run the robotic software and perform various robotic operations. As for the video server, it runs a camera management and image streaming software called “WebcamXP Pro”. This streaming software functions by capturing continuous images from the camera sources and streaming them to a client. The client keeps rapidly refreshing the streamed pictures in a web browser allowing it to surpass encoding and decoding delays. This streaming method also cuts down on the buffering delays that are observed at both the sender’s and the receiver’s sides. Due to the fast Gigabit link between the video server, robot controller, and the two PCs, data can be transferred with little communication delay and the system is able to run in a real-time fashion.

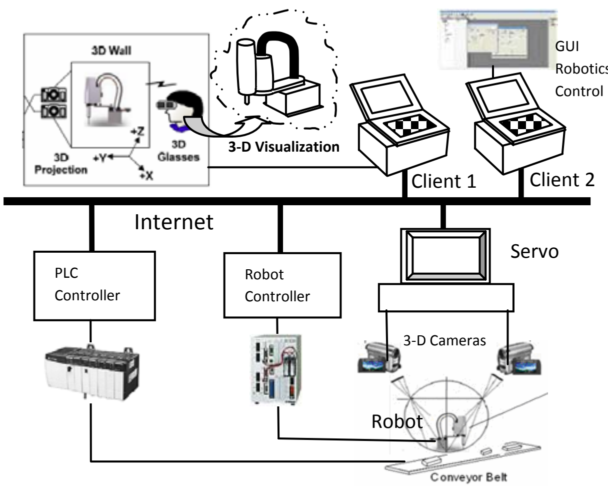

Figure 1: Real-time 3D E-Robotics

The choice of using polarization as the 3D technology for student education is based on the results of previous evaluations that the students have been asked to complete. Polarization works by creating the illusion of 3-dimensional images. This is performed by restricting the light that reaches each eye. A pair of orthogonal polarizing filters superimposes the images while being projected onto the screen. 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, each eye sees only its separately polarized image, creating the 3-dimensional illusion for the viewer.

3. ENHANCEMENTS TO 3D SYSTEM

As an extension to the research in E-Robotics, several improvements have been developed to both, the robot controller software and the 3D image quality. The new E-Robotic software, developed by Yamaha Robotics, introduces advanced Ethernet-based programming features. As for the 3D quality calibration, it is performed based on objective metrics while the quality assessment is based on subjective measurements.

New Robotic Software

The primary goal of utilizing the robotic software is to allow the remote control and programming of the Scara robots in the laboratory. Yamaha VIP, the previous version of the software, is driven towards supporting the serial communication protocol. The new software, Yamaha VIP+, is more Ethernet oriented and contains Ethernet-based options. Several new features such as auto-calibration, fast multiple controller management and debugging functions have been included in this new version. Yamaha VIP+ is used as assistant software for multiple multi-axis robot controllers and robots.

The software can run in manual, automatic, programming, system and utility modes. The manual, automatic, and programming modes are the essential modes for student applications. Figure 2 displays the manual control mode of the robot. The users are able to perform different types of manual robotic operations such as jogging, tracing, and speed tuning. Jogging the robot is possible on one axis at a time at definable increments. Tracing allows the user to define the point coordinates that the robot moves to. The units for jogging and tracing can be in both pulses and millimeters depending on the users’ settings. Manual control is essential for teaching points and testing the I/O modules of the robot controller.

