# Teaching Multidisciplinary Robotics and Mechatronics Integrated with Bionics and Solar Energy

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**Abstract**

Engineering Technology (ET) is an undergraduate degree program at Drexel University (DU). Several innovative laboratory components are integrated in MET 205 Robotics and Mechatronics (a 10-week upper-level undergraduate course) to achieve maximum effectiveness in teaching multi-disciplinary concepts in emerging fields. The primary educational objective of the course is to introduce students to the multidisciplinary theory and practice of robotics science and technology, integrating the fields of computer science, electrical engineering and mechanical engineering. This paper discusses laboratory development and the hands-on learning experience within the context of this capstone course on robotics and mechatronics. Topics covered include the innovation of teaching industrial robotics to undergraduate students working on solving real-world problems, particularly as it applies to multidisciplinary fields such as bionics and solar energy.

## Introduction

This paper presents the establishment of a robotics and mechatronics laboratory for teaching and research integrated with the emerging fields of bionics and solar energy through an NSF project involving undergraduate and graduate students, and faculty at Goodwin College of Drexel University. Mechatronics-based robotics is a well-recognized motivational vehicle for applied engineering education[1-5]. Not only is it an enjoyable topic for many students, it has a broad appeal due to its wide scope, including aspects of electrical, mechanical, computer engineering, and information technology. Further, the design of such systems is an excellent tool for reinforcing applied engineering concepts. It is important for instructors in robotics to understand, however, that robotics is not just a tool to teach other aspects of engineering. Rather, it is a robust and mature discipline in its own right, with important applications in a wide range of fields.

This laboratory development component in this NSF-sponsored project integrates various tools such as robots, pneumatic actuators, sensors, web-cameras, conveyors, and programmable logic controllers (PLCs) Internet communications links are used to connect to cross-platform systems. Visual Basic Net is used to create graphic user interfaces (GUIs) for performing online analysis and to allow remote interaction with the system. These tools can be used by students to develop their own ideas in the fields of bionics and solar energy, obtain industrial experience in participating in cutting-edge research and development efforts, and develop familiarity with various sensors while learning different ways to make them work together with various robotics and mechatronics. Here we describe a set of experiments and classroom discussions that allow students to compare traditional (microprocessor-driven) robotics engineering with simulation using PLCStudio[6-8].

We have constructed a series of fully functional robotics experiments, and have been able to incorporate experiments involving many aspects of mechatronics in various classes throughout the Engineering Technology curriculum. These experiments can be integrated into course segments involving robotic systems, solar energy, bionics, and emerging science and technologies such as microrobotics and microfluidics. Integrating these topics into courses across the Engineering Technology curriculum provides fresh, exciting topics of study and research for Engineering Technology students[9-16]. Furthermore, the establishment of the state-of-the-art laboratories allows Drexel to develop learning schemes for engineers in the Greater Philadelphia Region's key industries. Four laboratory development efforts are described in this paper.

**1. Web-enabled Robotic Lab**

Our Laboratory facility (constructed with the support of Yamaha Robotics) is shown in Figure 1. The equipment includes the following: Yamaha YK250X, Yamaha YK150X, Yamaha YPX250, Yamaha YP330A, Yamaha RCX40 /w opt. on-board Ethernet card, Yamaha RCX40 /w opt. on-board Ethernet card, Yamaha PRCX-T, Yamaha QRCH, Yamaha DRC-R, DLink DCS-5300, machine vision DVT, Conveyor Dorner 6100 Series, HP m1050e, and Allen Bradley 1756 Series PLC. The PLC is capable of connecting to the Ethernet and can also be controlled using a PC/Server. An Ethernet camera is used for constantly viewing the robot movement. The machine vision sensor and conveyor belt are also integrated in the system.

All the devices, such as the robots, web-camera, sensors, programming logic control (PLC), are connected to the Ethernet LAN. This reduces the wiring infrastructure needed to link every device and enables users (students) to operate/control all the equipment, either locally or via the Internet.

