"Robot Phone Home"

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Abstract:

The College of Engineering and Technology at Northern Arizona University employs a sequence of four courses, known as Design4Practice, to provide increasing levels of design experience as students progress from freshmen to seniors. The sophomore level course in this sequence is based on a semester-long project to design, build, and test a computer-controlled electro-mechanical robot that performs some useful function, frequently with an environmental application. The system always consists of a fixed base station and a mobile robot. The base station consists of a computer, power supplies, and computer input/output interface circuitry. Since the inception of the course, an umbilical cable has been used to connect the robot to the base station; using a cable has allowed a simple design, but has imposed severe limitations on the functions that the robot can perform and restricts the distance between the robot and the base station.

In the fall 2002 semester, the umbilical cable was replaced with a wireless communication system, and the needed power sources were placed on-board the robot. Introducing wireless communications and the associated electronics into this course was a major challenge since the electrical engineering majors, and frequently the mechanical engineers and computer science and engineering majors, have completed a basic AC and DC circuits course, but few have completed a course in electronic devices and circuits. This challenge was made manageable by using a low-cost 900 MHz cordless telephone set to provide two-way data exchange between the base station and the robot. Cordless telephones are familiar to the students and provide a reasonable way to introduce the concepts of radio frequency transmission and reception, frequency modulation, and digital and analog information encoding. This paper describes how wireless technology was introduced into the course and how the students adapted to the new design challenges. Sufficient details are provided to allow this approach to be used by others that might be interested.

Engineering Design at Northern Arizona University:

Since its inception in 1994, the Design4Practice program[1,2,3] has undergone continuous evolution, gaining national recognition in 1999 when Northern Arizona University received the Boeing Outstanding Educator Award. A very instrumental course in this four-course design sequence is the sophomore level multidisciplinary course entitled "Engineering Design, The Process." Every semester, students from five engineering disciplines join together in teams to design a computer controlled, electro-mechanical, robotic device that performs some specific task. For the fall 2002 semester, the task required a robotic device that could navigate through sewer pipes, visually inspecting the pipes and testing the effluent for temperature, pH, and conductivity. Previously, the robotic devices in this class have been designed with an umbilical cable to carry power and control signals to the robot and to return sensor data to the controlling computer. The usually heavy and somewhat inflexible cable had always been a limiting factor in the range and maneuverability of the robot. The usual cable would not be satisfactory for the current project since the robot would need to navigate through a maze of pipes with up to two inches of flowing water, make numerous turns, and negotiate abrupt elevation changes of up to 18 inches. This was clearly the time to cut the cable and create a freely moving robot.

Wireless Communication Between the Robot and the Base Station:

All control and sensor data processing functions were to be performed in a desktop computer located at the base station. A radio frequency link was selected to provide two-way communication between three base stations and their associated robots. Some experimentation had been done previously using 900 MHz transmitter and receiver modules from Linx Technologies[4], but these had limited range and channel separation and required sharing of some frequencies between base station and robot pairs using time division multiplexing. A prototype system was assembled and tested, but was too complex for a sophomore level course and had marginal performance. Standard model radio control systems were considered, but these are not conveniently interfaced to a computer and do not provide two-way communications. The answer to our need turned out to be something most every student uses every day – a standard, 900 MHz cordless telephone. These units are very low cost ($20 to $30), have a range of up to 300 feet, provide 40 full-duplex two-way FM communications channels, and come with power supplies. Most importantly, sophomore students of all engineering majors can easily grasp the idea of the base station and the robot "talking" to each other.