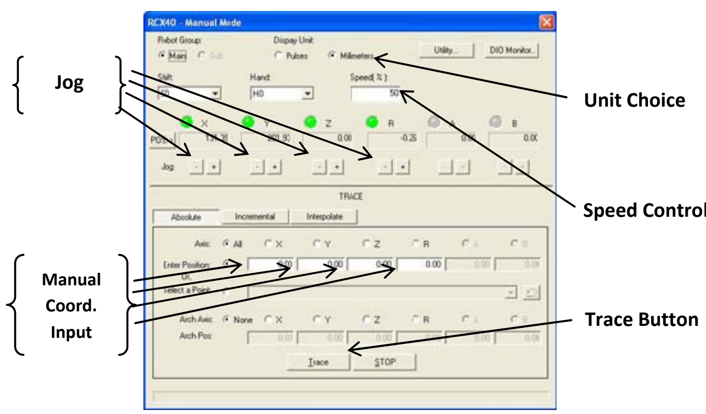

Figure 2: E-Robotics Manual Mode Control

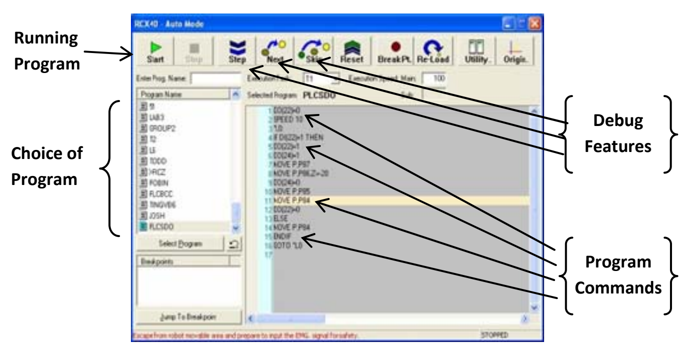

Figure 3: E-Robotics Automatic Mode Control

It is recommended to teach the required points before accessing the programming mode of the controller. Once the points have been taught correctly, the user is able to build the necessary program and compile it in the programming mode. The programming syntax used is developed by Yamaha Robotics and is specific for Yamaha robotic controllers. It includes high-level commands that allow users to control almost every aspect of the robotic motion. Testing and running the robotic program takes place in the automatic robotic mode. Figure 3 portrays the testing of a sample robotic program and the methods of using debugging features to capture any run-time errors.

3D Quality Calibration

The preliminary goals for the 3D stereoscopic system have been completed as shown in Figure 1. However, the results have shown variations in the quality of the 3D video. As a method of improving the 3D display, research has been devoted to determine the most effective parameters that might cause the quality distortions. Figure 4 describes some of the parameters that can play a big role in changing the comfort level and the effectiveness of the 3D images.

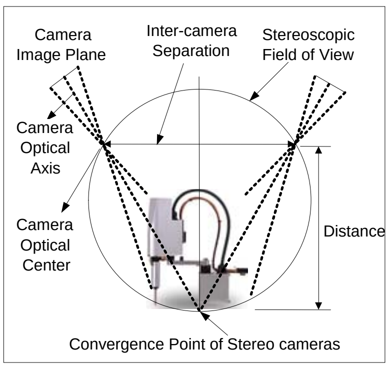

Figure 4: Parameters for 3D Quality Assessment

Although there are several factors to be considered in order to assure the 3D images' best quality and comfort, the most important factors, according to this research, are the distance between the lens of each camera and the object and the distance between the two lenses of the cameras. This study considers that the cameras are installed in parallel on the camera mounting bar. A more professional term used for the separation between the lens of the left and the right cameras while taking stereo photographs is known as "Stereo Base". It is defined by the formula:

$$STEREO\ BASE = \frac{P \times (L_{\max} \times L_{\min})/(L_{\max} - L_{\min})}{f} \qquad (1)$$

Where P (known as Parallax) is the maximum gap between the left and right images on the film, $L_{\max}$ is the maximum distance from the lens of the camera to the farthest subject, $L_{\min}$ is the minimum distance from the lens of the camera to the closest subject, and f is the focal length of the camera. The formula is based on a simplification of the Berkovitz formula and has been designed by Pierre Meindre [14-16]. The simplification can be called a "pin-hole formula" since it does involve focusing the camera. Figure 5 shows the different factors that are used for the Stereo Base calculation.

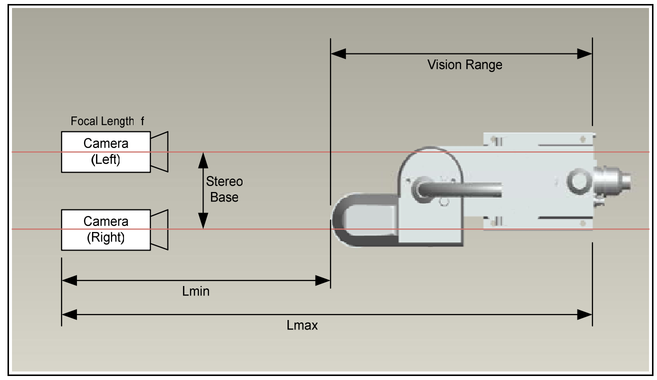

Figure 5: Stereo Base Factors

In order to calculate P, the following formula is used:

$$P = CCD\ width \times SSR \qquad (2)$$

Where *CCD width* is the width of the charge-coupled device in the camera. For the Sony DCR-HC62 cameras that are used for the 3D system, the *CCD width* is 3 mm. *SSR* is the stereo separation ratio and is calculated using the following formula:

$$SSR = \frac{desired\ separation\ between\ left\ and\ right\ images}{width\ of\ screen} \qquad (3)$$

Considering the silver screen to be the screen, the desired separation between the left and right images is chosen to be 400 mm and the width of the screen is 1200 mm. *SSR* in this case is equal to $\frac{400mm}{1200mm}$.

