AC 2012-4917: DESIGN OF A CELL PHONE-CONTROLLED BIONIC ROBOT

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Design of a Cell Phone-Controlled Bionic Robot

Abstract

This paper describes a mechatronics design-based architecture to build a cell phone controlled bionic robot in a robotics and mechatronics laboratory course. 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 and computer control can drastically influence the downstream design and testing processes. Materials, methods, and tools are outlined, including the use of servomotors and microcontroller-based control systems. Students in the Engineering Technology program are required to work with this robotic experiment as part of a laboratory session in the "MET 205 Robotics and Mechatronics" class. The project provides students with such robot design experience and enables them to improve their robotic skills by using wireless microcontrollers for performing different robotic applications.

Introduction

This paper presents the design of a cell phone-controlled walking robot for teaching and research integrated with the emerging fields of bionics 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. 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[1-5].

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.

This laboratory development component in this NSF-sponsored project integrates various tools such as robot, sensors, and PIC micro-controller. Internet communications links are used to connect to cross-platform systems. Basic Program is used to create graphic user interfaces 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 other applications, 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[6-9]. 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. The experiment can be integrated into course segments involving Web-based robotic systems, bionics, and emerging science and technologies. Integrating these topics into courses across the Engineering Technology curriculum provides fresh, exciting topics of study and research for Engineering Technology students.

Bionic Walking Robot Controlled by a Phone

In an attempt to add to the many possible ways of automating and implementing remote engineering, the project presents a complete, in depth, cost-effective solution for controlling a robot through phone calls. Various extension possibilities are being discussed as well (instructing a robot for vacuum cleaning, changing switches, moving objects, surveillance etc). Mobile Robots have numerous applications: unmanned exploration, land mine removal, energy plants and manufacturing factories.

We introduce a cost-effective robot. With the introduction of video cell phones it will be possible for the user to see the robotic movement in real-time and possibly perform educational exercises using a simple interface at a distance. Examples include "calling" a robot on the way home from work and have it do various jobs like vacuuming the home and sprinkling the garden. This could also be done by logging on to a web server via an internet connected device and sending signals to the robot, or directly sending specific commands to the robot through cellular phones to a wireless (or cellular) server at home (with or without a web connection).

We focus on communication with the robot. The main objective was to make the robots more user-friendly and be able to communicate with them as we can communicate with other people around the globe. Thus we decided to design a simple prototype of a robot that can be controlled via smartphone.

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 eight servomotors are controlled by a PIC16F887 microcontroller, allowing the robot to perform complex movements. Several canned routines (walk forwards, walk backwards, turn right, turn left, spin right, spin left, stand-low, stand-mid, stand-high, sit/stay, lie down, and stop) are implemented by the on-board microcontroller. Seven-bit command words are passed to the servo microcontroller via a dedicated 8-bit bus (the 8th bit is used for synchronization). The control system used is the RN-41 Bluetooth module, which is mounted on the breadboard. This Bluetooth module is wired to the onboard microcontroller and sends the proper 7 bit command values to trigger the desired canned routine.

The programming for both the servo and command microcontrollers is developed in PIC assembly (for a PIC16F887 microcontroller). Microchip MPLAB IDE v8.40 is used to develop and debug the firmware as well as to download the program to robot. The programming for the Bluetooth control via smartphone is written and run on the Android smartphone itself. The program is written in BASIC using Mintoris BASIC 4.0 for Android devices. This program takes the accelerometer values from the phone and based on the amount of axial tilt sends the corresponding 7 bit command to the Bluetooth module on the robot. Simple commands are then issued to the servo microcontroller from the Bluetooth module. This hierarchy allows easy and efficient changes in the implementation of the command scheme without requiring a redesign of the entire servo firmware package. Figure 1 shows the block diagram for the whole walking robot system.
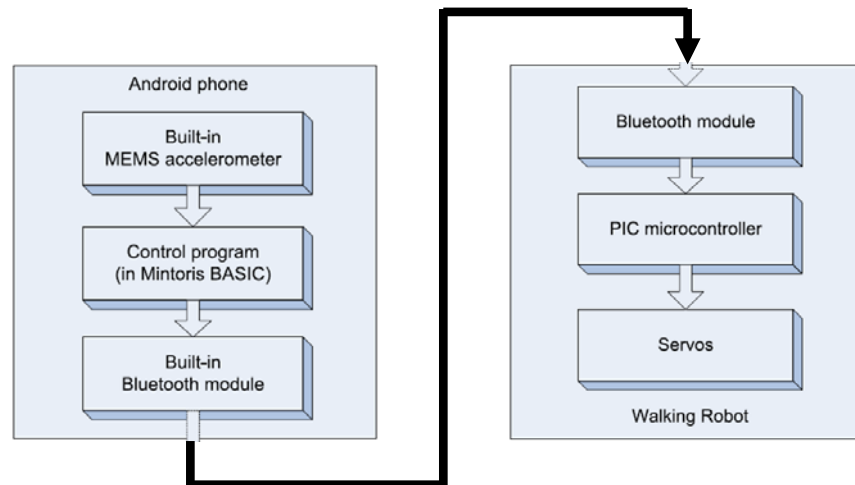

