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Developing Control Experiments as a part of a Remote Laboratory Facility

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Pramod P Kaushik, Northern Illinois University

Pramod Kaushik, a graduate from Northern Illinois University specialized in robotics and VLSI. He had great passion towards robotics and was dedicating his time to implement robotic projects while at school. With bachelors in electronics and communication engineering from Anna University, India, Pramod had a strong background in electrical engineering. The ability to learn new tools and software quickly and to use them in projects made him an idea candidate for research assistant under Dr Abul Azad. Under the able guidance of Dr Azad, Pramod designed and implemented various projects in robotics and among them, the most notable work is "Developing Control Experiments as a part of Remote Laboratory Facility".

Developing Control Experiments as a part of a Remote Laboratory Facility

Abstract

This paper presents the customization of engineering systems for their integration with a remote laboratory web portal. The author starts with a brief discussion on remote laboratories along with the customization requirements of equipment for their use within a remote laboratory. The paper then illustrates the hardware and software customization of two engineering systems, a mobile robot, and a flexible robot manipulator. Finally, it discusses the structure of a remote laboratory portal along with some of its operational details.

1. Introduction

Smart devices are growing exponentially, and our everyday life has changed dramatically with the advent of the Internet and networking technologies. Related to these technologies, one emerging entity is the IoT (Internet of Things). This is a developing concept of making an open network of devices equipped with sensors and RFIDs (radio frequency identification) aimed at interconnecting all things electronic to make them more intelligent and programmable. According to Cisco, a leader in IoT and supported by IEEE, about 20 billion machines and devices could be linked by 2020.[1] Smart devices are already being used for various remote activities, such as to check soil moisture in vineyards, control home environments, alert drivers to traffic jams, and monitor patients' vital signs—all without human intervention. However, users will have a major role to play as they generate and use the data coming from the myriad of devices. This IoT will offer plenty of opportunities but also challenges to building ever more complex systems, dealing with lack of standards, analyzing and managing the data, and securing privacy.[2] In academic areas, IoT is appearing in the form of remote laboratories where physical (real) laboratory equipment is being controlled remotely over the Internet.[3, 4] This paper will discuss some of the issues related to the remote laboratories.

Remote laboratories are gaining popularity among researchers and educators, and there are a number of reported initiatives in terms of system design, technology use, and pedagogical issues. These laboratories have great potential and can bring a new dimension for teaching the STEM (Science, Technology, Engineering, and Mathematics) disciplines.[5, 6] However, the integration of a number complex technologies and the current development structure of remote laboratories have made it difficult to develop and obtain sustainability.[7]

As a continuation of Internet accessible remote laboratory facility development, the lead author recently integrated a couple of control system experiments into the facility. This paper presents the design and development of two control experiments and their integration process into the remote laboratory facility. The pedagogical design details are provided in a separate paper, which is submitted to the ASEE 2014 annual conference Section 2 illustrates the importance of remote laboratories, followed by a section describing the essential components of a remote laboratory. Section 4 presents the customization process of two engineering systems for their integration with a remote laboratory. Section 5 shows the makeup of a remote laboratory web portal that can be used for a remote laboratory course delivery and is followed by the conclusion section.

2. Why Remote Laboratories?

Traditional laboratory classes are scheduled for only a limited time period. Considering the mixed ability level of the students, they sometimes want or feel the need to perform additional experiments beyond their assigned tasks.[8] It is usually difficult to accommodate any extra time due to the lack of resources to keep the laboratories open, but ironically, too much experiment equipment lies idle during most of its usable lifetime.

Remote experimentation facilities can provide cost effective and unlimited access to experiments and maximize utilization of available resources.[9] Moreover, these facilities will allow inter-experiment collaboration among universities and research centers by providing research and student groups with access to a wide collection of expensive experimental resources at geographically distant locations.

The development process for an Internet accessible remote laboratory is complex, as it involves multiple disciplines: software, hardware, computer interfacing, Web development, Web security, user interface, and learning management.[10, 11] However, a number of research groups have developed remote laboratories (and some are in the process of doing so) and have demonstrated their potential in the fields of teaching, research, and industry.[12, 23, 14]

3. Components of Remote Laboratories

The basic purpose of a remote laboratory is to make equipment available over the Internet so it can be manipulated remotely to perform experiments needed by a student or a researcher.[15, 16] There are a few simple steps to implement a remote laboratory (Figure 1):

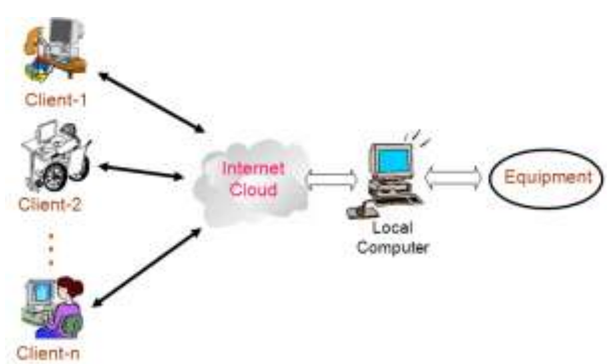

Figure 1: Basic concept of remote laboratories.

a) The first and foremost thing is that the equipment should have interfaceability with a computer (or with a networked device) along with the ability to exchange its input(s) and output(s) as needed to perform experiments.
b) The next required item is a local computer that will provide the processing requirement for an experiment along with hosting a graphical user interface (GUI). The GUI will allow a remote user to perform experiments using the local computer without any physical intervention within the laboratory in which the equipment is located.

c) The third step is connecting the local computer with the Internet, allowing the GUI to be accessed from remote locations using an Internet browser.