Thus, P is calculated to equal to 1.

$$P = 3 \times \frac{400mm}{1200mm} = 1$$

In order to calculate the focal length f, the CCD size, the distance from the lens to the object, and the maximum size of the target object to be imaged have to be taken into consideration. Equation 4 shows the formula to determine the focal length:

$$f = \frac{CCD\ Size \times Dist.\ from\ Lens\ to\ Object}{Object\ Size} \qquad (4)$$

Based on all these parameters, the Stereo Base can be calculated and the quality of the 3D display can be adjusted.

3D Quality Assessment

In order to verify the equations in this application, several subjective metrics have utilized. Different combinations of the distance between the lens of each camera and the object and the distance between the two lenses of the cameras have been designed to be tested. The distance between the lens of each camera and the object is identified by the symbol D and the distance between the two lenses of the cameras, known as Stereo Base, is identified by the symbol *SB*. The combinations of data are shown in Table 1:

Table 1: Stereo Base Calculations

D	*f*	*SB*
142 cm	20.29 mm	9.62433517 cm
172 cm	24.57 mm	12.15348393 cm
202 cm	28.86 mm	14.62038755 cm
232 cm	33.14 mm	19.58689541 cm

The system is set up according to Table 1 where the values of *D* are defined by the system engineer. Equations 1 and 4 are used to calculate the corresponding values of *f* and *SB*. To test and verify these equations, the 4 by 4 combination setup of *D* and *SB* is evaluated. Thus, for each *D* value, the different *SB* values are tested. The evaluations have been performed as part of the MET 205 Robotics and Mechatronics laboratory at Drexel University.

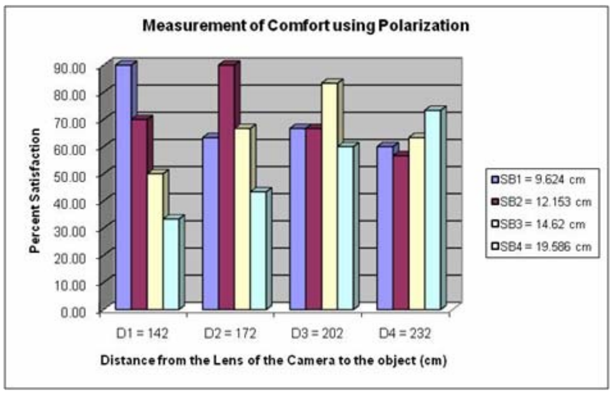

Figure 6a: 3D Comfort Level Assessment

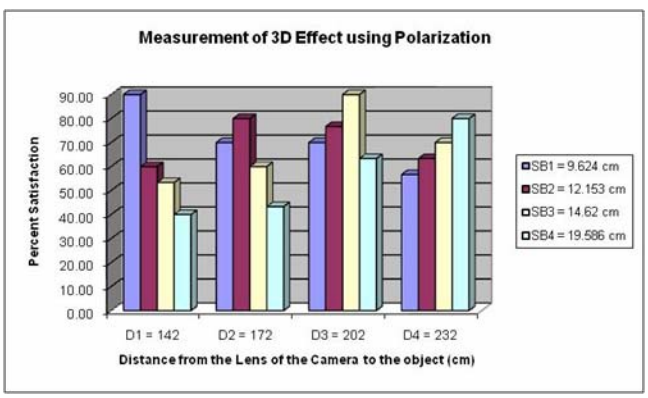

Figure 6b: 3D Effect Assessment

Figure 6a evaluates the students' comfort level with the 3D display in the Robotics laboratory. Figure 6b evaluates the students' 3D experience while using the designed 3D system. For each experiment, the students have expressed their preference of the setup that is based on the calculations from the Bercovitz formula. The results from both sets of evaluations verify that the equations are effective and can be relied on for calibrating the 3D system and offering quality 3D experience.

4. 3D REMOTE-CLASSROOM APPLICATION

The calibrated online polarized 3D vision system is ready to be utilized for remote robotic 3D applications. Experiments involving robot and PLC programming have been designed as part of the MET 205 Robotics and Mechatronics laboratory at Drexel University for the Winter of 2010. These experiments aim at educating students about the possibility of incorporating multiple robots and sensors through a remote real-time controller. Moreover, the students get to experience a virtual 3D robotic environment without the necessity of being personally at the laboratory site.

