MICRO-3D VISION FOR MEMS POSITIONING

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Abstract

Microelectromechanical manufacturing is a rapidly growing field in the micromachining industry. The miniature size of these electromechanical systems make it very difficult for engineers to micro-position certain features or identify any flaws in their designs. This paper introduces the idea of integrating online 3D robotics into Microelectromechanical Systems (MEMS) applications to help engineers overcome the obstacles of this technology. A 3D robotic system has been designed which uses highly focused close range cameras and a high precision robot. The video from the cameras is streamed through the Internet to the client side whose display system comprises of 3D polarized technologies. The new design provides the user with a more in-depth experience of a specimen while being able to use micro-increments to micro-position and detect any flaws in it. The system has been introduced as part of a laboratory experiment for a Robotics and Mechatronics course at Drexel University. The experiment has been followed by an evaluation session which has resulted in positive feedback from the students. The ultimate goal is to design a valuable tool for educating the engineers of the future and providing the MEMS industry with an approach to deal with micro-positioning and flaw-detection applications.

Introduction

The scaling down of technology has resulted in the development of micro-assembly plants which require highly accurate robots for manufacturing purposes [1]. Moreover, the impressive advancement of 3D technologies has greatly improved the ways human beings interact with modern applications which involve high levels of accuracy and precision [2]. Consequently, this paper introduces the notion of integrating modern 3D vision technologies into handling Microelectromechanical Systems, known as MEMS. MEMS is an area of research that has been rapidly growing in its applicability. These systems indicate the micro-technology that is used in designing extremely small mechanical devices which are controlled by electrical components. MEMS signify the future of industrial micromachining and are an essential component in the future of electromechanical system designs. However, modern engineers face difficulties while trying to micro-position certain features or identify any flaws in these systems [3-5].

The purpose of this paper is to demonstrate the feasibility of developing a mini robotic system that could be used for improving MEMS applications. The system is composed of a high precision SCARA robot and a highly zoomed-in 3D vision setup. The 3D system consists of two mini snake cameras whose focal length is designed for close range zoomed-in video streams. A custom made fixture positions the cameras in a parallel fashion so that stereoscopic 3D frames are created. By watching the 3D video and controlling the robot remotely through the Internet, a user is able to perform micro-positioning applications on a specimen. The 3D technology allows the user to get a more in-depth experience of the test chip, while the mini robot's high precision permits the exact position on the chip to be detected. This type of technology has also been integrated into highly accurate robotic surgeries and has portrayed very successful results [6-9].

The system has been introduced as part of a laboratory experiment for a Robotics and Mechatronics course. The laboratory is designed to enlighten engineering students about the future of micro-manufacturing technologies and educate them about the difficulties of micro-positioning in the field of MEMS. To enhance the education process, this 3D robotics system has been designed to provide the students with better depth perception and control of the micro-positioning process. As part of the laboratory, the students have been asked to perform a remote micro-positioning application. Following the laboratory, the students have been asked to complete an evaluation session to assess the effectiveness of this system. The results have shown that the students have grasped a broad understanding of the concepts related to online robotics and MEMS.

The paper consists of several sections which describe the system. The System Overview section portrays the various components of the overall structure of the project. This section is followed by a detailed description of the robotic software that has been used. The final part of the paper describes the remote laboratory experiment and analyzes the evaluation results. The 3D robotic system is a valuable tool for educating future engineers and providing the MEMS industry with an approach to deal with micro-positioning and flaw-detection applications.

System Overview

The robotic system is composed of two main parts, the robot image capturing mechanism and the display system. These sections are described in detail and their connections are explained. The overall system demonstrates how the system components are all integrated with each other.

Image Capturing

The experimental setup consists of two mini snake cameras which are fixed in place with a holder made by a rapid prototyping machine. The cameras have been specially ordered with a custom lens for short distance zoomed-in images. They use a 1/4" color CCIQ II technology with a resolution of 648x488 pixels and 400 TV lines. The lens has the specification of 8.3mm / F2.4 resulting in a 5 cm focal distance for short range purposes. In addition, each of the cameras is equipped with four tiny LEDs for illumination aid in case it is needed. Figure 1 displays the dimensions of the snake camera which has been used in the 3D robotic system.

Figure 1: The Snake Camera Used in the System.