In addition, access control to the experiment needs to be considered to ensure safety and proper use of the facility, pedagogical design issues, and management of the facility when offering multiple experiments at the same time. To address the later issues it is essential to consider developing or using a web portal that is suitable for a remote laboratory scenario.[17]

4. Customizing Control Experiments

Almost all commercially available laboratory equipment is designed with an idea that it is to be used within a laboratory when students/researchers are sitting nearby. As discussed earlier, the remote laboratory concept introduces a totally different mindset in which students/researchers would be remotely located and would not have any access to the laboratory in which the equipment is residing. This makes it essential to customize commercially available equipment before it can be integrated with a remote laboratory facility. The customization involves the processing of all input(s) and output(s) needed for performing experiments and makes it available to the local computer connected to the equipment. The paper reports the customization of two pieces of equipment used for remote laboratories. The equipment is a household mobile robot and a flexible robotic manipulator. The customization involves processing input(s), output(s) signals and interfacing the equipment with a host computer, and finally developing suitable GUIs. Safety is a key factor for remote laboratory offerings, and a sub-section is provided to describe how that issue has been dealt for these experiments.

4.1 Roomba Create- Household Mobile Robot

The RoCr (Roomba Create) is a complete robot development system that allows one to program new robot behaviors without thinking much about the mechanical assembly and low-level code. The RoCr system was developed by iRobot. RoCr's Open Interface (OI) provides a set of commands, such as 'drive' commands, demo commands, song commands, and sensor commands.[18]

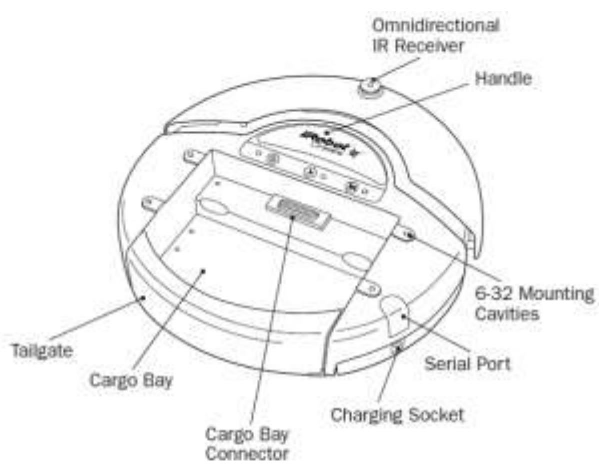

Figure 2: Image of a Roomba Create.

Through a serial communication, these commands can be used to develop new behaviors, add third party electronics, and write OI based programs to control the RoCr. An image of the RoCr is provided in Figure 2. In addition to the inbuilt sensors, one can attach additional hardware (sensors and actuators) to the RoCr via a cargo bay connector. These can be a robotic arm, light sensor, ranging sensor, light display, etc.

RoCr Open Interface

The OI consists of an electronic interface and a software interface for controlling the RoCr's behavior and reading its sensors.[18] The hardware interface includes a 7 pin Mini-DIN connector for connecting the RoCr with a PC and a DB-25 connector in the cargo bay area. The software interface allows a user to read its sensor and manipulate the RoCr's behavior through a series of built in commands. The commands include the mode, drive motors, song, demo, and sensor status request.

The RoCr OI has four operating modes: Off, Passive, Safe, and Full. Once it receives the Start command, the RoCr can then enter into one of the four operating modes by sending a mode command to the OI. It can switch between operating modes at any time by sending an appropriate command to the OI. Depending on the requested packet ID, the RoCr sends back one or all 43 different sensor data in the form of packets. The sensing items are the bumps and wheel drops, wall, cliff left, cliff front left, cliff front right, cliff right, virtual wall, over currents, IR byte, buttons, distance, angle, charging state, voltage, current, battery temperature, battery charge, battery capacity, wall signal, cliff left signal, cliff front right signal, cliff right signal, user digital input, user analog input, charging sources available, OI mode, song number, song playing, number of stream packets, velocity, radius, right velocity, and left velocity.

Modified Roomba Create

The RoCr comes with a setup for its stand alone operation and needs to connect with a computer via a cable for any changes to its program. For its navigation, the RoCr is fitted with bump sensors. The customization task involves the wireless connection of the RoCr with a computer using a Bluetooth link, attaching a number of IR (infrared) sensors for obstacle sensing before hitting an object, and attaching a wireless camera so remote users can get a view of the RoCr's navigating path. A block diagram of the modified RoCr is shown in Figure 3; while an image of the modified system is shown in Figure 4.