Robot Programming

The students program the robots remotely using Yamaha's VIP+ software tool. They are able to define working points, jog the robot, create programs and perform other operations. A sample experiment from the MET205 laboratory asks the students to implement a simple robotic operation to pick and place an object from and on the conveyor belt once detected by a photoelectric sensor. A 4-axis Scara robot is to be programmed to execute the corresponding motion. Figure 7 displays the flow chart for the robotic program in the Scara robot controller. The system is initially at reset stage. Once the students command the system to start by pressing the start button in the auto mode of VIP+, the conveyor belt is turned on and the photo sensor is monitored by the PLC (to be programmed). When an object has been detected, the robot picks and places it after the conveyor belt has been ordered to stop. Following the pick-and-place operation, the conveyor belt is turned on again and the robot returns to its initial position. The program will continue looping until the user orders it to stop.

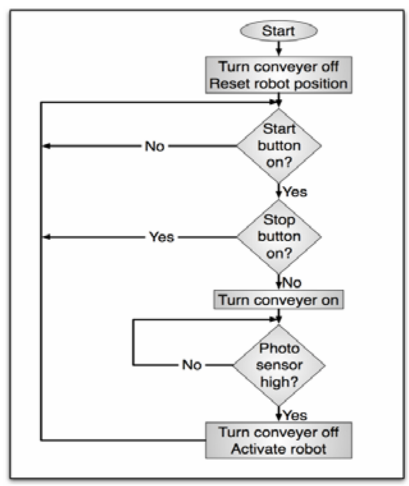

Figure 7: Robotics process flow chart

The calibrated 3D system allows the students to remotely pinpoint the correct locations for defining the working points. The increased comfort level and 3D experience has shown positive feedback from the students while operating the 3D system to program the robot. The students use the manual mode in Yamaha VIP+ to jog the robot across the conveyor belt to the correct coordinates. The programming mode is used to create and type in the program commands for the pick-and-place operation described in Figure 7. Once the robot is programmed, the auto mode of Yamaha VIP+ allows the students to debug and execute the program. Figures 8 and 9 show how the students are using Yamaha VIP+ to build the robotic program while using the 3D display to accurately define the points and robotic motion.

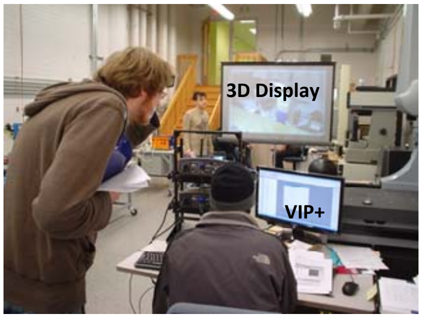

Figure 8: Students programming the Yamaha Robot

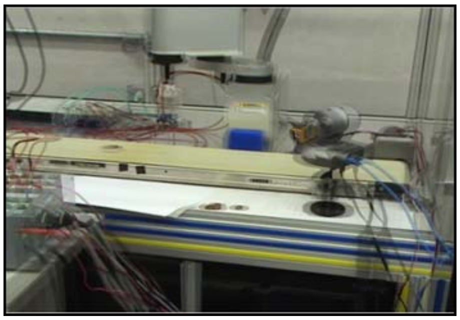

Figure 9: Polarized Picture of Robot

PLC Integration

Complementing the remote robot programming performed in the MET 205 laboratory and to connect all the automation components together, students have also been taught how to remotely program a PLC and logically control the different parts in a robotic system. In this laboratory, students create a program for the ControlLogix processor and then verify that it is operating correctly, as shown in Figure 10. The ControlLogix processor uses RSLogix 5000 programming software. Students learn that the tag names on the left identify the tag as referring to a local (versus remote) module, in slot 0 or 1, and data type of input (I), or output (O). These tags all refer to the input and output modules. Students learn how to enter a rung that is used to monitor the bit 0 input (the first input) of the input module in slot 0. Therefore, the inputs from slot 0 can be selected. In addition to the actual data, students can get information such as a timestamp, and open-wire detection. These advanced features of the module can be used in diagnosing problems in the PLC system.