Figure 1: Bionic robot control system block diagram

Bluetooth is a 2.4GHz digital radio communication protocol developed and licensed by Ericsson. Serving the "personal area network", Bluetooth devices can come and go *ad hoc*. In contrast, the WiFi protocol, operating at the same frequency, is more suited to longer-term wireless infrastructure, with each individual node needing to be assigned a fixed IP (internet protocol) address. Bluetooth is now solidly entrenched in the mobile phone market. Intel intends to incorporate Bluetooth into its Centrino 2 chipset.

Not only will this allow PCs to connect wirelessly to printers, etc, but it will boost the growth of VoIP (voice over internet protocol), *i.e.* phone calls over the internet.

The Bluetooth standard provides interfaces for a wide range of communications protocols, from a simple serial port to audio. Like many higher-level protocols such as OBEX file exchange, PIC micro-controller sits on top of the serial port emulation layer of the Bluetooth protocol stack. It is not part of the "official" Bluetooth standard. However, the standard is relatively open in that anyone is free to create software for remote devices, and product-side components such as the FlexiPanel module are manufactured under license, just like any Bluetooth radio module. The first FlexiPanel products were software libraries to provide remote control for Windows applications and high-end embedded systems. The internal accelerometer values get fed into the program developed using BASIC 4.0 on the phone, and these values are then analyzed and the proper command value is then sent wirelessly to the Bluetooth module on the robot. The commands based on axial tilt are shown in Figure 2.
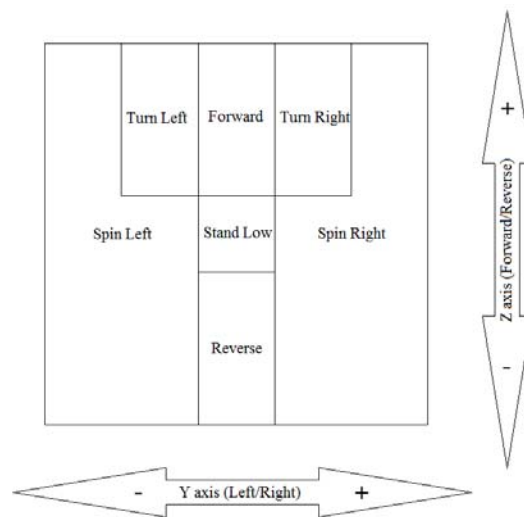

Figure 2: Robot commands based on phone tilt

The accelerometer in the android phone is a three-dimensional accelerometer, in that it can sense acceleration along the x, y, and z axes. Currently, only the x and y axes are used for control, but it is possible to utilize all three for control purposes. The reason tilting the phone produces an acceleration value that can be recorded is due to the acceleration of gravity on the phone. When an axis is in line with the direction of gravitational acceleration then the accelerometer will read 1G or ~9.81m/s^2. By tilting the phone so that a chosen axis is normal to the direction of gravity, then the accelerometer will read ~0m/s^2 along that axis. By varying the axis angle relative to the directional acceleration of gravity, the measured acceleration changes in accordance to sin θ*~9.81m/s^2. By specifying a range of values in the BASIC control program, these acceleration values can be used to trigger the commands that are sent to the walking robot.

The servos are controlled by PWM (Pulse Width Modulated) signals. One control line is used for each of the eight servos. The microcontroller produces a 50Hz sequence