Stereoscopic 3D images are created by using a dual camera configuration. The two mini cameras have been placed in parallel using a custom designed fixture. The distance between the two cameras is adjusted based on the calibration criteria described in the simplified version of the Berkovitz formula which has been designed by Pierre Meindre [10-11]. The formula provides an estimation of Stereo Base, the separation between the lens of the left and right cameras. Equation 1 shows the Bercovitz formula.

$$\text{STEREO BASE} = \frac{P\ x(L_{max}\ x\ L_{min})/(L_{max} - L_{min}}{f} \quad (1)$$

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.

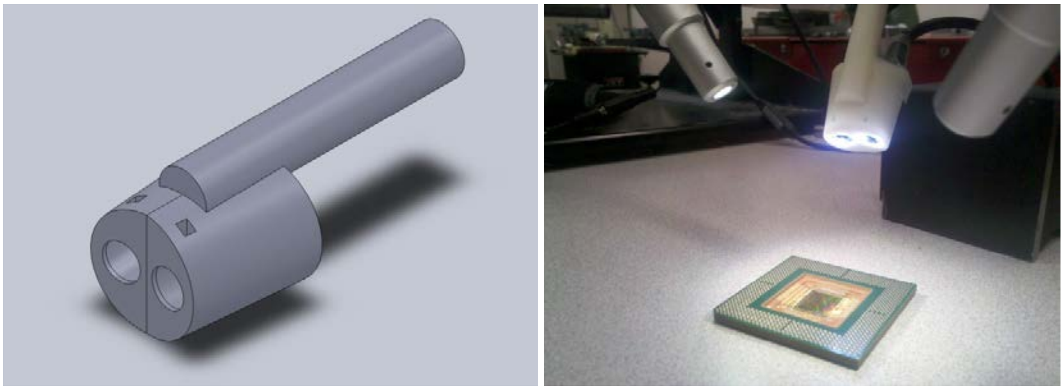

Figure 2: Schematic Design and Usage of the Camera Fixture.

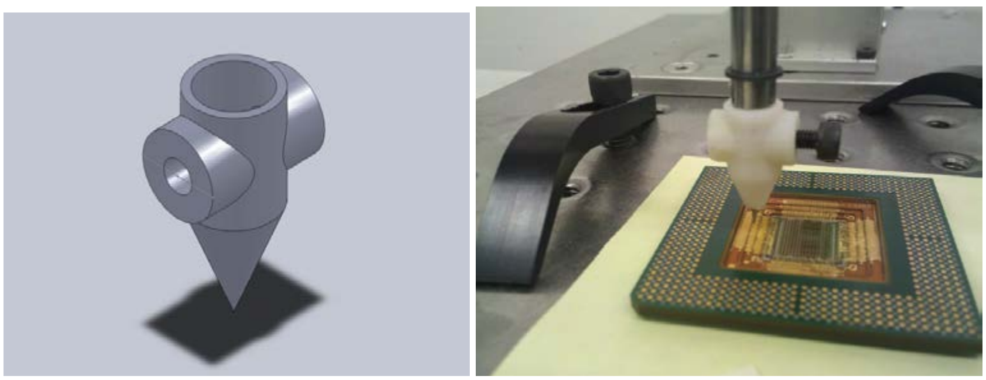

Figure 3: Schematic Design and Usage of the Robot Tip.

To allow the angle of the two cameras to be pointed at the same focal point, the holder has been designed with an inward 10 degree angle. This design permits the proper overlapping of the images to produce a better 3D effect. Figure 2 shows the schematic of the camera fixture and the way it has been used to capture the 3D images.

In order to capture and stream the video from the two snake cameras, a video capture card and a video web server are required. Two USB video capture cards have been used to digitize the videos from the cameras and input them into a PC. WebcamXP, a software-based video web server, is used to stream the captured video through the Internet. A client computer with the server's IP address is able to capture the stream and display it on a screen. The client-server setup provides the system with remote capability.

Robot Positioning

For micro-positioning purposes, a YK150X high-precision Yamaha Scara robot has been used. The robot's repeatability has been stated by Yamaha Robotics to be +/- 0.005 mm for the X and Y axes, +/- 0.01 mm for the Z axis, and +/- 0.006" for the R axis. The accuracy of the robot has been further tested using an MP2000 LVDT Schaevitz sensor system as discussed in [12]. The precision of the robot was proven to be accurate enough to Yamaha's standards. To be able to spot the location of the tip of the robot and locate its position on a chip, a special robotic tip has been designed. Figure 3 displays the schematic design for the new robotic tip that has been designed for accurate micro-positioning applications.