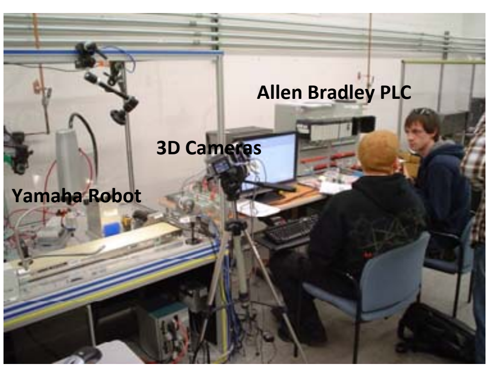

Figure 10: Yamaha Scara Robot with PLC Integration

Figure 11 displays sample logic code designed by the students for the purposes of this laboratory experiment. Each of the lines in the code is called a network. The first two networks in the logic code are ladder logic equivalents of digital electronic latches. The first network aims at facilitating the robot's control of the operation through the start and stop signals. The second network signifies the state whether the robot is busy performing its tasks or not. The states of the system in the first two networks are stored in memory bits that are used to control the third network of the logic. The third network is responsible for controlling the conveyor belt. When the system is started, the robot is not busy, and the photo sensor is not detecting any object, then the belt is signaled to turn on. The last network is responsible for activating and controling the pick-and-place routine of the robot. The initial requirement for triggering the robot is having the start bit high. Once the input from the photo sensor turns high, the circuit is completed and the trigger signal is sent to the robot controller.

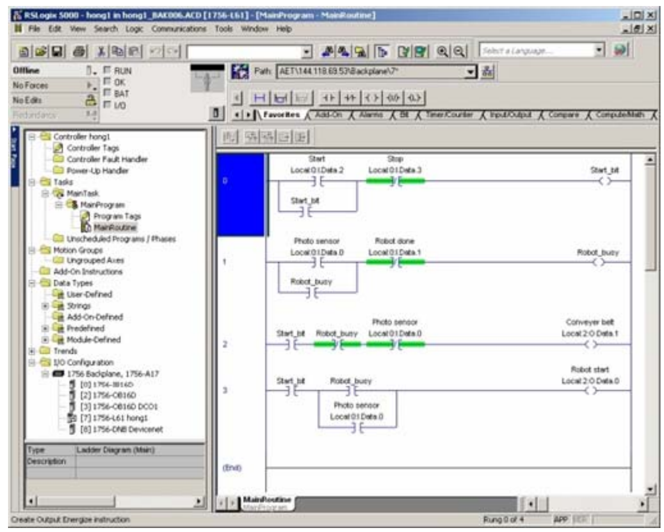

Figure 11: PLC Ladder Diagram

With the integration of the PLC in this application, the synchronization of the different robotic devices in a real-time fashion becomes possible. The students learn how to configure the different inputs and outputs of the PLC to control each and every device in the system. Having such knowledge allows the students to expand their understanding of systematic process control.

5. CONCLUSION

The integration of stereoscopic 3D technologies into Robotics learning has shown successful results. The quality of the 3D images has significantly improved after calibrating the system with several objective metrics and verifying its effectiveness with subjective measurements. In addition, updating the experiments to involve PLC programming and Yamaha's new robotic software, VIP+, helps in educating students with new automation concepts. These concepts include remotely developing a system with multi-robot control and incorporation of different automation components that vastly improve the efficiency and productivity of traditional robotic automation systems. This technology opens the doors for students in different universities to gain the unparalleled knowledge in the automation industry. Different students in different universities will have the chance to cross-control robotic components and enhance their experience. Moreover, the development of 3D stereoscopic E-Robotics has introduced a new level of realism and visual communications in the online robotics world.

6. FUTURE APPLICATIONS

As part of further improving the Robotics education at Drexel University, a new robotic setup has been proposed. As shown in Figure 12, the new robotic system will include two Yamaha Scara robots, a 1-D high speed robot, and a conveyor belt. The work for building this system is already under progress and is believed to highly support the move towards multi-robot integration. Overall, having multiple robots, together with the 3D Display system and PLC programming, will definitely build the foundations for a rich experience in E-robotic cell.

