

WEB-CONTROLLED DEVICES AND REMOTE MANIPULATION: DISTANCE LEARNING CASE STUDIES

T. Sobh,* R. Mihali,* B. Ghimire,* K. Vovk,* G. Gosine,* and P. Batra*

Abstract

Distance learning is being envisioned as an education mechanism that is more accessible, comfortable and closer to the learning individual. The distance being introduced is between the individual and the physical institution itself, but the exact requirements of a degree are maintained. The main idea in e-learning is to build adequate solutions to assure educational training over the Internet, without requiring a personal presence at the degree-offering institution. The advantages are immediate and of unique importance. To enumerate a few:

- Scholarship/education costs can be reduced dramatically (no need for room and board, for example).
- The usually tedious immigration and naturalization issues common with international students are eliminated.
- The limited campus facilities, faculty members, and course schedules an institution can offer are no longer a boundary.
- Working adults can consider upgrading skills without changing their lifestyles.

This article offers several instances of projects that can be mainly utilized for distance learning for lab-based courses. The projects have an engineering/laboratory flavour and are being presented in an arbitrary order. The control topics range from vision and sensing to engineering design, scheduling, remote control, and operation. The inclination is towards being able to set up physical labs online, thus allowing students to use equipment/machines (microscopes, manipulators—for handling substances or various objects part of experiments, pulleys, etc.); hence the goal of creating tools to allow engineering lab-based courses to be offered via distance learning.

Key Words

Distance learning, remote manipulation, web control

1. Introduction

Distance learning possibilities have been considered for quite some time; however, only the recent growth of the Internet made them a reality. One idea is to use the large information bandwidth that the Internet can offer and expose a variety of educational materials online. A course could, for example, be offered online through a comprehensive list of multimedia solutions ranging from an online

course book and online homework submissions to live video conferencing, auditing, and examinations. There are many methods to create an online course, and an appropriate one would have to be chosen, considering issues such as security/reliability of training, educational expectations such as work speed improvement (e.g., math and programming courses), or physical dexterity (e.g. mechanical, medical courses). Some courses might require specialized hardware (e.g., robotics and automation), such as haptic devices combined with virtual reality gear.

It is certainly easy to set up some of the courses online, such as computer programming, mathematics, and literature, but it is difficult to set up engineering or laboratory-based courses due to the custom and specific hardware required. For example, setting up chemistry or physics laboratories could present potential safety and cost issues. Medical laboratories bring many additional issues, and there could certainly be issues that the current technology could not solve for distance learning purposes.

We concentrate on some of the aspects of the mentioned problems and present a few implementations that could help in solving them. In an attempt to support faster distance learning implementations, we present here a sequence of projects that have been developed and can serve the process of distance learning education, ranging from simple "hobby" style training to professional guidance material. Before proceeding to the details of each project, we present a synopsis of each.

Internet controlled robot with video feedback. The project simplifies the control of an inexpensive mobile manipulator and offers a simple web-based interface with a video feedback that allows control of the robot from any point on the web with a few clicks of a mouse. The user can activate each link separately or move the robot to a given location, and a live stream of the robot will confirm its coordinates.

WWW gateway for the Mitsubishi MoveMaster-EX Robot. Like the majority of manipulators, the MoveMaster robot from Mitsubishi offers a mini language set that allows its control when connected to a computer. This project demonstrates the ability to interface the robot's language set with a simple web interface, thus allowing remote programming of the manipulator.

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Remotely controlled monitoring vehicle. The project demonstrates how a low-cost monitoring vehicle can be controlled from a remote location, providing visual feedback to the remote operator. The main applications include security, surveillance, child monitoring, and territory exploration.

2. Internet Controlled Robot with Video Feedback

This Internet-controlled robot is a robust and repeatable telerobotic manipulator that can be controlled from any Internet-enabled computer around the world. The aim of this project is to create a functional system that allows efficient control of a supervised telerobot. In supervised telerobotics, an operator at a local site utilizes input devices and graphical visualization tools to command the execution of a task at a remote site using a telerobot.