The Display System

The client side of the 3D robotic system consists of the display system for the 3D video. The 3D technology used in this system is based on polarization technology. To create the 3D effect, two projectors, polarizing filters, and a silver screen are used as discussed in [13-15]. Each of the video streams is superimposed separately onto the silver screen through orthogonal polarizing filters. The video streams are displayed through a custom website that is designed to act as a client page that would playback the video that is captured by the web server. On the screen, the two images should be overlapping and the adjustments should be performed manually by tuning an adjustable dual projector stacker unit. This will guarantee that the parallax and the separation levels will be adjusted as to obtain the best 3D image quality. The polarizing glasses contain a pair of similar orthogonal filters that only pass the light that is similarly polarized. When each of the eyes sees its corresponding polarized image, the 3D effect is created in the human brain and the viewer will experience the proper 3D depth perception.

Overall System

The overall system is displayed in Figure 5. On the server side, the web server captures the images from the two snake cameras and streams them over the Internet. The robot controller is also on the server side which the client can access through the Internet. On the client side, the client uses three screens, two of which are projected and polarized on a silver screen. The

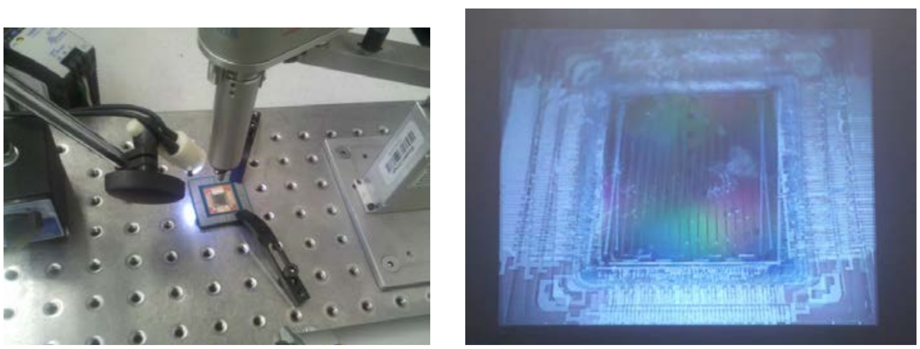

Figure 4: 3D Image Samples.

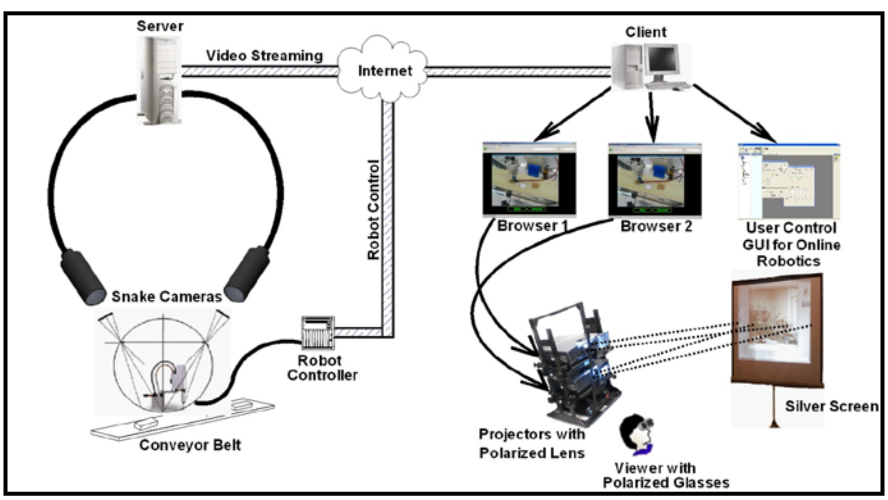

Figure 5: The Overall Remote Micro-3D System.

third screen is used for controlling the robot and positioning the robot tip. It is possible to display three screens from one PC by using a triple video output device. In this system, a Matrox TripleHead2Go device has been integrated for connecting three displays to one PC. The system has been designed to maintain the least possible delay by minimizing the buffering and optimizing the bandwidth on the server and client sides. The users on the client side should wear polarized glasses to experience the 3D effect.

Robotic Software

The robotic software used for this application is YRADS. It is the software used to control the YK150X Scara Robot at the Engineering Technology lab. The robot is controlled through a PRCX controller and is used for high precision applications. The only mode used to control the robot is the manual mode. The controller cannot be programmed and does not support any Input/Output peripherals. It contains temporary memory in which points can be defined.