of pulses, the duty cycle of which controls the commanded angle of each servo. For example, a 600us pulse could command the servo to move to its full counter-clockwise position; a 1320us pulse could command it to the center, or neutral, position, and a 2040us pulse could command it to move to the full-clockwise position. By varying the time that each control line is driven high by the microcontroller, the servo angles, and therefore the robot gait, can be controlled.
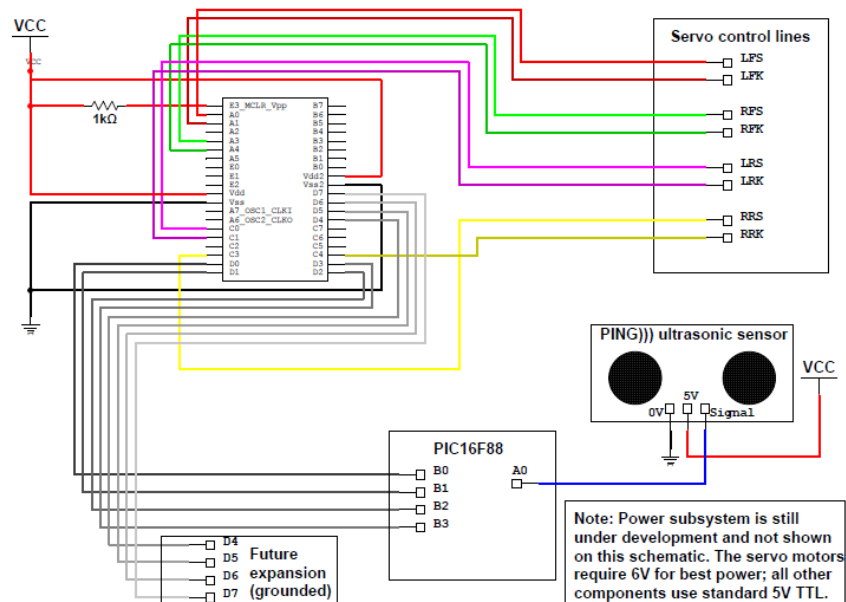

Figure 3: The SIGMA robot schematic including ultrasonic sensor

As shown in Figure 3, 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.

Ultrasonic sensor for the walking robot

With the addition of a Parallax PING))) ultrasonic sensor, the SIGMA robot can now sense objects in front of it. Preliminary alpha tests of the sensor were successful: the robot has been programmed to walk forwards until the sensor registers an object approximately 10cm in front of it. When an object enters this range, the robot is programmed to switch to its "spin right" mode. This causes the robot to turn away from the object before contacting it, demonstrating proof-of-concept object avoidance. The circuitry to add the PING))) sensor to the robot is very straightforward: a PIC16F88 is

used to poll the sensor using a single bidirectional signal line. The PIC is connected to the command input bus of the SIGMA robot's servo microcontroller, in order to send it tactical commands.

The sensor process begins when the PIC16F88 sends a short (5us) activation pulse to the PING))) sensor. After the pulse, the PIC releases the signal line and waits for 2ms, then checks to see if the output from the sensor is high. If so, no object is within the calibrated range, and the PIC outputs an 0x01 command word to instruct the robot to continue in a straight line. If the output from the sensor is low after 2ms, an object has been detected within the calibrated distance, and the PIC sends command word 0x06 to instruct the robot to spin right. After the appropriate command is selected, the 16F88 waits for an additional 10ms and then starts the process again. The cycle time is roughly 12-13ms, plus any extra time over 2ms that the sound pulse might take to arrive. The system therefore naturally becomes more responsive in close proximity to an object, which is desirable.

As the emphasis at this phase of the project is on the development of the walking robot application as a module suitable for inclusion in an Engineering or Engineering Technology program, data has not yet been gathered on robot performance. However, a qualitative observation does indeed provide enough proof that the robot is capable of semiautonomous forward, backward, and turning motions with feedback signals from ultrasonic sensor.

Firmware for PING))) sensor interface microcontroller for SIGMA robot

```
MAIN.ASM
        cblock 0x20
        TempA, TempB
        Delay1, Delay2, Delay3
        endc

#include <P16F88.INC>

        org 0x00
        clrf    TempA
        clrf    TempB


        call    Setup
        movlw   0x00
        movwf   PORTB           ;Send STOP command to robot
;Main program loop
;==================
Top:

;Send a ~5us pulse on PORTA, to start timing
;-------------------------------------------
;Grab PORTA.0 for output
        banksel TRISA
        movlw   0xFE            ;PORTA.0 goes to output mode
        movwf   TRISA
        banksel 0x00

;Send 2us low, 5us high, 2us low on PORTA.0
        banksel PORTA
        movlw   0x00
        movwf   PORTA           ;PORTA.0 low
        nop
        nop                     ;Delay 2us
```

```
        nop
        nop
        movlw  0x01
        movwf  PORTA          ;PORTA.0 high
        nop
        nop                   ;Delay 2us
        nop
        nop
        movlw  0x00
        movwf  PORTA          ;PORTA.0 low
        call   Delay_2us

;Release PORTA.0
        banksel TRISA
        movlw  0xFF
        movwf  TRISA          ;PORTA.0 back to input mode
        banksel 0x00

;Wait for 2ms.
        call   Delay_2ms

;Check if PORTA.0 is still high
        movf   PORTA, w
        andlw  0x01
        btfsc  STATUS, Z      ;If PORTA.0 not high, then
        goto   TurnRight      ;command robot to turn right.
        goto   GoStraight     ;Else, command robot to go straight.

GoStraight:
        movlw  0x01           ;Go-forward
        movwf  PORTB
        call   Delay_10ms
        goto   WaitForLow

TurnRight:
        movlw  0x06           ;Spin-right
        movwf  PORTB
        call   Delay_10ms
        goto   WaitForLow

;Wait for PORTA.0 to go low
WaitForLow:
        movf   PORTA,w
        andlw  0x01
        btfss  STATUS, Z      ;If PORTA.0 not low, then
        goto   WaitForLow     ;Go back and wait some more
        goto   Top

;Library files below this point
;==============================
#include "setup.inc"
#include "delay_8.inc"
        end
```