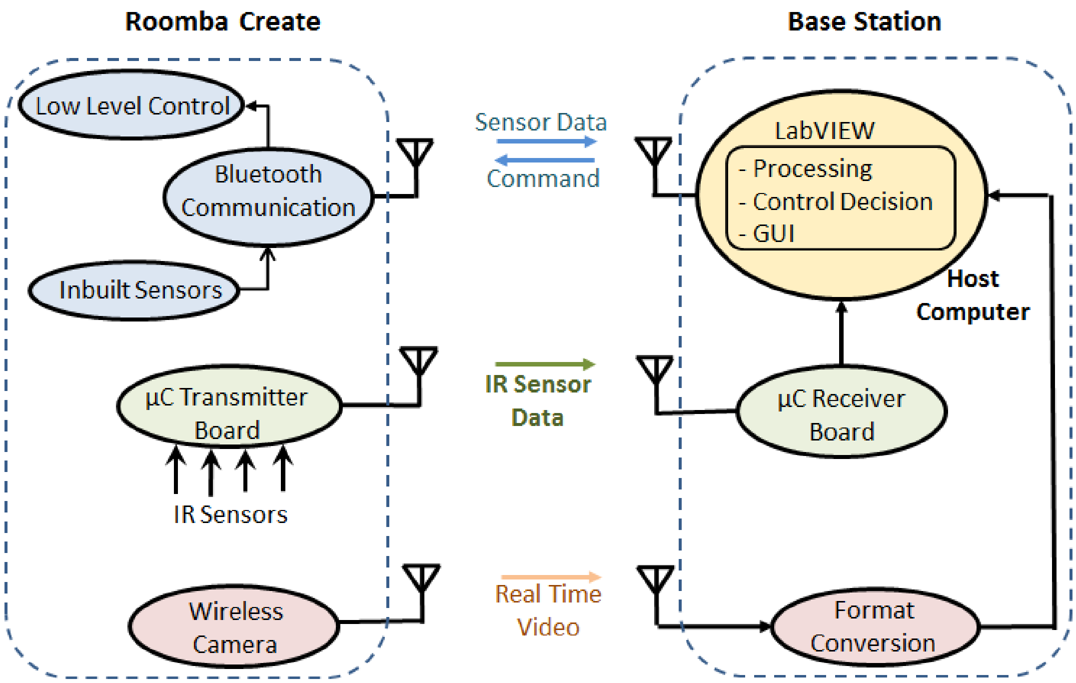

Figure 3: Complete system block diagram for controlling the RoCr.

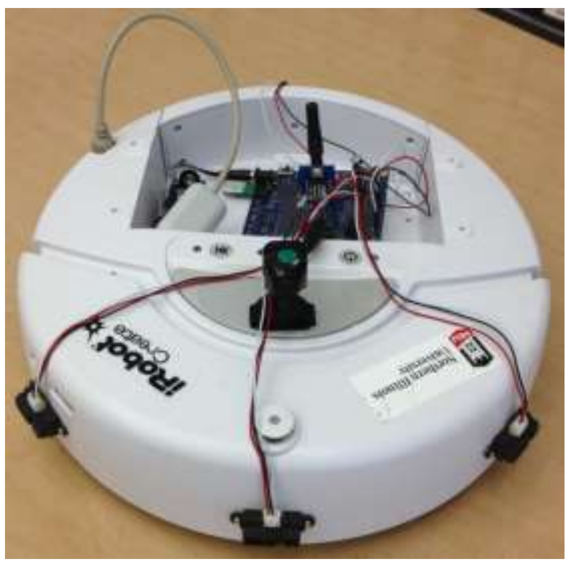

Figure 4: Image of sensors placement.

Bluetooth Interface

Bluetooth technology is used for creating wireless personal area networks (PANs). Unlike Wi-Fi networks, which can have hundreds of users, PANs were designed to be used by a single user. For this project, a BlueSMiRF was used for Bluetooth implementation. BlueSMiRF is a relatively inexpensive Bluetooth modem that implements the Bluetooth Serial Port Profile (SPP) and presents a normal 5V logic set of serial lines.[19, 20] When the BlueSMiRF is paired with the host computer, the serial lines are virtually connected to the computer as a normal serial port.