Figure 6 displays the YRADS robotic software. The yellow box on the upper right corner displays the current coordinate values of the robot. The user is given the choice to teach points by manually moving the robot or manually inputting the coordinate data. The coordinate system can be switched between the Pulse system and the Cartesian system. The user also has the ability to control the velocity and acceleration settings of the robot.

Remote Application

The developed micro-3D robotic system has been tested as part of a laboratory experiment for the MET 205 Robotics and Mechatronics course at Drexel University. The different parts of the system have been introduced and explained where the students have had the chance to learn about the 3D display setup in addition to the remote robotic software. The experiment's ultimate goal is to educate the students about the possibility of utilizing 3D technologies for micro-positioning and flaw-detecting applications, especially in the MEMS industry.

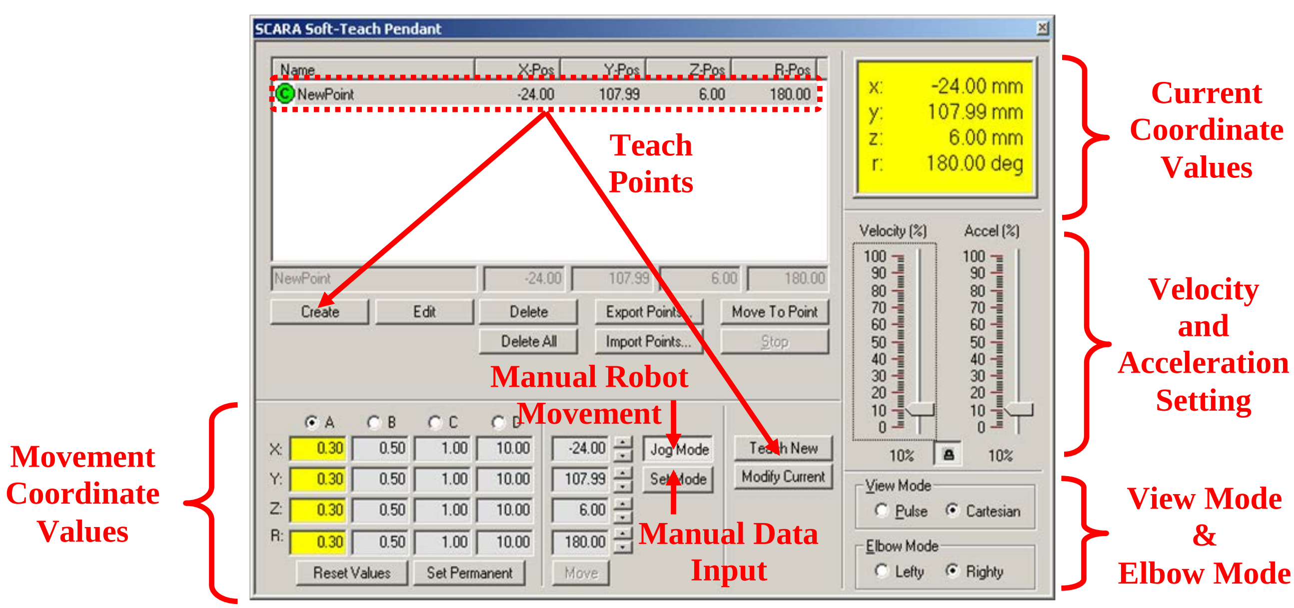

Figure 6: Yamaha Robotic Software.

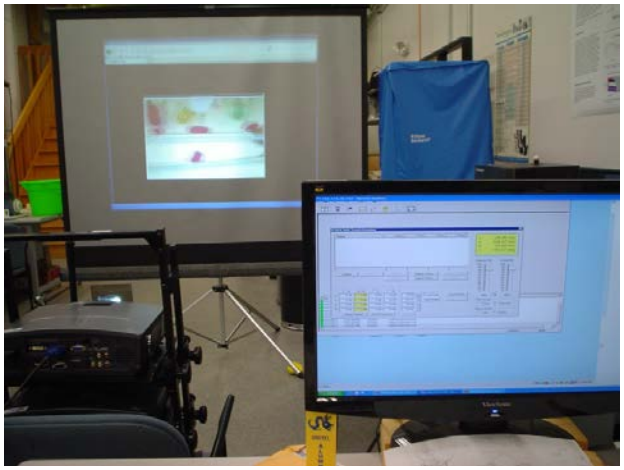

Figure 7: The Remote MEMS 3D Application.