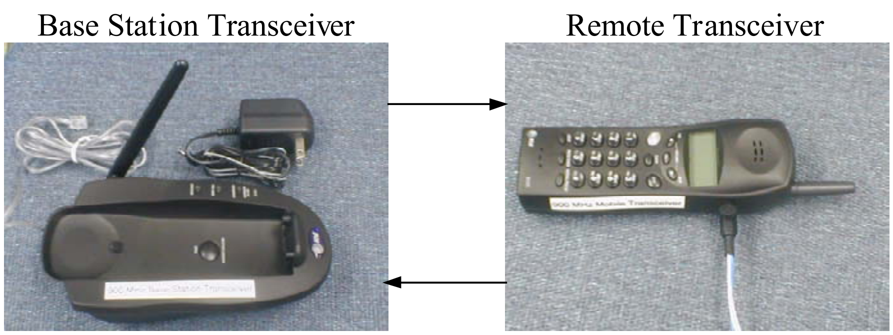

Figure 1: 900 MHz Communication Link

Wireless Data Formats:

Serial digital data was selected for conveying commands from the base station computer to the robot, but since all sensor data would be in analog form, it was decided to simply encode the information returned from the robot to the computer as a variable frequency tone using a voltage controlled oscillator. The base station and robot communication links are shown in Figures 2 and 3.

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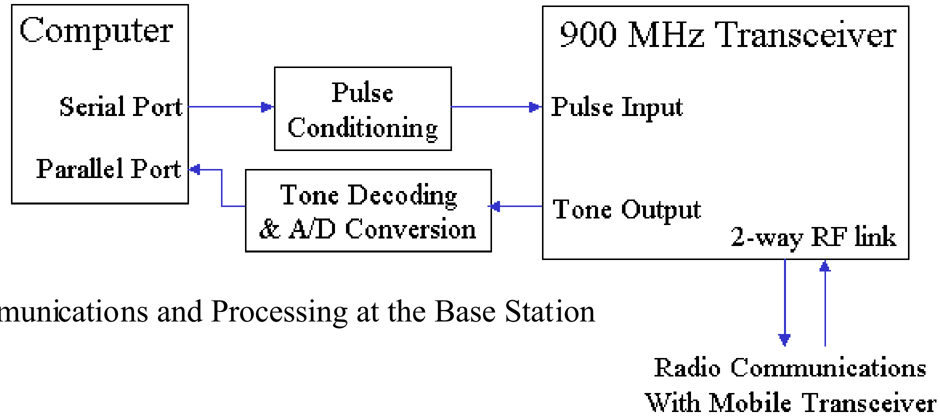

Figure 2: Communications and Processing at the Base Station

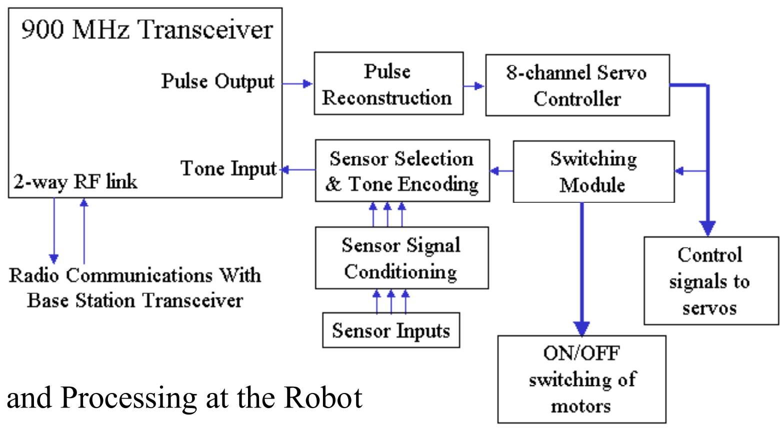

Figure 3: Communications and Processing at the Robot

Addressable Commands:

The heart of the serial digital data processing at the robot is a device called a Serial Servo Controller (SSC)[5] and is shown in Figure 4. This device accepts serial data input and provides pulse control output signals for 8 standard positioning servos of the type used in radio controlled model airplanes, boats, and cars. Motor speed controllers can also be connected to the SSC. Each SSC can be set to respond to 8 specific addresses, and multiple SSCs can be used to achieve up to 255 addressable channels of digital control. Figure 5 shows a representation of the functions performed by the SSC.