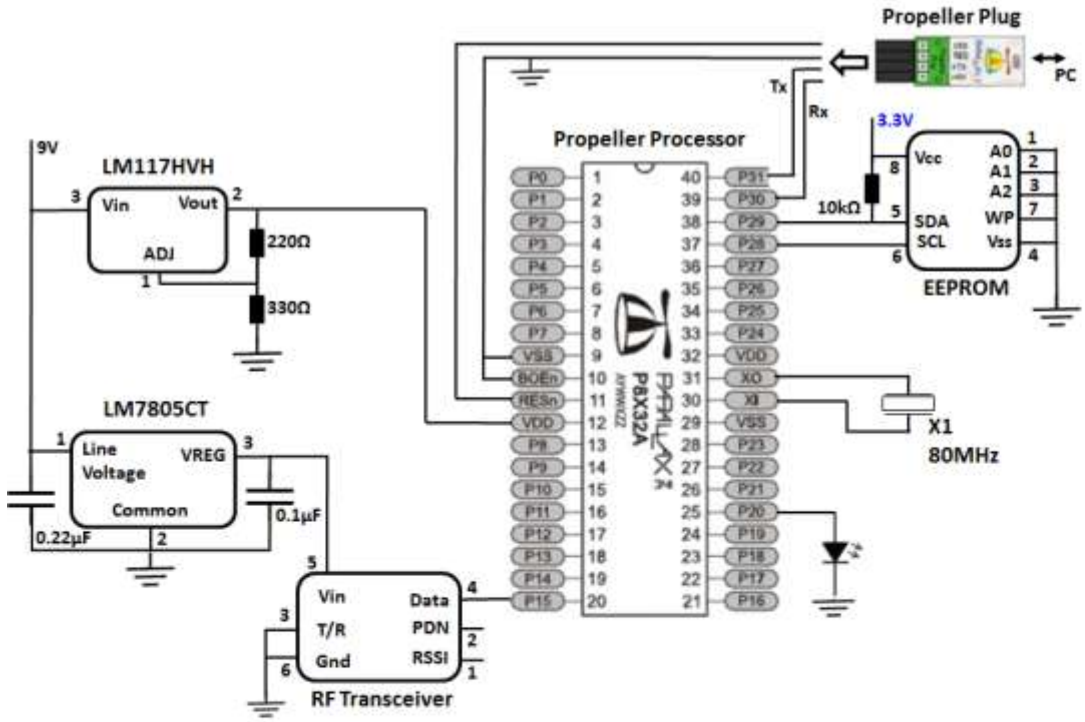

Figure 5: Schematic of receiver board.

Microcontroller based Infrared Obstacle Detection

In its original form, the RoCr uses three micro-switches to sense obstacles. These switches are mounted behind a spring-loaded bumper located at the front and sides of the RoCr. To allow the RoCr to detect an obstacle ahead of time and to avoid any contact with an obstacle, the RoCr has been modified by mounting four Infrared Sensors (IR). IR are used in this project to detect obstacles, and four IR sensors are mounted in different locations. Three of the sensors are in the front and two sides of the RoCr and one on the back. The sensor outputs are connected to a microcontroller system via A/D (analog to digital) converters. The microcontroller prepares the digitized sensor outputs in a serial format before passing these via an RF transmitter. A receiver unit is placed around the host computer where the data are collected by another microcontroller system and pass the collected data directly to the host computer. The schematic of the receiver part of the IR data communication is shown in Figure 5.

In terms of its operation, IR sensors send out IR signals and receive them if they bounce back. The strength of received IR signal corresponds to the distance between the sensor and the obstacle. The IR sensors are from Sharp and is a combination of PSD (position sensitive detector), IRED (infrared emitting diode), and a signal processing circuit.[21] The sensor outputs are connected to an onboard microcontroller system via A/D converters (MCP3202). The MCP3202 is a successive approximation 12-bit A/D converter with on-board sample and hold circuitry and is programmable to provide a single pseudo-differential input pair or dual single-ended inputs.[22]

A Propeller microcontroller is used for this project, and it is designed to provide high-speed processing for embedded systems while maintaining low current consumption and a small physical footprint.[23] In addition to being fast, the Propeller provides flexibility and power through its eight processors, called cogs, that can perform simultaneous independent or cooperative tasks. The Propeller can be programmed using ‘spin language,’ a high-level object-based language developed by the Parallax.[23] The spin provides control of the Propeller's multi core hardware and encourages the principles of the Propeller's real-time application design in ways that were not represented by existing languages. The spin can execute up to 160 MIPS (million instructions per second), i.e. 20 MIPS per cog.

Real-time Video Streaming

One of the features of the modified RoCr is to have an onboard camera to provide a real-time video of its surroundings. A miniature wireless camera is mounted on top of the RoCr that can provide a front view from the robot.[24] The camera uses 2.4GHz bandwidth for data transmission, and the signal is received by a base unit that converts images to PAL/CCIR/NTSC/EIA standards. The Radio AV receiver receives the transmitted signal and sends it through composite cables. The received video is then converted to digital format and passed to the computer using a Video Xpress.[25] A block diagram shows the implementation of the wireless camera (Figure 6).

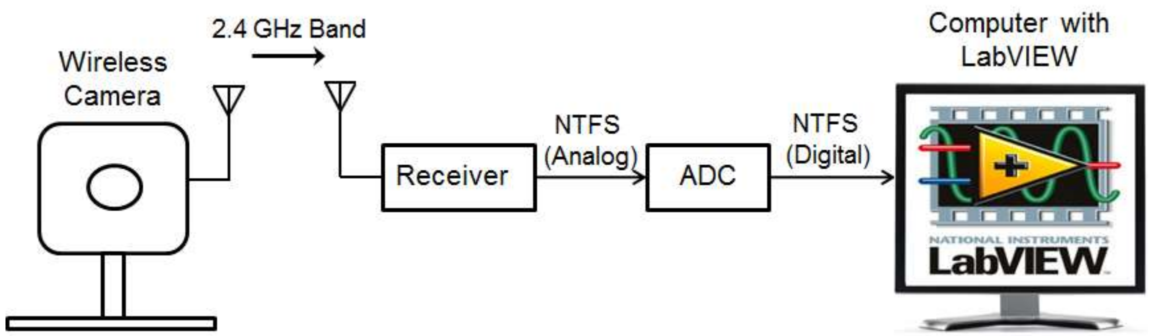

Figure 6: Shows a block diagram for wireless camera system.