The onboard servo microcontroller located on the circuit board directly controls the eight servomotors on the robot. It interprets the commands issued by the Bluetooth module, and produces the proper sequence of timed pulses necessary to move the eight servos to the desired positions. Using MPLAB greatly simplifies the student's task of programming the robot. The Bluetooth module receives and then transmits to the microcontroller the commands (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. For the time being, rubber bands are used to secure the solderless breadboard, circuit

board, and battery pack to the chassis. In general, the design can be prototyped as seen in Figure 4.
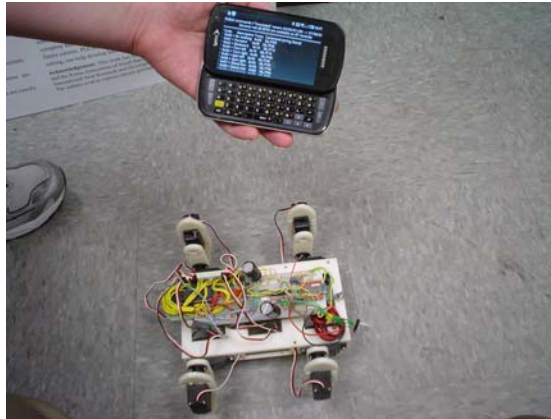

Figure 4: The walking robot in action

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

Real-time Bionic Robot Experiment for Student Learning Experience

The objectives of the bionic robot experiment include: 1. To learn about the design and operation of a cell phone-controlled bionic robot, 2. To measure the walking and sensor monitoring performance of the robot, and 3. To calculate the walking efficiency of the robot based on measurements taken. During the experiment, the students need to follow the procedure to evaluate the efficiency of the design of the cell phone controlled bionic robot from both mechanical and electrical design aspects: 1. Turn on cell phone and operate the walking speed of the robot, 2. Measure the forward walking speed of the robot, 3. Measure the mass and the leg lengths of the robot, 4. Measure the turning-gait turn radius of the robot, and 5. Calculate the robot's specific power efficiency.

To perform an exhaustive search of possible shoulder and knew servomotor angles, a program is written in FreeBasic to find the best fit for each point in the cycle. This program runs through the 180x180 possible combinations of knee and shoulder joint

angles for each position, and selects the combination which produces the best fit to the desired leg position for that phase. Students calculate the robot's specific power efficiency using the results from procedures 1 and 2 and find the specific power efficiency of the robot, as expressed in joules (watt-seconds) of power of movement. Finally, they compare the result with the electrical power (the robot's batteries provide ~4.8VDC, and the robot consumes roughly 1.3 amps of current at 4.4 V while walking forward). The gait sequence timing and walking efficiency are measured in the laboratory experiment as shown in Figure 5. The students in MET 205 Robotics and Mechatronics, working in groups, collect data for gait cycles of the walking robot.