The robot is controlled from a web page, where the operator handles the robot by using a graphical user interface. The operator can control each link of the robot separately, or move the robot to a given point in 3-D space by inputting the corresponding coordinates. The operator sees the movement of the robot on the computer screen in real time via a live video camera broadcast. This allows the operator to see the immediate effects of his or her control actions and correct them if necessary.

Such a system can be used to control a robot that operates in a hazardous or inaccessible environment. In addition, it offers the benefit that the operator does not have to be in the vicinity of the robot, but can be located anywhere throughout the globe. Practical applications of the system include remote-controlled operations in radioactive or toxic areas, which are dangerous for human beings, as well as remote reconnaissance and sample collection.

The designed robot features base-rotation, and shoulder, elbow, and wrist motion with a functional gripper along with two additional servos to provide steering. The electronics and the servo controller are completely assembled. A host PC is used to issue positioning commands.

For Internet control of the robot, we have created a distributed high-performance client/server architecture [1]. In this architecture the client provides a control interface for the user and transmits control commands to the server over TCP/IP, encoding the data before the transmission. The system architecture is based on the thin client model where the client performs only data validation and data transmission routines. The server receives and decodes control commands from the client. Once the transmitted command has been decoded, the server then performs inverse kinematics calculations on the data. This is necessary because the user inputs values of x, y, z coordinates via the client, and they have to be transformed into angular values, which the robot's microcontroller can understand.

The server then sends robot control signals over an RS-232 serial port to the robot's built-in microcontroller, which performs the required action as long as the requested position has been validated and confirmed as within the robot's workspace. The user receives visual feedback from a video camera that is focused on the robot. The video signal comes from a CCD camera connected to the server

via a Universal Serial Bus interface and has a resolution of 640 x 480 pixels. The signal is converted into streaming *RealVideo* format using RealProducer software, encoded at a bit rate of 150 Kbps and streamed to the client real video player.

The system flowchart in Fig. 1 illustrates the composition and the data flow of the complete robotic system. The flow of the data starts from the login prompt, where the user has to authenticate him/her self, and ends with the robot performing the actual motion [2]. The data itself are constituted largely of the operation commands to the robot, which are encoded during transmission.

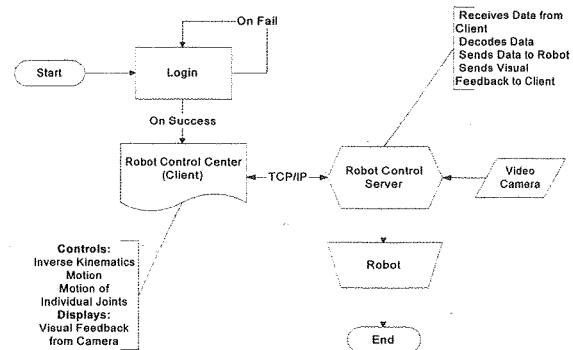


Figure 1. System flowchart.

The most difficult criterion for many web-based telerobots to meet is that of reliability. The robot must be available on a permanent basis while requiring minimal maintenance. While an operator is waiting for a response from the telerobot, they are unable to plan/submit the next request. To minimize this waiting period, the response time should be as small as possible [3].

Telerobots have the benefit of human cognitive and perceptual abilities; as they are operated by a human being, they can perform more efficiently in unfamiliar and dynamic environments.

3. WWW Gateway for Mitsubishi MoveMaster-EX Robot

3.1 Objective



Figure 2. Companion website: <http://www.bridgeport.edu/batra/robotics>.

The primary objective of this project is to create a www-interface to the Mitsubishi MoveMaster-EX robot (Fig. 2), thus allowing a user to connect to the robot and control it from a physically distant workstation without the need to download and install special software.