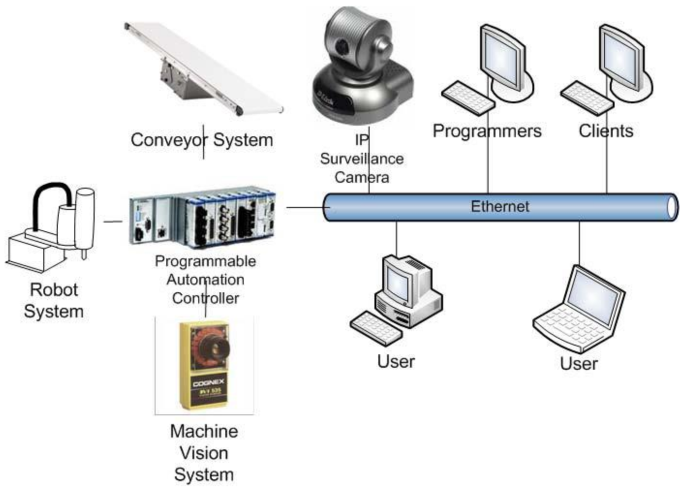


Figure 1: Internet-based robotics and mechatronics laboratory

The communications protocol utilizes TCP/IP (*Transmission Control Protocol/Internet Protocol*) which is a standard Internet Protocol so PCs with Internet Access can exchange data with the robot controller. This unit uses 10BASE-T specifications, so UTP cables (unshielded twisted-pair) or STP cables (shielded twisted-pair) can be used. This makes cables and wiring installation relatively user-friendly. Commands are sent to the controller using Telnet, a protocol which allows a computer to act as a remote terminal on other machine, anywhere on the Internet. The controller transparently accepts input directly from the user's computer (via a telnet client); output for the session is directed to the user's screen.

**A Case Study in a Robotic Control Experiment through Internet**

Directly under the online robotic control system interface is the IP surveillance camera view (shown side-by-side with the control module in Figure 2.) The user is able to view the live streaming image from the IP surveillance camera with this module. Users can view the camera by pressing on the green play button located under the surveillance screen. When this screen is accessed, users are able to perform tasks such as zooming in and out on the web-camera screen. The video itself streams in real time. At the bottom of the screen is a [Stop Program] button, which allows the user to terminate the program at any time during testing.

To the right of the IP surveillance camera display is a DataLink module (labeled [DATA]) that allows users to view the radius of the test pieces. The radius of the object on the conveyor belt is determined, in order to check if it conforms to the required statistical process control limits.

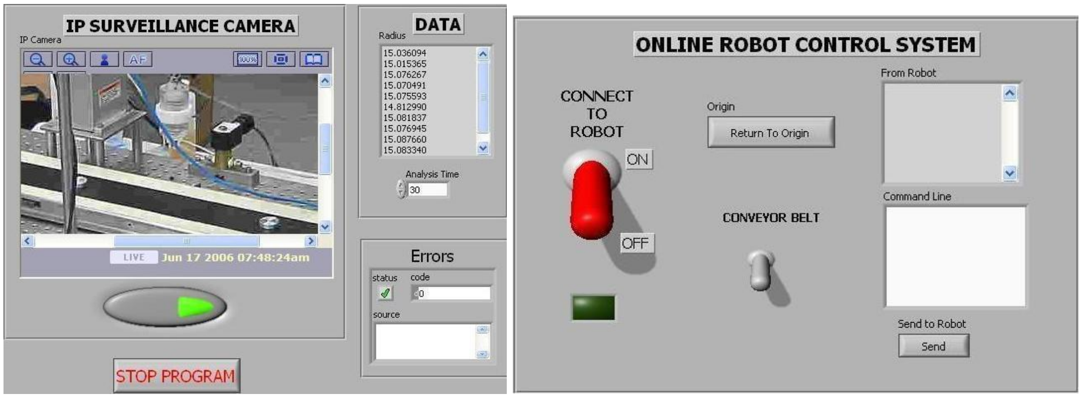

Figure 2: Online robot control system module, surveillance camera module, and DataLink module