Figure 7 displays the 3D system's setup in the classroom. The same PC has been utilized to capture each of the 3D video's streams and to run the robotic software. It is possible to output all three displays by using the Matrox TripleHead2Go device. The 3D video sources are streamed to the two projectors while the robotic software is displayed on the LCD monitor. The video from the projectors is polarized onto a silver screen. By wearing a pair of polarizing glasses, the students are capable of remotely viewing the 3D video while simultaneously remotely controlling the high precision robot.

Figure 8: Students Testing and Experimenting the Micro-3D System.

The students have the chance to program the robot remotely using the YRADs software tool. With the more advanced perception of depth and reality, they are capable of defining working point, jogging the robot, and micro-position specific detailed part of a small object. In this laboratory experiment, the students have been asked to pinpoint tiny defects in a microchip. The students have been asked to job the robot and let the tip of the robot touch each of the defective parts of the chip. The second part of the experiment has instructed the students to pick and place some miniature objects such as tiny screws, LEDs and pins. They learned to remotely position the robot and teach it points. Figure 8 displays how the students have tested and experimented the Micro-3D system.

Evaluations

The experiment has been followed by an evaluation session which has resulted in positive feedback from the students. The questionnaire that has been provided to the students is demonstrated in Figure 9. The questionnaire is designed to reflect the students' understanding of the overall 3D system and target the benefits of 3D technologies for highly accurate engineering applications. The questionnaire also examines the students' experience with the notion of having an online laboratory as compared to being in the classroom. The histograms in Figures 10 and 11 demonstrate the final results for the questionnaire provided to the students. The outcome of the evaluation session has shown a significant enhancement in the students' learning of utilizing 3D systems for performing highly precise tasks. The online lab facility has provided an adequate means of visual, auditory, and textual information in terms of operating a robot remotely. The 3D online laboratory experience has proven that incorporating new types of technologies into robotic teaching can be an effective tool and an intelligent tutoring system, while maintaining the conventional classroom setting. Moreover, the new micro-3D robotic system has allowed the students t micro-position the robot and to perform basic MEMS applications.

	Survey Question	MA	A	N	D	MD
Q1	I understand the meaning and nature of online lab courses, as opposed to the conventional lab courses.	**O**	**O**	**O**	**O**	**O**
Q2	I perceive online lab experience with conventional lab experience.	**O**	**O**	**O**	**O**	**O**
Q3	The learning effectiveness from online lab courses versus conventional lab courses is highly comparable.	**O**	**O**	**O**	**O**	**O**
Q4	I understand robotics and network technologies that enable the remote operation of equipment	**O**	**O**	**O**	**O**	**O**
Q5	I understand the importance of remote robotic operations using advanced technologies.	**O**	**O**	**O**	**O**	**O**
Q6	I understand technology is related to online laboratory learning.	**O**	**O**	**O**	**O**	**O**
Q7	I perceive lab instructions, lab manuals, and other lab materials are very important for online lab courses.	**O**	**O**	**O**	**O**	**O**
Q8	I perceive technology influences online laboratory learning in different ways.	**O**	**O**	**O**	**O**	**O**
Q9	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 system, enhancing students' learning	**O**	**O**	**O**	**O**	**O**
Q10	I perceive the shortcoming can be overcome by incorporating new technologies, such as intelligent tutoring system.	**O**	**O**	**O**	**O**	**O**
Q11	I can equally learn well this online course and conduct all lab exercises over the Internet as in the classroom setting.	**O**	**O**	**O**	**O**	**O**
Q12	Online laboratory experience using remotely operated robots is important in terms of acquiring skills and knowledge that will help prepare my future.	**O**	**O**	**O**	**O**	**O**

***MA:** Mostly Agree ***A:** Agree ***N:** Neutral ***D:** Disagree ***MD:** Mostly Disagree

Figure 9: The Evaluation Questionnaire.