3.2 Requirements

The following hardware and software were used for implementation:

- IBM-compatible PC
- Windows NT server 4.0 (operating system)
- Internet Information Server 4.0 (web server)
- RS232 Serial port interface and cable (to connect to robot)
- Active Server Pages (enabled in IIS)
- The *aspexec.dll* component
- Visual Basic (to code the app to write to the serial port)

3.3 Implementation

The objective was accomplished by setting up a web server on the PC connected directly to the robot (through the RS232 interface) [4, 5]. Users connecting to the web server through the World Wide Web were able to send commands to the robot by using the ASPEXec component that the Active Server Pages used to execute writetoport.exe. This executable communicated with the robot by sending these commands through the serial port interface.

As the Mitsubishi MoveMaster EX allows direct and inverse kinematics control directly through the serial port, there was no need to produce and use any of the kinematics equations. For example, the robot can tolerate through the serial port, a string such as "MV 100,30,0,40,50,0,-3", where the first five values represent the angles in degrees for each of the joints and the last two values represent the pitch and yaw of the end-effector. The majority of robots nowadays do tend to have fully solved IK through their hardware, the evaluation of these equations mainly being appropriate in conjunction with the dynamics equations when the robot needs complete software control (note that the Mitsubishi Movemaster does not provide dynamics control, providing only a set of fixed values for speed and no direct torque/actuators control).

3.4 The ASPEXec Component

ASPEXec allows the execution of DOS and Windows apps through the Active Server Pages (*commandrobot.asp* executes an executable called *writetoport.exe* which sends the appropriate command to the robot through the RS-232 serial interface). The following functionality is available through ASPEXec:

property Application: Set the path (optional) and exe/com filename.

property Parameters: Set the app parameters.

property TimeOut: Set the timeout to wait (milliseconds). Used only for ExecuteDosApp and ExecuteWinAppAndWait.

property ShowWindow: Set whether the executing app is visible or not. Used only for ExecuteWinAppAndWait and ExecuteWinApp.

ExecuteDosApp: Executes the specified app as a DOS app and returns *stdio* as string.

ExecuteWinAppAndWait: Execute the specified app as a Windows app and wait for the specified timeout if exec is successful.

ExecuteWinApp: Execute the specified app as a Windows app and return result code immediately.

Installation: To use this ASP component, we moved the DLL into a subdirectory (such as \winnt\system32 for NT or \windows\system for Win95/98) and type: **regsvr32 aspexec.dll**.

For the source code for controlling the robot, see Appendix A. Fig. 3 shows a screenshot of the controlling interface.

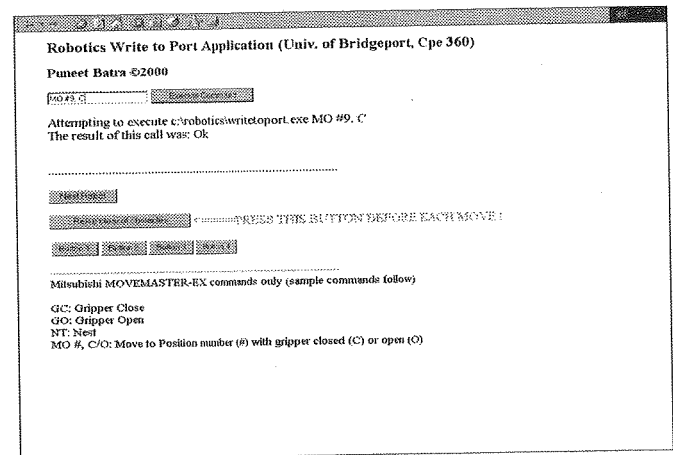


Figure 3. A screenshot of the main interface page. (<http://216.87.101.211:8080/satcontrol/aspexec/commandrobot.asp>)

In this interface, the user is allowed to type any of the commands that the robot was designed to accept through the serial port, given that the user is aware of their correct syntax (using the robot's user manual is recommended). Simple commands such as GC, GO, NT, and MO (specified on the interface page) are easy enough to use and assure a predictable positioning of the manipulator once the positions have been defined.

4. Remotely Controlled Monitoring Vehicle

4.1 Objective

The objective is to come up with a prototype for a low-cost monitoring vehicle that can be controlled from a remote location providing visual feedback to the remote operator.