We further explore how robotic simulation can be adapted to the classroom in conjunction with a physical setup to enhance the students' learning experience. PLCStudio was created with the intention of being used in industry for the purpose of designing and simulating a complete robotics and PLC system before physically implementing it on the factory floor. Other software packages used by manufacturers are designed solely to model the physical layout and kinematics of the robots. With the integration of sensors, robots, conveyor belts, and other devices, it is not sufficient to simulate only the robots' movements.

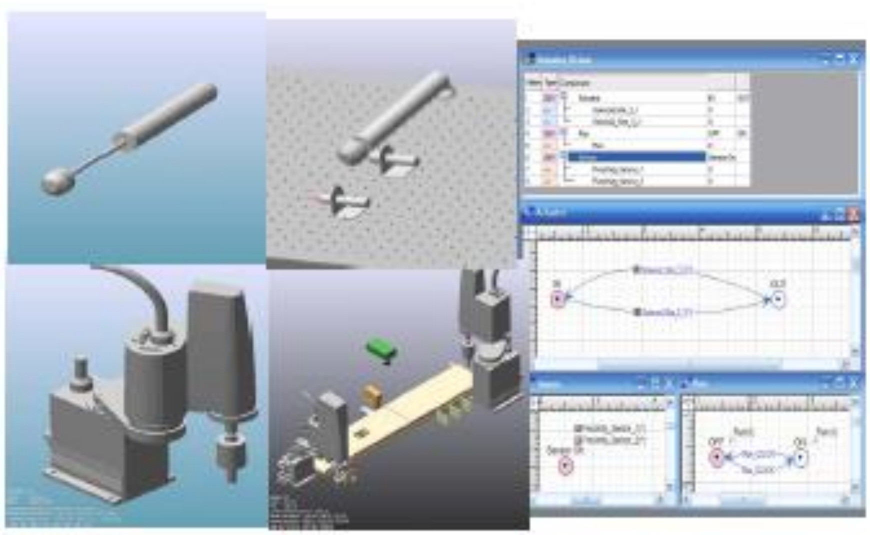
Figure 3: Component Model, logical I/O model, and cell 3D model for simulation

All of these components must be able to communicate with each other through varied inputs and outputs. This is commonly performed today through a PLC, which uses programming to emulate mechanical switches and relays. Systems consisting of inputs and outputs do not require structured testing to be constructed, but for more complex systems, testing the designed PLC code becomes vital. PLCStudio works in conjunction with STEP 7 to allow the user to not only fabricate a virtual 3D representation of the factory floor, but also write and test the PLC ladder logic in a virtual environment before it is run on a physical PLC. PLCStudio's design process can be broken down into three main steps: the component model, logical I/O model, and cell model. These three steps are performed in hierarchical phases to produce the final virtual model as shown in Figure 3.

**Advanced application –robotic control**

This experiment performs quality control testing on machined parts and sorts them based on preset tolerances. The devices used in the physical part of the experiment are an YK220X SCARA robot, YK250X SCARA robot, machine vision camera, conveyor belt, and a photoelectric sensor. The layout of the components in the workcell can be observed in Figure 4.