Graphical User Interface

A GUI is one of the most important components of a remote laboratory facility. In this development, LabVIEW is the main driving force for GUI design and development. The sensors’ data collected by the host computer via the Bluetooth are passed to LabVIEW. The digitized form of video is also collected by the LabVIEW for display within the GUI. The LabVIEW design involves a connection with the Bluetooth, collecting data from the microcontroller receiver unit, and collecting the digitized video as transmitted from the RoCr. Once the data are collected, the task is to manipulate them to implement control strategies as well as display real time video through a GUI. The communication interface includes configuring the Bluetooth, by setting up the baud rate and serial port. Once communication is established between the RoCr and the host PC, communication between LabVIEW and the RoCr can be initiated. Figure 7 shows a screen shot of the developed GUI that controls the RoCr. As shown, the GUI includes all the desired control functionalities as well as sensor status and video.

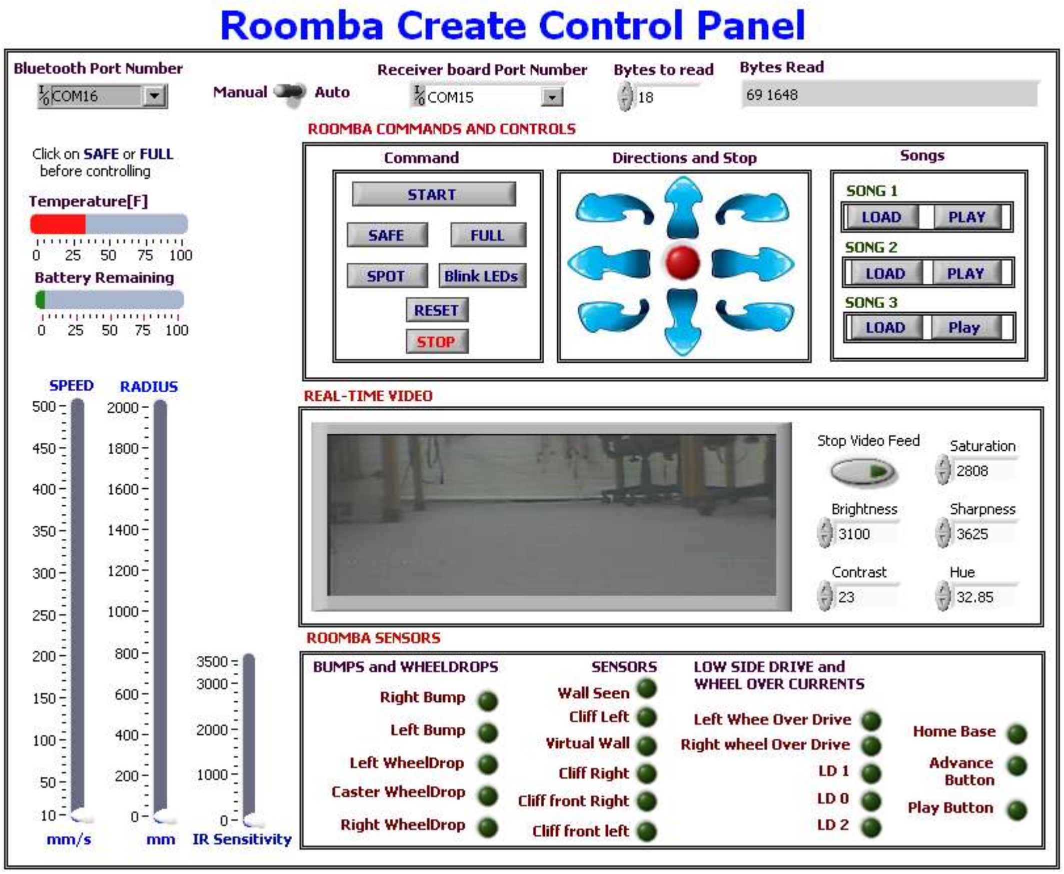

Figure 7: View of the front panel of the developed GUI.

The top part of the GUI provides the initialization and port setup process. The left bottom part of the GUI shows the speed and turning radius adjustment markers. The remaining area is divided for the RoCr command and control buttons, displaying video, and showing the RoCr sensor status. The available commands within the GUI are move forward, move backward, turn right, turn left, stop, load and play tunes, and change speed and turning radius. The sensor data used for making decisions (in the back end of GUI) are right bump sensor, left bump sensor, override current sensor, and IR sensors. Apart from the last one, the others are inbuilt sensors of the RoCr. In addition, the GUI displays a few other sensor statuses: home detect sensor, wheel drop sensors, battery temperature sensor, and battery charge sensor.

Control Strategies

The main goal of controlling the modified RoCr is to avoid any obstacle in its way and to develop an alternative path when necessary. Initially the controller will drive the RoCr in a straight-line path and check the IR obstacle sensors as well as the bounce sensors. Upon receiving an obstacle signal, the controller will automatically redirect the RoCr in a revised course. In addition to automatic control, the RoCr can also be controlled manually via a GUI, where the manual control has a higher priority than the automatic control.