4.2 Purpose

A small-scale prototype of the described product can demonstrate the low cost and ease of set up of a device with an enormous number of potential applications, including security surveillance, child monitoring, hostile territory exploration, and even as a toy [6, 7].

4.3 Available Resources

The resource available to build the prototype were limited to the following list: *vskip 6pt Hardware:* PCs (IBM compatible), Mitsubishi Movemaster EX robot, generic RC car, radio frequency (RF) transmitter, cables and connectors, controller box for Mitsubishi Movemaster EX, and wireless camera (for visual feedback).

Software: operating systems (Windows NT, Linux) and programming languages (C++, Java, VB).

4.4 Description

The two major implementation issues are (1) issuing commands to the server from a remote machine, and (2) interpreting these commands and sending the appropriate signal to the car through the RF chip.

Issuing commands to the server from a remote machine. Initially we set up a web server (Internet Information Server 4.0 was the server of choice, as it is the most stable one available for a Windows NT platform). The next step involved setting up HTML forms that allowed users to issue the appropriate commands to the server. However, an obstacle here was that these commands needed to be sent to the RF-chip through the serial port. The web server does not have direct access to the computer's serial port as this is a major security issue [8]. To overcome this issue, we wrote a DLL, which allows ASP pages to run commands on the local machine. We then wrote a simple application, which took commands to be sent to the RF chip as command-line arguments. The ASPExec module then ran this application with the necessary commands as command-line arguments, which were sent to the RF-chip.

However, the web-server/browser approach was dropped because it was not possible to limit access to a single user and a number of security problems existed. Furthermore, a browser would not be able to provide two-way communication between the client and the server (for purposes of a visual feedback).

Hence, a Java-based approach was sought. We wrote an RMI-based server, which accepted a maximum of one connection from the client software, which was also written in Java. This design also allowed IP screening and other security features. The Java server also had direct access to the local machine's serial port, thus avoiding the need to write a separate DLL, which proved to be a security hole by itself [9].

Interpreting these commands and sending the appropriate signal to the car through the RF chip. The major implementation issue at this point involved deciphering the commands and having the RF chip transmit

the appropriate signals. To resolve this issue, we needed an FPGA controller that would send a unique signal to the RF chip, depending on the signal it received from the serial port. This approach was the most efficient but involved an expensive FPGA chip and expensive software, which was unavailable to us at development time [10, 11].

The solution we chose was to use a robot to decipher the signals from the server, and to manually manipulate buttons on the RF chip to send one of four signals (back, forward, left, right) to the vehicle. The availability of all the necessary resources made us pick this as our option for the prototype.

The controller box for the Mitsubishi Movemaster-EX robot accepts commands as strings from a PC's serial port (RS-232). As our client already had this capability, we had to program the robot to teach it certain positions and send it commands to move to these positions in order to manipulate the controls on the RF-chip.

The complete design flowchart is depicted in Fig. 4.

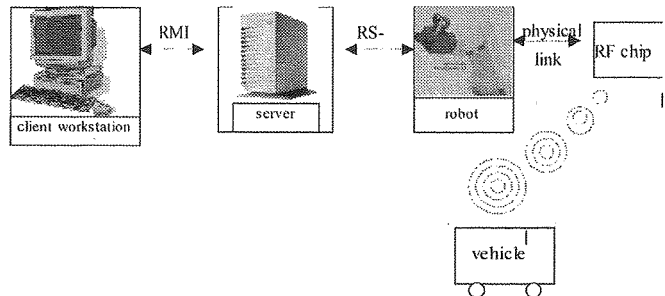


Figure 4. Execution flow diagram.

4.5 Applications

Potential applications of our web-based system include security surveillance vehicle, exploration of hazardous environments, wartime espionage, remote transportation of objects, and support for disabled individuals [12].

5. Internet Controlled Satellite Transponder (Using a Remotely Controlled Robotic Manipulator)

5.1 Objective

The objective is to be able to control a satellite transponder from a remote location by using a robotic manipulator to mechanically change controls on the receiver or an UHF/infrared remote control of the receiver.