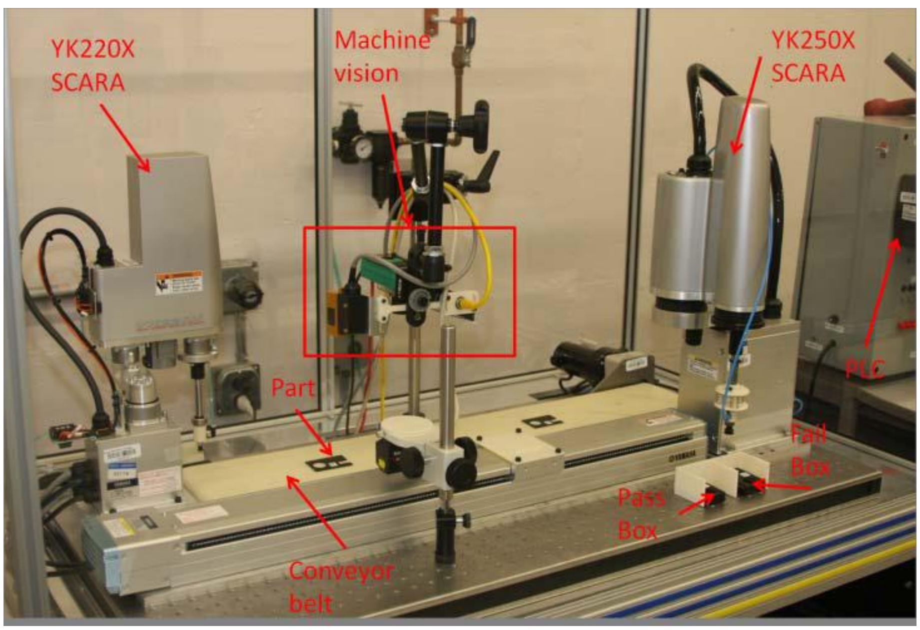


Figure 4: Robotic workcell equivalent to PLCStudio virtual system

Students are given the cell model and I/O model for the simulation. To run this simulation, the students must create a ladder logic program that uses the input data from sensors and sends appropriate commands to the robots. Figure 5 shows the ladder logic utilized by PLCStudio on the left and the logic used by RSLogix on the right. It is necessary to use RSLogix because PLCStudio is only compatible with STEP 7 which works with Siemens PLCs, whereas the PLC used in the lab is made by Allen Bradley which utilizes RSLogix.


Figure 5: Students building a robotic cell and programming automation by PLCStudio

PLC programs can be tested in PLCStudio and implemented in the robotics and mechatronics laboratory. The robot sequence timing is measured in the laboratory experiment. The students collect data to measure the cycle time of the robotic cell. If the robot receives a pass signal, then it runs the "pass" routine which sorts the part into the pass bin. If it receives a fail signal input then it runs its "fail" routine which sorts the part into the fail bin.

**3. Bionic Robotics**

Bionic Robotics allows students to develop their knowledge of engineering and become familiar with a variety of advanced components that are used. This knowledge can benefit students in fields such as Mechanical, Electrical, Industrial, and Bio-Engineering. Providing students with a hands-on approach when teaching robotics classes enables students to become aware of how mechatronic design, rapid prototyping, and computer control can drastically influence the downstream design and manufacturing processes. This is especially helpful for students in the mechanical, electrical, and industrial concentrations, since they have a high probability of designing parts that will require machining processes during their manufacture. A research case study on bionic robotics is presented here. It demonstrates the practical usefulness of biologically inspired computing for the mobile robotic domain and realization of multiple disciplinary features.

**Robotic Control System Design**

A biologically-inspired walking robot has been designed, and is used as an educational example in MET 205 Robotics and Mechatronics. The walking robot contains components such as rapid prototyped legs, servomotors, and a Bluetooth wireless communication module. It contains a programmable PIC16F887-I/P microcontroller which is programmed using PIC Assembly language.
The onboard servo (slave) microcontroller located on the circuit board directly controls the eight servomotors on the robot. It interprets high-level commands and produces the proper sequence of timed pulses necessary to move the eight servos in the desired sequences. The microcontroller on the breadboard produces a sequence of timed 7-bit

command words (such as walk-forward, stop, stand up, walk backwards, sit, etc). The microcontroller on the circuit board receives these commands and implements them as canned timing signal sequences to be sent to the eight servomotors – one shoulder servo and one knee servo per leg. The shoulder servos sit inside and are attached directly to the underside of the chassis. The knee servos fit inside each leg of the robot. The prototype robot can be seen in Figure 6.