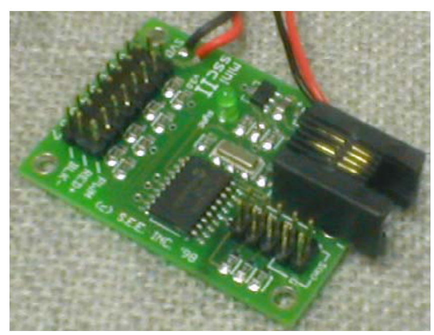

Figure 4: Serial Servo Controller

The signal at each of the SSC outputs is a variable width pulse intended to control positioning servos. Additional external circuitry is needed to convert the pulse signals to on/off or logic level voltages for controlling relays or interfacing with digital circuitry. An example of logic signal control was to select one of four analog sensor

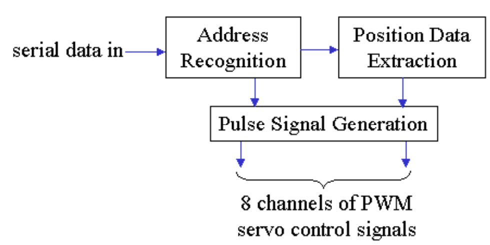

Figure 5: SSC Block Diagram

signals to be returned through the 900 MHz communication system to the base station computer.
Cordless Telephone Modifications:

The modifications to the 900 MHz cordless telephone were very simple. No modifications were required to the mobile handset; input and output signal connections were made through the headset connector on the side of the unit. Input signals to the telephone base unit were made through the normal two-wire telephone connector. In its standard configuration, the two-wire telephone connection is bi-directional, with both input and output signals sharing the same pair of wires; that is why you can hear your own voice in the receiver when you speak. To separate the input and output signals, an internal modification was required to route the received signal to a new output connector rather than merging it with the telephone input signal; this was easily accomplished by cutting one jumper wire on the main phone printed board and soldering two wires to output signal and ground connections on the board. These modifications are shown in Figure 6.

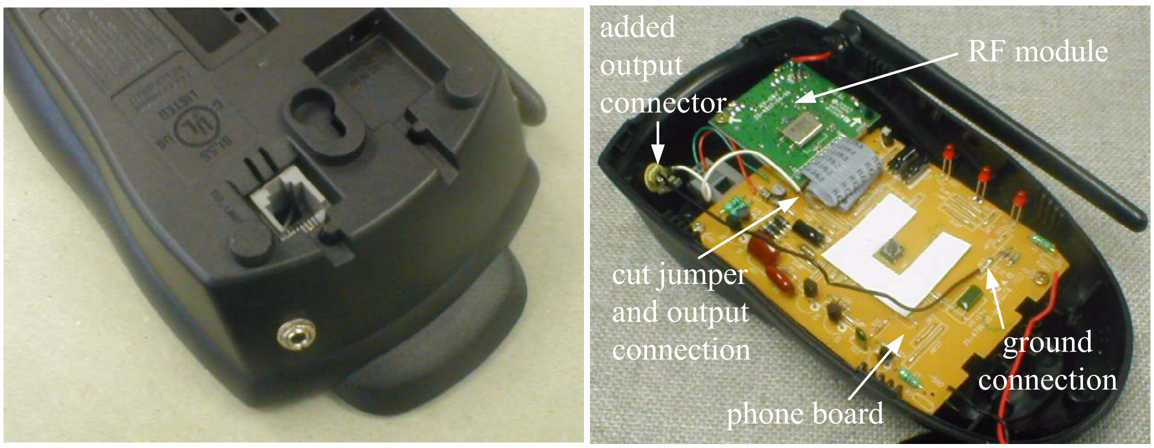

Figure 6: Cordless Phone Base Unit Modifications

Sending Digital Serial Data Through the Telephone:

Normally a modem is used to convert serial data digital pulses to sets of audio tones for transmission over telephone lines; another modem at the receiving end converts the received audio tones back to serial digital pulse signals. In the interest of simplicity, we did not use modems and just sent the pulse signal directly through the 900 MHz phone link. In order to do this, circuitry is needed to fool the telephone base unit into thinking it is connected to a phone line and to place the pulse signal on that simulated phone line. When received at the mobile handset, the pulse signal is rather distorted due to the limited bandwidth of the phone link, and it must be reconstructed by circuitry on the output. Figure 7 shows the phone line simulation and pulse conditioning circuit, while Figure 8 shows the pulse reconstruction circuit. Figure 9 shows the distorted digital pulse as received and after reconstruction. This system was able to communicate serial digital data at the rate of 2400 bits per second, or 2400 baud. Each serial character consists of 10 bits: one start bit, 8 data bits, and one stop bit; the resulting data communication rate is 240 data bytes per second, which is quite adequate for real time robot control.