The reasons a robot was used to mechanically manipulate the controller unit instead of hard-wiring the controller unit (or the UHF remote control) to the server were: (1) the process of hard-wiring can permanently damage the expensive controller unit and subsequently render the transponder useless [13, 14], and (2) the robot can be easily reprogrammed to adapt to different controller equipment, such as working with a remote controller.

To establish communication between the remote client and the robot via the server and enable the robot to carry out the desired commands without exceeding its limited

workspace or running into obstacles, the following tasks need to be implemented.

1. Interfacing between robot and server (RS-232)
2. Interfacing between receiver and server
3. Interfacing between the server and Internet
4. Teaching the robot (trajectory planning and generation)

A flowchart of the proposed system is shown in Fig. 5.

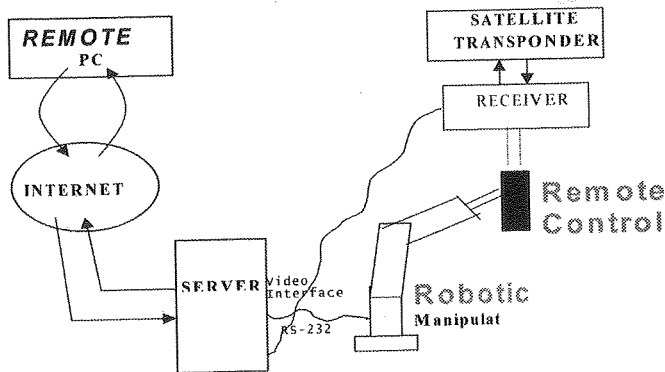


Figure 5: System schematics.

Interfacing between the robot and the server is carried out via the RS-232 serial port, which is a standard on the main board of any IBM-compatible PC. The robot's controller box simply receives commands as ASCII strings through the RS-232 connection. An important issue that arises is that there is only one-way communication, that is, once the computer issues commands to the robot, the controller box does not send back a signal to indicate a successful or unsuccessful command interpretation and application [15]. To overcome this, it is important that a flawless trajectory be planned during initialization of the robot and implemented in a manner such that obstacles do not pose a problem.

Sample commands (among others) that can be issued to the robot include:

GC: Closes the gripper
GO: Opens the gripper
NT: Nest the robot

Interfacing between the receiver and the server is implemented through a special interface card, which takes the analog feed from the transponder's receiver and converts it into a digital format ready to be broadcast over the Internet. The PC card receives a feed through a standard coaxial cable such as that used for cable television. The transponder can point at different "look-angles," and at each look-angle it can receive feeds at numerous frequencies.

Interfacing between the server and the Internet is relatively simple, as it involves setting up and configuring a web server to serve HTTP requests from clients. Security is an important issue here, and user authentication is vital because it is undesirable to have unauthorized individuals controlling the robot remotely and causing damage to the equipment. It is also important to ensure that only one

individual is controlling the robot at one time and to initialize the robot so that it starts at a position known to the software. Initialization also involves defining key positions in the robot's workspace and defining trajectories that the robot should travel along.

Lastly, the robot must be "taught" about its surroundings and the environment that it will be operating in. This can be done by fixing the position of the remote control unit and defining its position relative to that of the robot. This allows the robot to "know" where the controller unit is and where particular controls on the unit are. The robot must be nested prior to operation to ensure that it always starts from the same point, thus allowing error-free software control.

5.2 Constraints and Limitations

The following constraints apply:

- A limited set of commands that the robot's controller box can understand
- Only one-way communication between the server and the robot's controller box
- Web server's clients have no access to the serial port, which is the only means of talking to the robot
- Time constraints
- Compatibility issues force usage of a certain operating system

5.3 How Were the Above Limitations Overcome to Achieve the Objective?

The following tasks had to be carried out:

- Configure the server-to-server HTTP requests
- Write software allowing HTTP clients to issue commands to the robot via the RS-232 port
- Write software to initialize the robot and define the work area

Server configuration was less complicated, and setting up an NT server with an IIS web server to process requests and enabling security authentication and control was smoothly performed.