The addition of a RN-41 Bluetooth module allows the students to control the robot from certain Bluetooth capable devices, such as smartphones or laptops. This gives them hands-on experience with wireless control of embedded systems. A control program has also been implemented on an Android smartphone using Mintoris Basic for Android. The program allows for remote control of the robot via Bluetooth, by utilizing the smartphone's internal accelerometer. By tilting the phone along different axes, the canned movement routines programmed into the robot's onboard microcontroller can be executed. This type of application provides students an interesting and functional example of how different systems can be integrated together for control of robotic applications.

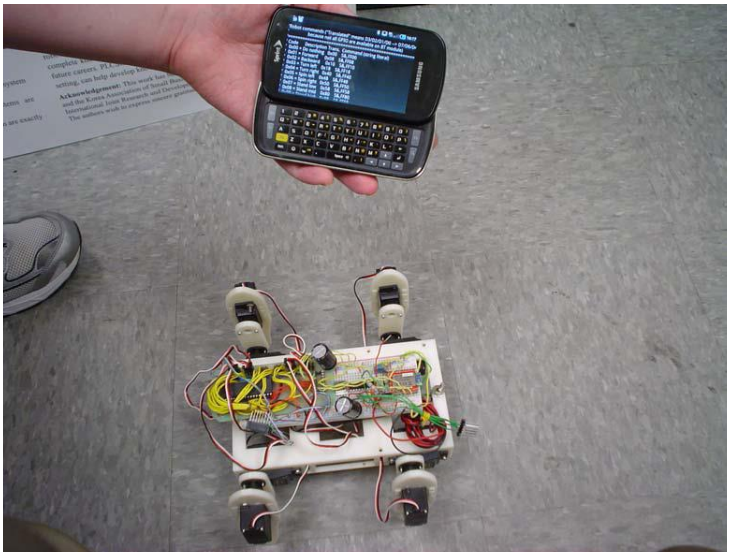

Figure 6: The walking robot in action

As currently implemented, the robot is a two-degree-of-freedom quadruped (using eight servos) with the circuit itself upgradeable to hexapod configuration with three degrees of freedom (which would use a total of eighteen servos) if the MCU speed is increased to 20MHz or more. Our robotic laboratory experiment emphasizes those aspects of microcontroller-based control systems and robotics that are most closely related to computer science. These aspects include the following:

• Architectures and instruction sets of microcontrollers
• Interfacing a microcontroller with memory and I/O
• I/O techniques (serial, parallel, etc) • Microcontroller programming languages and techniques
• The use of timing in development of the gait system

• Walking efficiency of the robot
The current walking gait is hand coded and is diagrammed in Microsoft Excel as an X-Y plot. An initial estimate at a footfall sequence and foot path was made by slow-motion video observation of a walking draft horse. Specifically, the gait sequence used is: LR  LF  RR  RF etc, with a 90 degree phase angle between each. Unlike a horse, however, the SIGMA robot uses reverse symmetry: the front legs of the robot "pull" while the rear legs "push." (This allows closer spacing of the onboard servos, allowing a smaller physical size for the chassis.) The footfall sequence and the foot paths are reversed for the backwards gait. (Essentially, the backwards gait is the same as the forwards gait reversed in time.) The "spinning-in-place" and turning gaits are loosely based on the walking gait. The gait sequence timing and walking efficiency are measured in the laboratory experiment as shown in Figure 7. The students in MET 205 Robotics and Mechatronics, working in groups, collect data for gait cycles of the walking robot.

Figure 7: Students measuring walking gait and efficiency of the bionic robot in MET 205 Robotics and Mechatronics.