Within the automatic control approach, there are three control strategies for handling three different obstacle scenarios. The scenarios are obstacle on the right, obstacle on the left, and obstacle in the front. This paper explains only one of the scenarios, obstacle on the left. When the left IR sensor detects the presence of an obstacle, the controller (within the host computer) sends a signal to the RoCr (via Bluetooth) and turns toward the right with a given turning radius for a period of time and then drives in a straight path. The turning radius and speed of the RoCr can be adjusted by a user via the GUI. Figure 8 depicts the movements for this scenario.

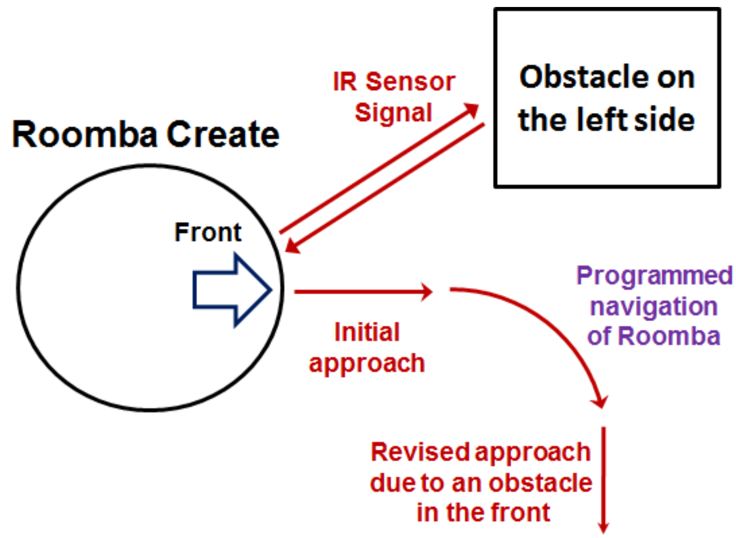

Figure 8: Motions after detecting an obstacle in the left side of the RoCr.

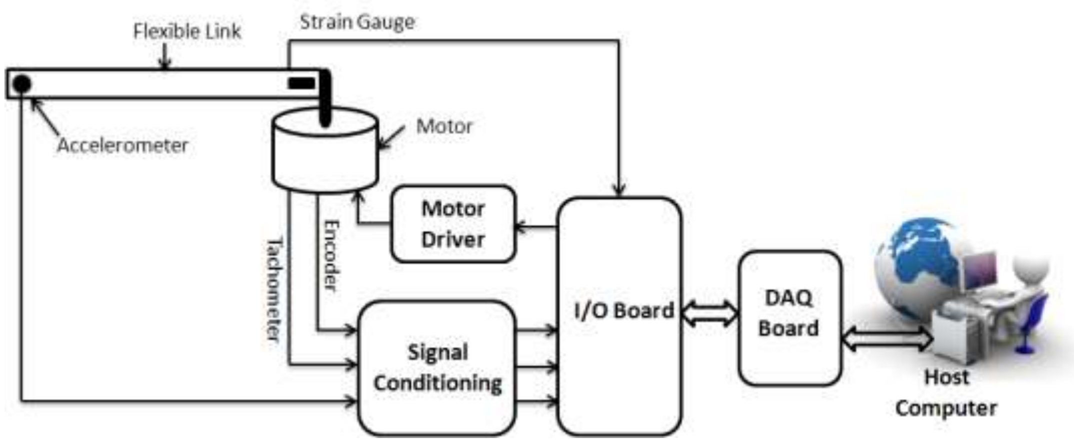

Figure 9: System block diagram for the modified flexible manipulator system.

4.2 Flexible Manipulator System

The flexible manipulator system was acquired from Quanser Inc., a company that markets educational experiment systems; most of their products are in the control discipline. A block diagram of the customized system is shown in Figure 9. The flexible manipulator system is a single-link manipulator that can move only on the horizontal plane. The manipulator link is approximately 17 inches long, 0.82 inches high, and 0.034 inches thick. At the hub, one end of the link is connected to a motor for rotation on the horizontal plane.