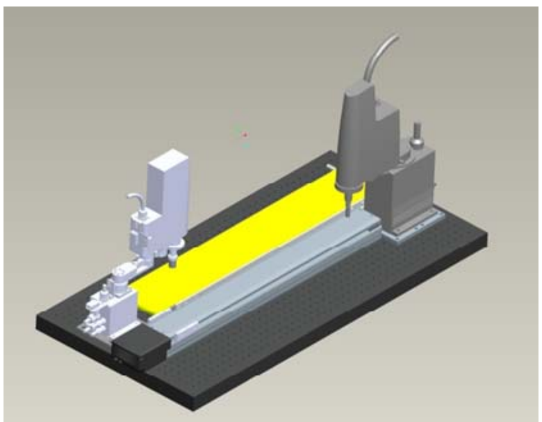

Figure 12: Future Robotic Cell

7. ACKNOWLEDGEMENTS

This work has been supported by the US National Science Foundation (CCLI Phase II DUE-0618665) and the US Dept. of Education (Award # P116B060122), This work has been also partially supported by the Korea Association of Small Business Innovation Research (KASBIR) under the International Joint Research and Development Program, Contract Number #00035088. The authors wish to express sincere gratitude for their financial support.

8. REFERENCES

[1] Chiou, Richard, Kwon, Yongjin, Rauniar, Shreepud, and Sosa, Horacio, “Laboratory Development for Robotics and Automation Education Using Internet Based Technology,” *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, June 18-21, 2006, Chicago, Illinois.

[2] Richard Chiou, Yongjin Kwon, and Prathaban Mookiah, “Manufacturing E-Quality Through Integrated Web-enabled Computer Vision and Robotics,” *International Journal of Advanced Manufacturing Technology*, Volume 43, Numbers 7-8, pp. 720-730, August, 2009.

[3] Paul I-Hai Lin, Hal Broberg, and Aik Mon, ”A Web-based Lab for Distance Learning,” *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*.

[4] Richard Chiou, Yongjin Kwon, Bill Tseng, “Java Programming for Online Quality Control Laboratory Integrated with Remote Robot,” *Computers in Education Journal*, Vol. XVIII, No. 3, pp. 42, July-September, 2008.

[5] Kwon, Y., Rauniar, S., Chiou, R. & Sosa, H., “Remote Control of Quality Using Ethernet Vision & Web-enabled Robotic System,” *Journal of Concurrent Engineering: Research and Applications*, Vol. 14, No. 1, pp. 35-42, 2006.

[6] Lee, J., 2003, “E-manufacturing—fundamental, tools, and transformation,” *Robotics and Computer-Integrated Manufacturing*, Volume 19, Issue 6, pp. 501-507.

[7] Koc, M., Ni, J. and Lee, J., “Introduction of e-manufacturing,” *Proceedings of the International Conference on Frontiers on Design and Manufacturing*, Dalian, China, July 2002.

[8] Pang, Linjuan, Jiang, Gangyi, Zhou, Yu, Yu, Mei. "Research and Application of Stereoscopic Video Based e-Learning System." *Springer-Verlag Berlin Heidelberg (2006)*: Vol. 3942, pp. 156-160.

[9] Ashibani, Majdi, Ben Shatwan, Fathi. "Efficient Video Streaming Scheme for Next Generations of Mobile Networks." *Journal of Systemics, Cybernetics and Informatics*, 2005, Vol. 3, Number 2, pp. 11-16.

[10] Hsieh, Sheng-Jen and Patricia Yee Hsieh, “Web Based Programmable Logic Controller Learning System,” *32nd ASEE/IEEE Frontiers in Education Conference*, November 6 - 9, 2002, Boston, MA.

[11] Jang J, Koo PH, and Nof SY, “Application of design and control tools in a multirobot cell,” *Computers and Industrial Engineering*, Vol. 32, pp. 89–100, 1997.

[12] Rullan A, “Programmable logic controllers versus personal computers for process control,” *Computers and Industrial Engineering*, Vol. 33, Issue 3-4, pp. 421–424, 1997.

[13] Richard Chiou, Yongjin Kwon, Bill Tseng, Robin Kizirian, and Yueh-Ting Yang, “Enhancement of Online Robotics Learning Using 3-D Visualization Technology,” *International Symposium on Engineering Education and Educational Technologies*, Orlando, Florida, USA, July 10th-13th, 2009.

[14] John Bercovitz, “Image-side Perspective and Stereoscopy”, *IS&T/SPIE’s Stereoscopic Displays and Applications IX*, (January 1998, San Jose, California, USA), vol.3295, pg 288-298.

[15] P. Campisi, P. Le Callet, and E. Marini, “Stereoscopic images quality assessment,” in *Proceedings of 15th European Signal Processing Conference* (EUSIPCO '07), Poznan, Poland, September 2007.

[16] Stereoscopic Photography from New Zealand by John Wattie http://www.kiwizone.org/stereo/3dtake/fbercowitz.htm