**4. Automated Solar Cell Surface Roughness Measurement System**

Renewable Energy includes solar energy, hydro power, wind energy, biomass, etc. Solar energy is one of the most popular and widely used types of renewable energy. The applications of solar energy science and technology range from grid electricity generation to running small embedded appliances. The abundance of sunlight delivers tremendous amounts of power to the surface of the earth. Solar cell conversion efficiency is determined by the various factors involved with the collection and conversion from light energy to electrical energy. Thus, the quality of solar cells is a crucial factor in determining their efficiency. Hands-on renewable energy related classes, labs, and projects promote alternative energy efficiency education.

Figure 8 shows the architecture of the remote surface roughness measurement system. The PC-based remote inspection system is composed of a YK250X 4-axis SCARA robot, RCX 140 controller, a F1010-700 1-axis robot, SR1-X robot, a laser check sensor, an IP Surveillance camera, and an Allen Bradley PLC controller. The laser check sensor has a built-in processor which allows it to perform real-time algorithms, along with live monitoring capabilities. The process is designed to be Ethernet-based using TCP-IP communications. After a successful TCP handshake, images and extracted measurements can be sent back and forth remotely between the servers and clients. The laser check sensor is programmed with necessary algorithms to calculate the various surface roughness parameters. In the LabVIEW-based graphic user interface (GUI), statistical quality algorithms for remote measurement are calculated. The controller communicates with the robot to instruct it to perform the required operations.

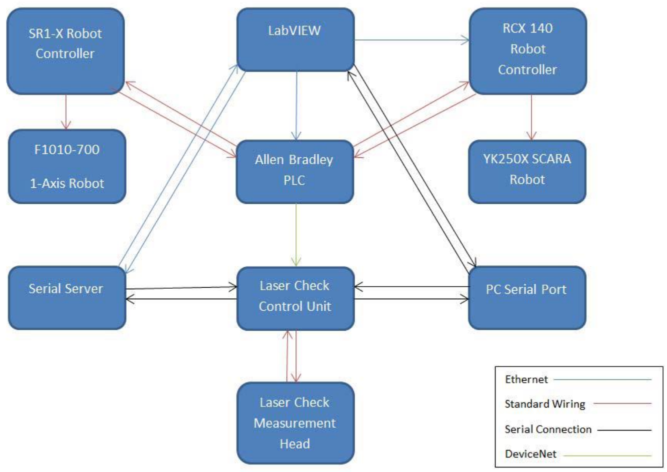


Figure 8: Automated surface roughness system diagram

## Robotic Workcell

Utilizing robots in the process of performing surface roughness scanning allows for both full automation as well as precise and repeatable measurements. The two robots used in this cell are the Yamaha YK250X SCARA 4-axis robot and the Yamaha F1010-700 1-axis robot. The measurement head of the Laser Check system is mounted to the tool arm of the SCARA robot. The piece to be scanned is mounted to the 1-axis robot. The scan is performed by incrementing the 1-axis robot in what shall be designated as the y-axis $i$ number of times. Once completed, the 1-axis robot moves back to its initial position and the SCARA robot increments in what shall be designated as the x-axis, and the 1-axis robot begins its incrementing cycle again. This process repeats $j+1$ times, $j$ being the number of increments the SCARA robot makes. This produces a 2D array or matrix of data: $M_{i+1,j+1}$, which can later be used to plot a 3D graph. The robotics workcell can be seen in Figure 9.