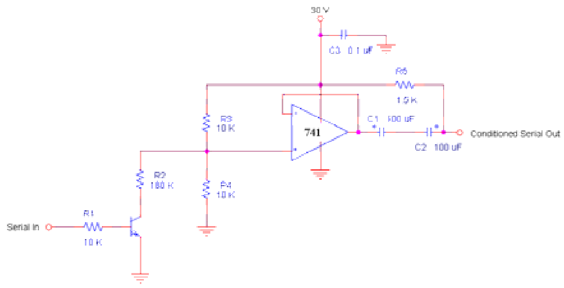

Figure 7: Telephone Line Simulation Circuit

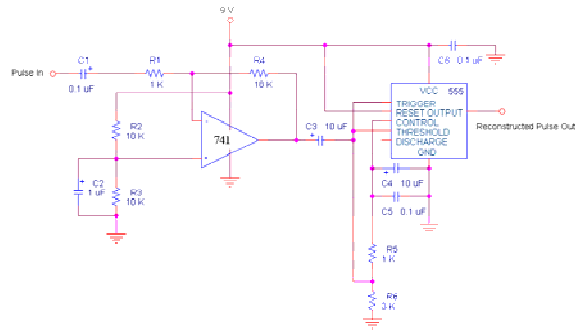

Figure 8: Pulse Reconstruction Circuit

The pulse reconstruction circuit functions as a Schmitt trigger, changing states only when the input signal exceeds the upper or lower threshold levels. Careful adjustment of the telephone handset output volume is required, but once set, it is stable and does not vary with RF signal strength because of the FM modulation method used by the cordless telephone.

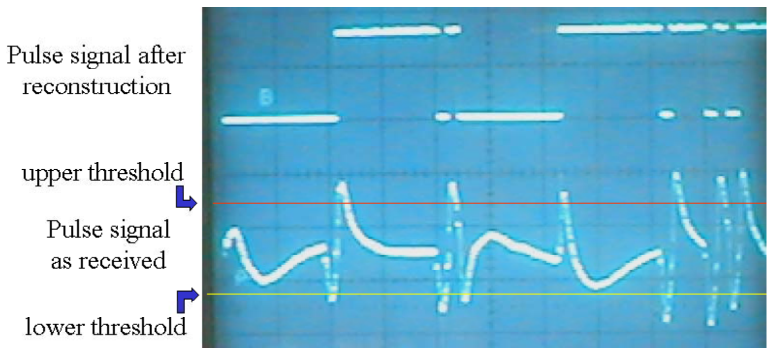

Figure 9: Distorted and Reconstructed Serial Data Pulses

Eyes and Ears for the Robot:

A wireless audio and video link was used to give the robot vision and allow the remote operator to inspect the inside of the pipes and manholes as the robot navigates through the simulated sewer system. The sound channel provided some information about the operating status of the robot, since running motors and servos could be heard. The small color video camera, 2.4 GHz transmitter, and receiver shown in Figure 10 were used.[6]

Figure 10: Wireless Camera System

The Navigation Challenge:

Navigating through the simulated sewer pipes presented little challenge, except for the flowing water that could be up to 2 inches deep in a 10 or 12 inch pipe. The pipes have a very slight slope

(¼ inch per foot), but are straight. The difficulty is encountered at manholes, where several pipes converge. The challenge presented to the design teams was to exit a sewer pipe level with the bottom of the manhole and continue into another pipe that enters the manhole 18 inches above the floor of the manhole. Three options were provided: 1) elevate the robot vertically 18 inches and enter the end of the pipe; or 2) slither up a 90° elbow connected a vertical 10 inch diameter riser, and then enter the main pipe via a tee; or 3) enter through a 45° elbow, climb a 10 inch diameter pipe inclined at 45°, and enter the main pipe through a wye connection. The three options are depicted in Figure 11.