As the emphasis at this phase of the experiment is on the development of the bionic robot application as a module suitable for inclusion in an Engineering Technology program with data gathered on robot design performance. A qualitative observation does indeed provide enough proof that the robot is capable of autonomous forward, backward, and turning motions. Judging from student interest and participation in the experiment thus far, we can definitely conclude that this is an experiment which not only provides a suitable vehicle for teaching many advanced robotics related concepts, but one which also captures students' interest and can foster student enthusiasm for Mechatronics design as a career.
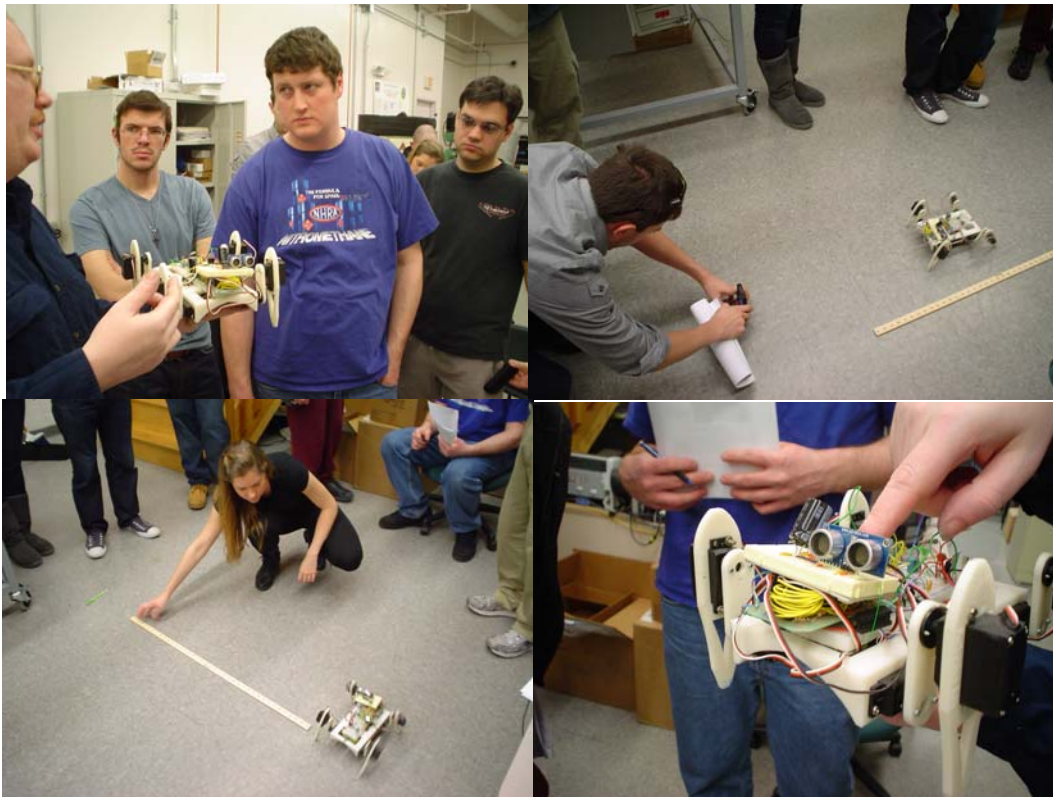

Figure 5: Students measuring walking gait and efficiency of the bionic robot in MET 205 Robotics and Mechatronics.

The bionic robotic control experiment has been implemented in the course MET 205 Robotics and Mechatornics as a part of this laboratory development at Drexel University. The course provides the students with a comprehensive knowledge of remote control using bionic robot and other mechatronic components. The specific robotic control methodologies chosen are related to computer, cell phone, and ultrasonic sensor. The laboratory assignment was used to reinforce lecture information and to give hands-on experience on testing bionic robot walking efficiency. It is believed that the student learning experience about cell phone based robotic control is enhanced. Course reviews by students were very positive. Students commented that they enjoyed hands-on testing experience in the lab. An additional benefit to students was that they could claim on their resumes that they had experience on cell phone control integrated with robotics and mechatronics. Some students complained about too much time involved with the laboratory assignments, but many commented positively about the knowledge they gained. Students commented that they enjoyed working in the laboratory. Overall, the evaluation results showed the highly supportive evidence toward the intended course outcomes.

Educational benefits

This experiment has provided valuable design experiences with the state of the art remote robotic control technologies using cell phone to the undergraduate junior students. Engineering technology students get exposure to the contemporary control and automation technologies such as sensor feedback, cell phone Bluetooth, microcontroller, rapid prototyping, bionics, and automation. But, seldom have they got to use all of these technologies to address an interesting real-world problem. Experiment like this provides them with opportunities to apply the advanced control and automation concepts that they have learnt during the course of the program. The integration of these advanced technologies provides the students with the real-world innovative robot design experience in dealing with the problems in industries. Cell phone control is fast becoming an accepted technological practice to solve the problem posed by industrial automation designs. These industries need engineers and technologists who have been trained in this advanced field of robotics and mechatronics development. Entrepreneurial opportunities in this area of advanced robotic control are another huge plus for the budding engineers/graduating students in the engineering technology programs. Hence, there is a need to include this emerging remote control technique in the engineering technology curriculum. This technique has been included in the existing course MET 205 Mechatronics and Robotics. The Engineering Technology Program at Drexel University has included this advanced robotics technique as one of the key laboratory component in the engineering technology curriculum.

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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