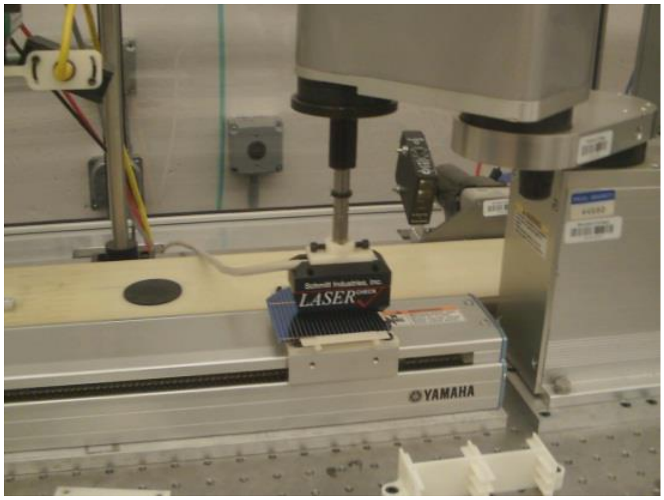

Figure 9: Robotic workcell for solar cell surface roughness measurement

## LabVIEW Program

To initiate a connection, a configuration block specific to the type of connection is used. Once the connection is established, TCP/IP or Serial Read/Write blocks are used to issue a call for data to the Laser Check system and read the data that comes in. To control the flow of incoming data, so that data is not erroneously read twice or skipped over, a case structure is employed, which is triggered by the falling edge of the laser trigger in the PLC. This essentially allows the program to read the data only right after the laser turns off. The data that flows in comes in the form of an ASCII string. To convert this into a floating point value, the string is parsed and header and footer values are removed. The remaining value is then converted to a float value using a type cast function. This data is then sent along and placed into a 2D array that is a set of 1D arrays that represent each scan along the face of the material. This array is then sent to the 3D graph and table on the front panel, as well as to an external spreadsheet file. The connections between the program and the robots are made through both the PLC and through Telnet communication using TCP/IP. The 1-axis robot's controller does not support an Ethernet connection, and as such, the program is initiated by connecting to the PLC via Ethernet and flipping a control bit, which initiates the 1D scan. The SCARA robot's controller does support Ethernet, and is connected to directly using TCP/IP.

## Surface Roughness Measurement of Solar Cells

The one-axis robot positions the solar cell precisely under the sensor. The controller can be externally triggered by one of the robots or a controlling software package. The surface of the cell is scanned by stepping the one-axis robot in 1 mm increments; the surface roughness data is then captured by the controller. This setup can be incorporated with the blob analysis vision system to encompass a fully-developed quality control procedure to evaluate the efficiency of solar cells. Figure 10 shows how multiple SCARA robots can help in constructing surface profiling through the use of LabVIEW program.

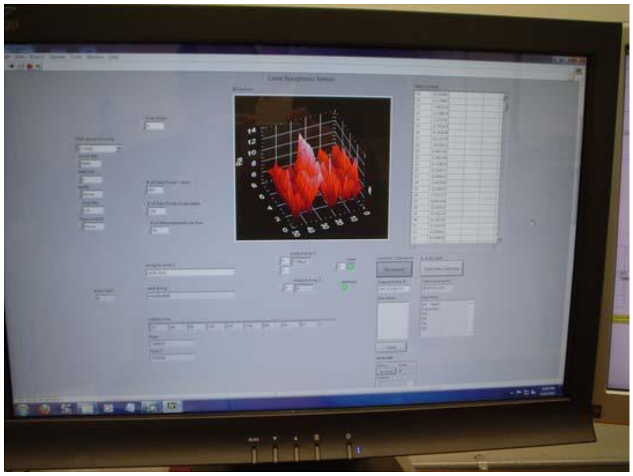

Figure 10: LabVIEW serial and Ethernet front panels interface for surface profiling

There are minor differences between both front panels, which can be seen on the left side of each. These differences are due to variations in connecting and reading from the serial connection either locally or via Ethernet. The two buttons on the right are responsible for connecting to the robots and subsequently running their programs. The graph in the middle of the screen plots a visualization of the incoming height/roughness data, and the table next to it displays the raw numerical data as it comes in.

## Conclusions

This paper describes laboratory innovations for the enhancement of undergraduate level teaching of a capstone course (MET 205 Robotics and Mechatronics) integrated with emerging technology. The trends in emerging fields of bionics and renewable energy have changed the teaching schemes for industrial robots. The new developments allow the students to program, monitor, and control robotic operations through the Internet using the Windows-based graphical user. Also presented is a non-contact-based approach to evaluate certain performance methods and characteristics of solar cells by using image processing. This allows remote control and monitoring of robotic operations, including bionic robotics and renewable-energy systems control via TCP/IP and Bluetooth.