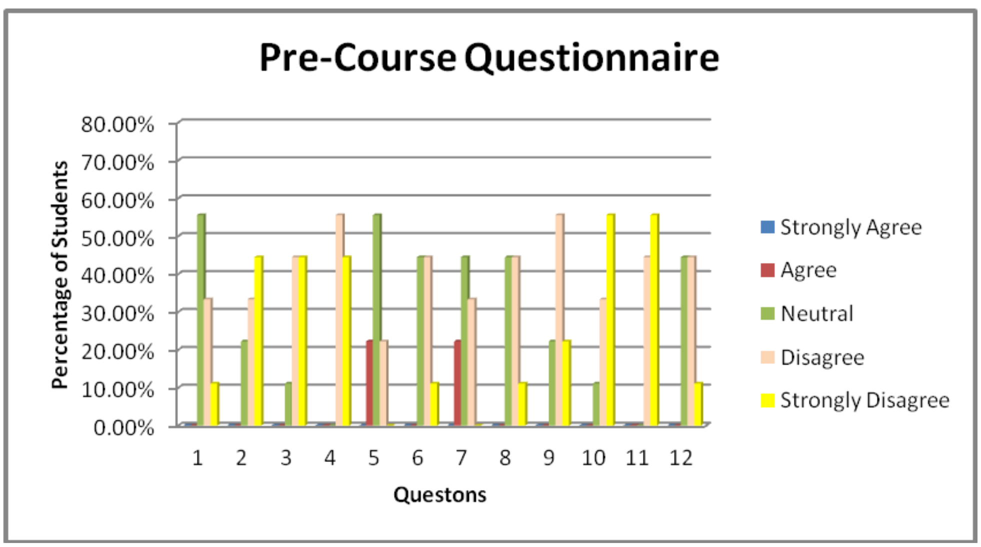

Figure 10: Pre-Course Evaluations.

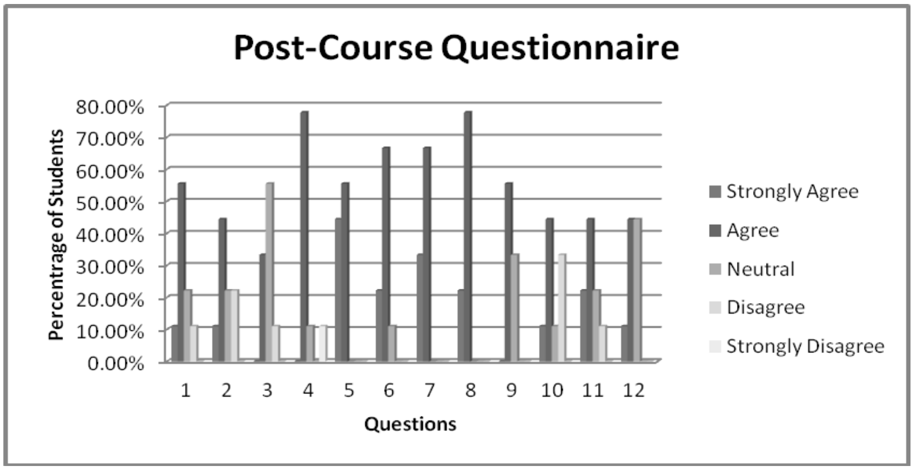

Figure 11: Post-Course Evaluations.

Conclusion

The rapid growth of microelectromechanical manufacturing and the popularity of MEMS necessitate teaching future engineers about these systems. It is crucial to educate them about the difficulties and obstacles that are faced with this type of manufacturing and provide them with sample systems that are capable of improving MEMS applications. This paper demonstrates a 3D mini robotic system that has been designed to enhance the micro-positioning of MEMS. The system has been tested and evaluated by the students at Drexel University as part of a laboratory experiment for a Robotics and Mechatronics course. The results have demonstrated the students' approval of utilizing micro-3D technologies for high precision and accurate MEMS experiments. The in-depth experience has significantly aided the students to jog the robot in micro-increments and detect any flaws in the experimental specimen. The new robotic system has proven to be a valuable tool for educating the engineers of the future and updating the MEMS industry with a new scheme of handling micro-positioning and flaw-detecting applications.

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Biographical Information

Dr. Richard Chiou's background is in mechanical engineering with an emphasis on manufacturing. Dr. Chiou is currently an Associate Professor in the Goodwin School of Technology and Professional Studies at Drexel University. His areas of research include robotics, mechatronics, and internet based automation. He has secured many research and education grants from the NSF, the US Department of Education, and industries.

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Dr. Bill Tseng is an Associate Professor and Graduate Program Director of Industrial, Manufacturing and Systems Engineering at the University of Texas at El Paso. Dr. Tseng's educational background is in IE with an emphasis on artificial intelligence and web based technologies in manufacturing and others. In addition to his many years of industrial experience, he has taught many different engineering courses at undergraduate and graduate levels.