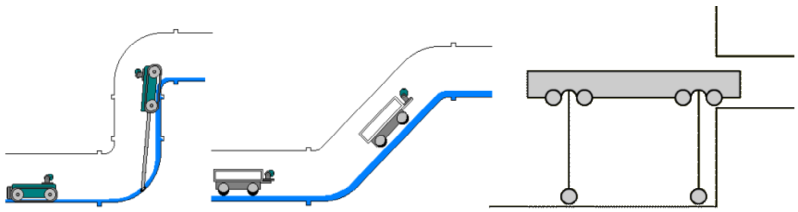

Figure 11: Three Options for Negotiating the 18 Inch Elevation change

Each of the three design teams selected a different approach to negotiating the elevation change. One team designed a twelve wheel vehicle that could jack itself up to the level of the pipe entrance, place its front wheels in the pipe, raise its front axel, move further into the pipe until the rear axel could be raised, and then proceed into the pipe. Implementation of this design was more of a challenge than the students were prepared for; the robot was very heavy and proved to be somewhat unstable when the axels were fully extended, but the team was able to demonstrate their concept and achieved partial success.

A second team opted for tracked robot that could expand to fit snugly against the walls of the pipe and slither up through the elbows and vertical riser. This design, as depicted in Figure 12, turned out to be a nightmare to implement mechanically, and the team was not able to complete their robot.

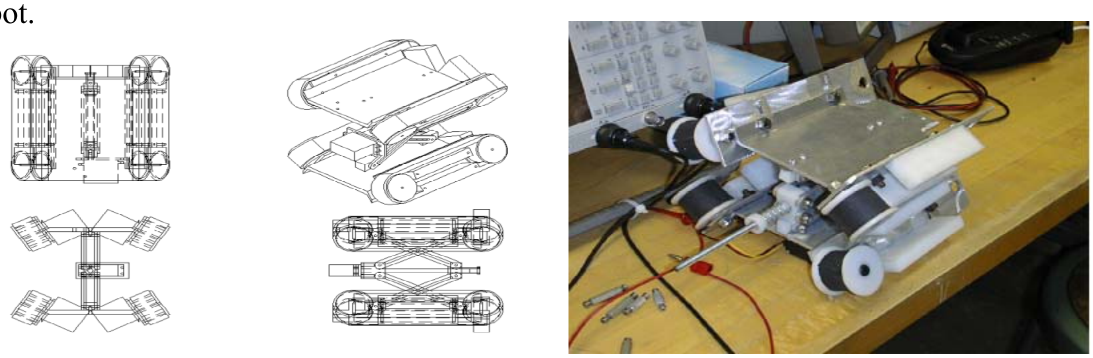

Figure 12: An Expandable, Tracked Robot

The third, and most successful, team selected the easiest path through the elevation change and created design that was much easier to build. That robot is shown in Figure 13. The housing is Plexiglas and the cordless telephone can be seen “stuffed” inside along with the batteries and all the control circuitry. The video camera with horizontal and vertical servos can be seen on the front of the robot. The sensors are mounted on a hinged arm beneath the robot and are hidden in the picture. The robot employed true four-wheel drive, using standard positioning servos modified for continuous rotation. The drive servos and wheels were angled to provide optimum contact with the walls of the sewer pipe and to elevate the servos above the water level. The students experimented with wheel materials and selected a material that had better traction when wet than when dry. In early testing using an external power source, the robot had no difficulty climbing a 45° slope. In the final demonstration, however, with partially discharged and somewhat heavy batteries, the robot could not quite make 45°.