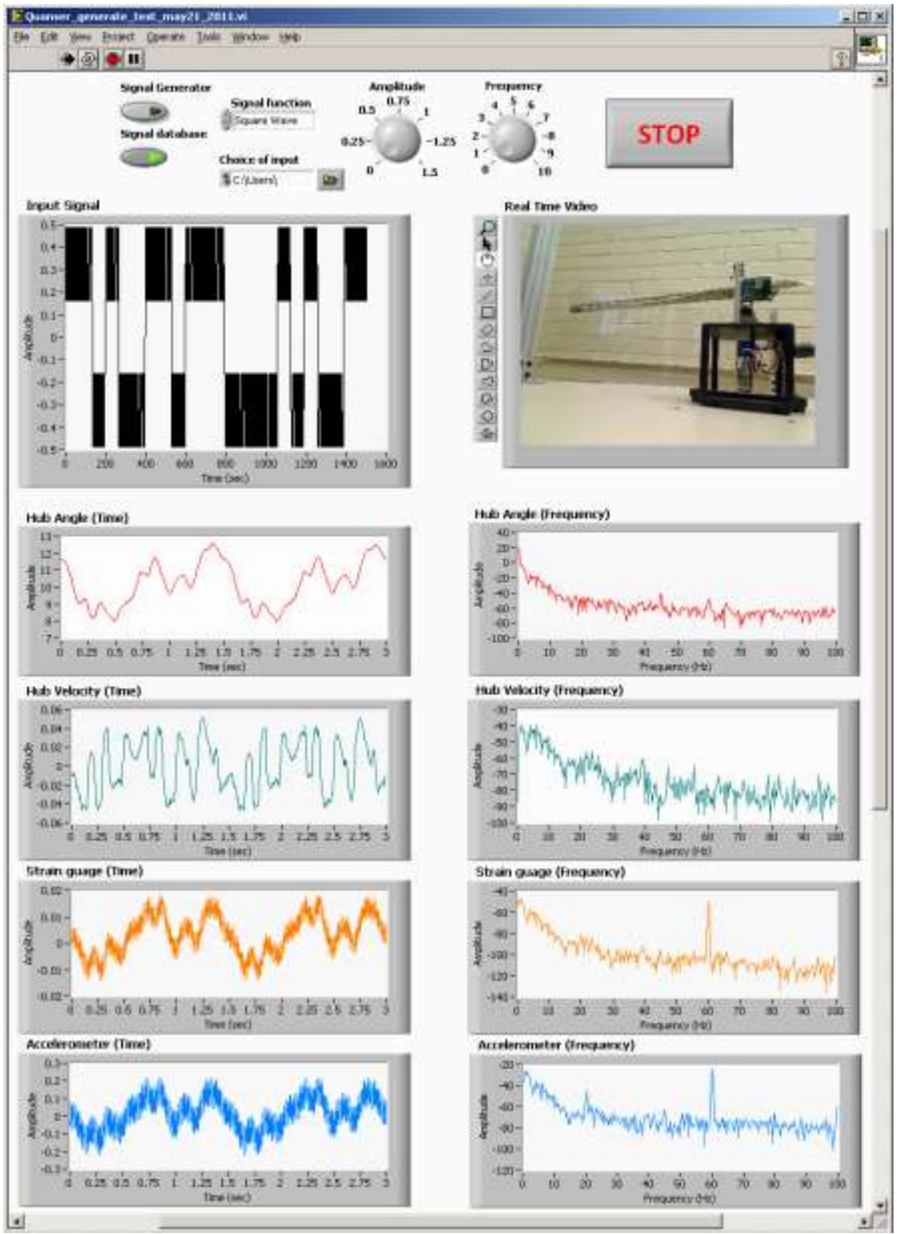

Figure 10: A GUI for studying the behavior of a flexible manipulator system.

The motor is connected to a motor driver. Four sensors are connected to the system to collect vibration and motion information: encoder for hub angle, technometer for hub velocity, strain gauge close to the hub area for strain information, and accelerometer for end-point acceleration.[26, 27] The collected sensor signals are passed through a signal conditioning system for the required amplification and noise filtering. All these sensor outputs and actuator inputs are connected to an Input/Output (I/O) breakup board and then to a networked computer via a DAQ board. The DAQ board provides required interfacing of the signals to the computer using appropriate digital to analog and analog to digital converters. The DAQ board is an NI USB-6211 acquired from National Instruments and provides 16 analog inputs and 2 analog outputs, (both with 16-bit accuracy) along with a number of digital inputs and outputs. The host computer has LabVIEW software and is used for both the controller implementation and GUI development.

Figure 10 shows an image of a GUI that is used by students to observe and validate the vibration properties of a flexible manipulator system over the Internet. The upper part of the GUI shows the control points where a student can start and stop the experimental system and choose an input signal to the system as well as control the properties of the input signal. Just below (the left hand side) is a graph window showing the shape of the desired input signal, while the right hand side window shows the remotely located experimental system. The bottom part of the window shows four pairs of sensor signals that are collected from the experimental system (both in time and frequency domains). The right hand side ones are in the time domain, and left hand side ones are in frequency domain. In addition, one can also download all the input and output signals on the host computer for further processing.

4.3 Safety Issues

Care must be taken while operating an electro-mechanical system from a remote location, especially when the remote location can be potentially unmanned. Improper use of the system can lead to equipment breakdown, damage to the system and surroundings, even the trigger of a fire. Several measures were taken to address these issues. This involves physical measures to protect the systems and limiting the control actions that a remote operator/user can perform. The RoCr is usually placed within a confined location where it can perform its activities without any serious damage to the system or its surroundings. Even while working outside the area it can protect itself from hazardous activities, which is ensured via its programming. The limitation provided via a program includes the setting of a maximum allowed speed limit for RoCr. This is to restrict impact on a collision. In case of a motor overdrive, the RoCr will turn itself down automatically. The second scenario can happen if someone directs an RoCr to an obstacle for longer time. The flexible manipulator is also protected physically and programmatically. In terms of physical measure, limit switches are placed on two sides so that the flexible link can rotate only for 180 degrees, while the system control program limits the maximum amount of torque and duration one can apply, hence limiting the speed of the system.