An ActiveX control needed to be written in Visual C++. This component allows Active Server Pages to run executables on the server itself.

An executable called "writetoport.exe" did the simple task of taking command-line arguments and sending these arguments to the robot as commands via the serial port. This application was first implemented in C++ under a DOS environment, but when ported to Windows NT, the operating system's security management features did not allow direct access to the computer's serial ports [16]. This application needed to be rewritten in a Windows environment using Visual Basic.

5.4 Robot Initialization

As mentioned previously, robot initialization is vital to ensure error-free operation, especially as the robot's controller unit sends back no signals to the server itself. The

position of the remote control needs to be fixed, and positions within the robot's work area need to be defined.

There are two basic types of movements:

- Point to point (PTP) movement
- XYZ movement

PTP movement involves specifying the joint variables (the joint angles in this case) and changing them according to the desired position of the robot.

XYZ movement involves moving the end-effector in an x , y , or z plane. The joint variables are calculated based upon position and desired motion, and accordingly changed and recalculated at every point within the trajectory [17].

XYZ movement is much slower and more inaccurate than PTP movement because the robot needs to perform repeated calculations to determine the desired position. Hence PTP movement was used to minimize error between the desired trajectory and the actual trajectory. In order to use PTP movement the trajectories need to be well defined; each of the joint angles need to be specified and effected simultaneously to allow smooth trajectories.

5.5 Resources

The following list is not exhaustive.

- Mitsubishi MoveMaster EX robot
- Satellite transponder and receiver
- Interface card for receiver
- IBM-PC or compatible
- Windows NT 4.0 (server)
- Internet Information Server 4.0
- Languages: C++, Visual C++, Visual Basic, VBscript (for ASP technology)

5.6 Advantages and Potential Uses:

Some users are: remote satellite feed for Internet users, remote communication, and distance learning. The project demonstrates the synergy created by combining robotic and computing power. On a larger scale, this concept can be ported to pragmatic and useful web applications using robots.

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Appendix

Source Code for the commandrobot.asp page

```
<HTML>
<head><title>ASPEXec Test (ExecuteWinApp)</title></head>
<body bgcolor=white text=black>
<blockquote>
<H3>Robotics Write to Port Application (Univ. of
Bridgeport, Cpe 360) </H3>
<H4>Puneet Batra &copy;2000</H4>
<FORM ACTION="commandrobot.asp">
<INPUT TYPE=TEXT SIZE=20 NAME="command">
<INPUT TYPE=SUBMIT VALUE="Execute Command">
</FORM>
<%
    cmd = request.querystring("command")
    Set Executor = Server.CreateObject("ASPEXec.Execute")
    Executor.Application = "c:\robotics\writetoport.exe"
    Executor.Parameters = cmd
    Executor.ShowWindow = True
    Response.Write "Attempting to execute "
        Executor.Application & " "& Executor.Parameters
    & "<br>"
    strResult = Executor.ExecuteWinApp
    Response.Write "The result of this call was: " &
strResult
%><BR><BR><BR>
<HR ALIGN=LEFT WIDTH=50%>
<FORM ACTION="commandrobot.asp">
<INPUT TYPE=HIDDEN SIZE=20 NAME="command" VALUE="NT">
<INPUT TYPE=SUBMIT VALUE="Nest Robot">
</FORM>
<FORM ACTION="commandrobot.asp">
<INPUT TYPE=HIDDEN SIZE=20 NAME="command" VALUE="MO
9, C">
```



```

<INPUT TYPE=SUBMIT VALUE="Raise clear of obstacles">
<FONT COLOR=RED>
<=====PRESS THIS BUTTON BEFORE EACH MOVE !</FONT>
</FORM>
<TABLE>
<TR>
<TD>
</FORM>
<FORM ACTION="commandrobot.asp">
<INPUT TYPE=HIDDEN SIZE=20 NAME="command" VALUE="MO
1, C">
<INPUT TYPE=SUBMIT VALUE="Button 1">
</FORM>
</TD>
<TD>
<FORM ACTION="commandrobot.asp">
<INPUT TYPE=HIDDEN SIZE=20 NAME="command" VALUE="MO
2, C">
<INPUT TYPE=SUBMIT VALUE="Button 2">
</FORM>
</TD>
<TD>
<FORM ACTION="commandrobot.asp">
<INPUT TYPE=HIDDEN SIZE=20 NAME="command" VALUE="MO
3, C">
<INPUT TYPE=SUBMIT VALUE="Button 3">
</FORM>
</TD>
<TD>
<FORM ACTION="commandrobot.asp">
<INPUT TYPE=HIDDEN SIZE=20 NAME="command" VALUE="MO
4, C">
<INPUT TYPE=SUBMIT VALUE="Button 4">
</FORM>
</TD>
</TR>
</TABLE>

<HR ALIGN=LEFT WIDTH=50%>
<SMALL>
Mitsubishi MOVEMASTER-EX commands only (sample
commands follow)
<BR><BR>
GC: Gripper Close<BR>
GO: Gripper Open<BR>
NT: Nest<BR>
MO #, C/O: Move to Position number (#) with gripper
closed (C) or open (O)
</SMALL>
</blockquote>
</body>
</html>