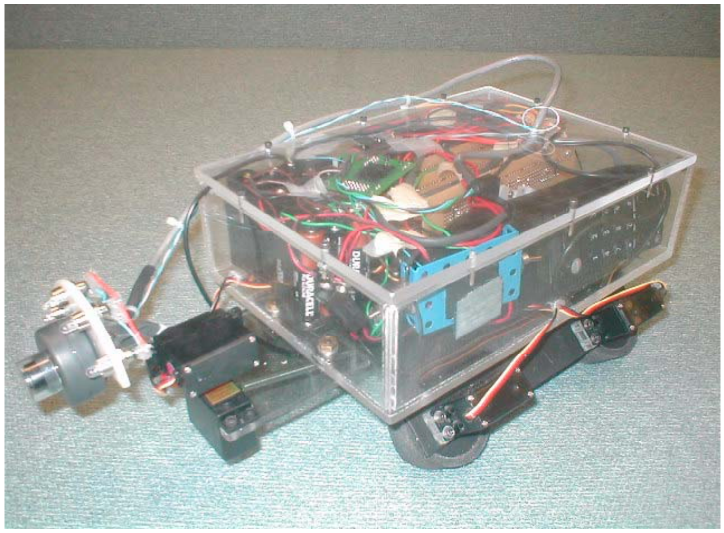

Figure 13: The Sewer Navigating, Wireless Robot

What is Success?

In this course, the design process is the main theme; whether the final product meets all the goals is not that important. In fact, students learn more when they encounter major problems than when everything goes just as planned. The teaching team considered all three teams to be successful, however, the students' perception is different. The students are much happier if their final product performs to all expectations and particularly if their design outperforms those of the other teams.

Would We Do It Again?

This project was probably the most challenging of all the projects in the history of the course. The mechanical challenge was too great, or maybe the students should have been given more encouragement to not select such complex designs. The electrical technology was quite advanced for students that had completed only a first course in electrical circuits; they were given considerable help in the design of the circuitry, but they had great difficulty finding and fixing problems in the assembled circuits.

Since this project, we have identified a potential replacement for the SSC, which was the heart of the addressable multi-channel digital control system. The

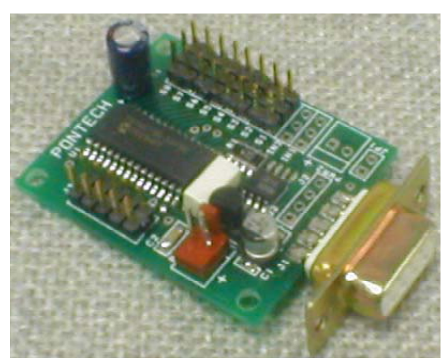

Figure 14: SV203 Servo Motor Controller

device we would consider using next time is a SV203 Servo Motor Controller,[7,8] as depicted in Figures 14 and 15.

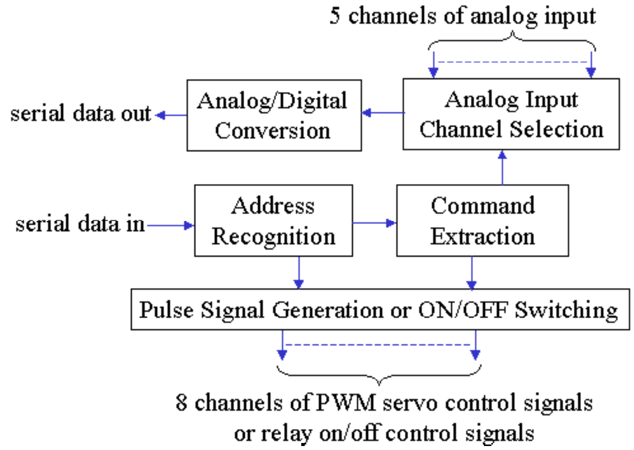

Figure 15: Block Diagram of the SV203 Controller

Similar to the SSC, the SV203 has 8 output channels for controlling positioning servos. However, these outputs can be configured as digital on/off signals. In addition, there is a five channel multiplexed analog to digital converter which would allow analog data to be sent from the robot back to the base station with no added conversion circuitry. Using this module would significantly reduce the complexity of the system as seen by the students. Another area to be explored would be to use two audio tones to represent the two binary states of the digital data communicated through the 900 MHz cordless telephone system; this might be less complex and less sensitive to adjustment than the pulse conditioning and reconstruction circuits.

Conclusion:

This project was a real learning experience for both the students and the teaching team. Using the 900 MHz cordless telephones was a low cost and effective way to achieve two-way wireless communication between the robot and the base station. Improvements and simplifications will be made for the next project, which involves a boat or amphibious vehicle that can navigate around a pond, make measurements at various depths, and retrieve a sample from the bottom.

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