5. Remote Laboratory Portal

Offering laboratories over the Internet involves a number of experiments being delivered at the same time to a group of student. In addition, the experiments should change with time as the course progresses. There should also be a provision for maintaining the safety of the laboratory in terms of operational hazard and integrity and to accommodate activities that will allow one to achieve pedagogical objectives. All these require a suitable portal that will provide password controlled access to the facility, activating and deactivating experiments with time, tracking student activities for pedagogical issues, and ensuring safety and system integrity.

A system diagram showing how the laboratory experiments are connected to the Internet via a web portal is provided in Figure 11. Within the diagram, the 'Laboratory Management Server' hosts the web portal that provides all the web applications that manage and control remote access to the facility and manage all of the laboratory-related activities. Equipment needed to perform experiments are gathered within the 'Equipment Bank' where they are connected with a Switching Matrix'. A 'Switching Matrix' allows one to change an experiment configuration (hardware connection) via a 'Host Computer'. A 'Host Computer' holds the GUIs along with a provision for the video and audio feed of the experimental system. Along with local access, the GUIs (with video and audio) are available over the Internet as a dynamic web page. As mentioned earlier, access to the GUIs is managed by the 'Laboratory Management Server'. A user can access the GUIs to perform experiments from remote locations via the server.

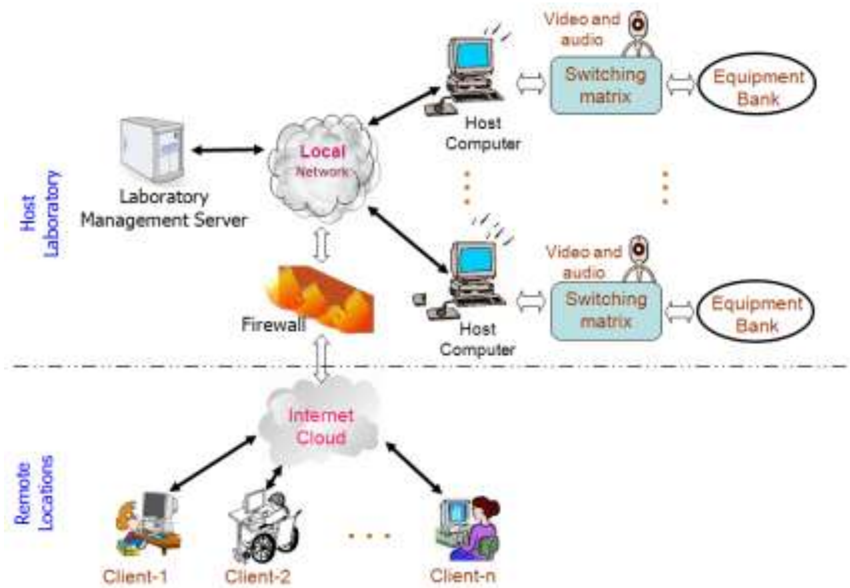

Figure 11: Block diagram of a generic remote laboratory system.

An image of the web application page that is available via the 'Laboratory Management Server' is shown in Figure 12. This application page is developed by using .NET technology connected to an SQL Server. The page provides a portal to the remote laboratory facility while facilitating all of the requirements mentioned earlier.

Figure 12: Shows the image of administrator home page.

6. Conclusions

The paper provides an illustration of customizing two control experiments for integration within a remote laboratory facility. This involves preparing inputs and outputs for hardware interfacing with a local computer, software design, development of GUI, and finally their integration with a remote laboratory facility. The process needed additional hardware and software along with the provision of audio and video feed of the experiment environment. The developed GUIs provide an environment in which a remote user can control the systems without any physical presence within the host laboratory. After the integration of the experiments, the remote laboratory portal ensures the safety and integrity of the experiments. In addition, it provides a provision of experiment management and pedagogical design tools.

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[19] The BlueSMiRF Silver is the latest Bluetooth wireless serial cable replacement from SparkFun Electronics. Website : https://www.sparkfun.com/products/10269

[20] SparkFun is an online retail store that sells the bits and pieces to make any electronics projects possible. Website : https://www.sparkfun.com/

[21] GP2Y0A21YK0F Distance Measuring Sensor Unit Measuring distance: 10 to 80 cm Analog output type. Website: http://www.parallax.com/tabid/768/ProductID/776/Default.aspx . Other product related information can be found at http://sharp-world.com/products/device/lineup/data/pdf/datasheet/gp2y0a21yk_e.pdf

[22] MCP3202 2.7V Dual Channel 12-Bit A/D Converter with SPI Serial Interface. Website : http://www.parallax.com/Store/Components/AllIntegratedCiRoCruits/tabid/154/CategoryID/31/List/0/SortField/0/Level/a/ProductID/232/Default.aspx and the document containing more specific details about the ADC is given in the website : http://www.parallax.com/Portals/0/Downloads/docs/prod/appkit/ltc1298.pdf.

[23] Propeller Information available at: http://www.parallax.com/PropellerDownloads/tabid/832/Default.aspx.

[24] Wireless Surveillance Camera system, which was used in this project, can be found here. http://www.intelspy.com/4ca2wimicoau.html.

[25] Video Xpress is a converter that can get analog signals from the composite cable to digital signal through USB. This product is developed by ADS Technologies Inc. and this product can be bought at http://www.tigerdirect.com/applications/SeaRoCrhTools/item-details.asp?EdpNo=3428849

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