```

Biographies



Tarek M. Sobh received the B.Sc. in engineering with honours in computer science and automatic control from Alexandria University, Egypt, in 1988, and the M.Sc. and Ph.D. degrees in computer and information science from the University of Pennsylvania, in 1989 and 1991, respectively. He is currently Dean of the School of Engineering at the University of Bridgeport, Connecticut; the

Founding Director of the Interdisciplinary Robotics, Intelligent Sensing, and Control (RISC) laboratory; a Professor of Computer Science, Computer Engineering, Electrical and Mechanical Engineering; and the Chair of the Prototyping Technical Committee of the IEEE Robotics and Automation Society. He was the Interim Chair of Computer Science and Computer Engineering and the Director of External Engineering Programs at the University of Bridgeport, Associate Professor of Computer Science and Computer Engineering at the University of Bridgeport from 1995–1999; Research Assistant Professor of Computer Science at the Department of Computer Science, University of Utah, from 1992–1995; Research Fellow at the General Robotics and Active Sensory Perception (GRASP) Laboratory of the University of Pennsylvania from 1989–1991; and Chair of the Discrete Event and Hybrid Systems Technical Committee of the IEEE Robotics and Automation Society from 1992–1999. His background is in the fields of computer science and engineering, control theory, robotics, automation, manufacturing, AI, computer vision, and signal processing. He has published over 100 journal and conference papers and book chapters in these and other areas. Dr. Sobh has been awarded many grants to pursue his research, and is a Licensed Professional Electrical Engineer (P.E.) and a Certified Manufacturing Engineer (CMfgE) by the Society of Manufacturing Engineers, a member of Tau Beta Pi (The Engineering Honor Society), Sigma Xi (The Scientific Research Society), Phi Beta Delta (The International Honor Society), and Upsilon Pi Epsilon (The Computing Honor Society). Dr. Sobh was the recipient of the 1998 Best Paper Award at the World Automation Congress Conference (WAC 98) in Anchorage, Alaska.

Raul C. Mihali received the B.Sc. and M.S. degrees in computer programming with honours in computer science and automatic control from the University of Bridgeport, USA, in 1999 and 2000, respectively. He is currently completing the Ph.D. in computer engineering at University of Bridgeport. He has published over 20 journal and conference papers and book chapters. His current research interests include CAD/CAM and active sensing under uncertainty, robots and electromechanical systems



prototyping, modelling and applications, mobile robotic manipulation, algorithms and programming techniques, stealth and security-oriented robots, polymorphic structures, and robot actuators and sensors for unusual execution tasks and self-manufacturing. In addition to his research work, Raul is a key development director at Divine Inc, a lead enterprise content integration and normalization company.

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