## Acknowledgement
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### Bibliography
1. V.B. Sunil & S.S. Pande 2003, "WebRobot: Internet based robotic assembly planning system," Computers in Industry 54 (2004) 191–207.
2. Melinda F. Robinette, Associate Member, IEEE & Rachid Manseur, Member IEEE, "ROBOT-DRAW, an Internet-Based Visualization Tool for Robotics Education," IEEE Transactions on Education, Vol. 44. No. 1, Feb 2001.
3. Angeles, Jorge, "Fundamentals of Robotic Mechanical Systems: Theory, Methods and Algorithms," Springer-Verleg, New York, Incorporated Date: 2002.
4. SME – Machine tools begin connecting to the Internet Manufacturing, 9/2001.
5. Higley, J., McLees, C., and Zahraee, M., "A Case Study in Laboratory-Based Online Courses – Teaching CNC Programming," *Proceedings of IMECE'03 2003 ASME International Mechanical Engineering*

*Congress*, Washington, D.C., November 15–21, 2003.
6. Hu, H., Yu, L., Tsui, P. W. and Zhou, Q, "Internet Based Robotic System for Teleoperation, Assembly, and Automation," *International Journal of Assembly Automation*, Vol.21, No.2, pp.143-151, 2001.
7. Potgieter, J and Bright, G., "Modular Mechatronics Control System for Internet Manufacturing," *Proceedings of the 18th International Conference on CAD/CAM*, Robotics and Factories of the Future, Porto, Portugal, pp. 529-536, July 2002.
8. Taylor, K. and Dalton, B., "Internet Robotics: A New Robotics Niche," *IEEE Robotics and Automation*, Vol.7, No.1, pp.27-34, March 2000.
9. Pew Charitable Trusts, "Who's Winning the Clean Energy Race?" March 2010, www.pewtrusts.org/uploadedFiles/wwwpewtrustsorg/Reports/Global_warming/G-20%20Report.pdf.
10. Sage, Daniel; Unser, Michael. "Teaching Image-Processing Programming in Java." *IEEE SIGNAL PROCESSING MAGAZINE*, Nov. 2003. <http://bigwww.epfl.ch/publications/sage0303.pdf>.
11. Bloechle, Walter. "Measuring Surface Roughness with an Optical Sensor." *Hohner Corp*, 8 July 2009 <http://archives.sensorsmag.com/articles/0499/0499_58/>.
12. Ordaz, Miguel; Lush, Gregory. "Machine Vision for Solar Cell Characterization." *International Society for Optical Engineering*, 1 Dec. 2009.
13. Laliberté T., Gosselin C. and Côté G., 2000, "Rapid Prototyping of Lower-Pair, Geared-Pair and Cam Mechanisms," Proceedings of the ASME Mechanisms and Robotics Conference, Baltimore MD, September 10-13, 2000, Paper DETC2000/MECH-14202.
14. Won J., DeLaurentis K. and Mavroidis C., "Rapid Prototyping of Robotic Systems," Proceedings of the 2000 IEEE International Conference on Robotics and Automation,
15. "Bailey, S. A., Cham J., G., Cutkosky, M. R., Full, R. J., "Biomimetic Robotic Mechanisms via Shape Deposition Manufacturing," Robotics Research: the Ninth International Symposium, John Hollerbach and Dan Koditschek (Eds), Springer-Verlag, London, 2000.
16. Bhömer, M. t., Bartneck, C., Hu, J., Ahn, R., Tuyls, K., Delbressine, F., et al., "Developing Novel Extensions to Support," Prototyping for Interactive Social Robots, Proceedings of the 21st Benelux Conference on Artificial Intelligence (BNAIC 2009), Eindhoven, pp. 11-17, 2009.