Remote Sensing with GPS Sensor and Cellular Modem

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Abstract

In this paper, a remote sensing project is presented for a senior technical elective telecommunications course in the Electrical Engineering Technology Baccalaureate Program at Penn State Erie, The Behrend College. There are several noteworthy characteristics of this project. First, the project used a GPS sensor and a cellular telephone to allow GPS data to be accessed from the remote site. Second, it used LabVIEW as a graphical software development tool for automatically uploading data from the remote site, and downloading the data to a local site.

The remote site consisted of a dedicated laptop PC with one RS-232 port, interfaced alternately to the GPS sensor and the cellular telephone. LabVIEW software was designed to first read the data, such as position, speed, and direction, from the GPS sensor through a serial port. Then a cellular telephone, configured as a wireless modem, was connected to the serial port, and LabVIEW software was designed to automatically dial the local site to establish a communication link between the remote and local sites. Then the data was automatically uploaded from the remote site to the local site.

The local site consisted of a dedicated PC with an internal modem connected to a phone jack. Once the communication link between the local and remotes sites was established, LabVIEW software was designed to automatically download and display the data collected by the GPS sensor from the remote site. Also, control information was sent to the remote site to determine the number of data points to collect by the GPS sensor at the remote site for the next data collection iteration.

Results are shown to successfully demonstrate the remote collection and display of GPS data. Also, results from a student assessment form are presented. Conclusions regarding the educational benefits of using this design project within a baccalaureate EET program are shown.

I.   Introduction to the Project

A senior technical elective course in telecommunications is offered as part of the Baccalaureate degree in Electrical Engineering Technology at Penn State Erie, The Behrend College. There are two prerequisites for this course. The first prerequisite course is a junior level communications systems course which emphasizes an introduction to analog communication techniques. The second prerequisite course is a junior level measurements and instrumentation course which introduces LabVIEW.[1] LabVIEW is a graphical software programming language that was used for data acquisition. The senior telecommunications systems course emphasizes voice and data

communications techniques. There are approximately seven laboratory experiments covered within this course. Each of the experiments utilizes LabVIEW and typically requires two weeks to complete. As part of the course requirements, students complete a group project in place of taking a final exam. Students select the team members and the project. Four team members chose to work on this remote sensing project.

A detailed listing of the requirements for this project is shown below.
- Automatic collection and display of remote GPS data including position (latitude, longitude, altitude), speed, direction, and time (hour, minute, second) using a GPS sensor and a cellular telephone.
- Software development using LabVIEW.
- Oral presentation of results.
- Demonstration of results.
- Report documenting results.

The overall project grade was worth 20% of the final grade for the course. The oral presentation was worth 50% of the project grade and the demonstration of the project and report were worth 50% of the project grade.

The design for the project consisted of a remote site and a local site, interfaced together through the telephone network, as shown in Figure 1. The remote site consisted of a laptop PC with one RS-232 port, which was used to interface alternately to the GPS sensor and the cellular telephone. The program first read data, including position, speed, and direction, from the GPS sensor through the serial port and temporarily stored the information. Then a cellular telephone, configured as a wireless modem, was connected to the same serial port. Software was designed to automatically dial the modem at the local site to establish a communication link between the remote and local sites. Then the information was automatically uploaded from the remote site to the local site.

The local site consisted of a PC with a modem connected to a phone jack. Once the communication link was established between the local and remotes sites, software was designed to automatically download and display the data collected by the GPS sensor from the remote site. Also, control information was sent to the remote site in order to determine the number of data points to collect by the GPS sensor at the remote site for the next data collection iteration.

GPS Satellites

Local Computer

GPS receiver

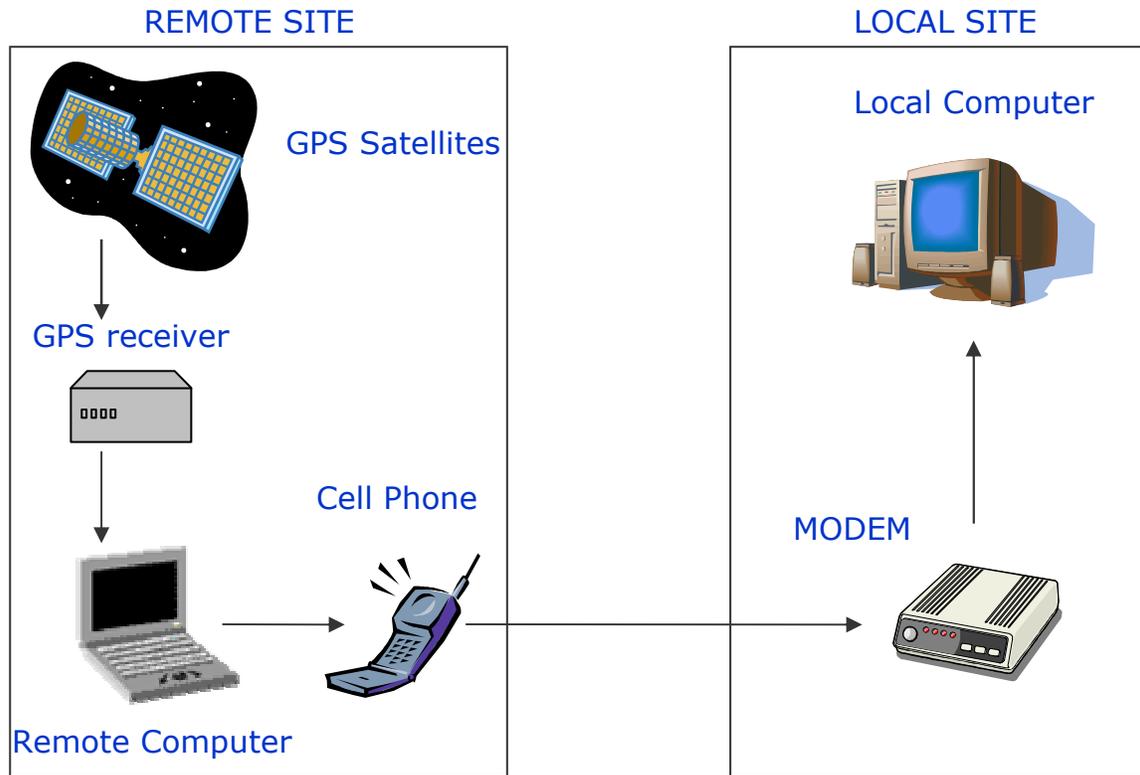Cell Phone

MODEM

Remote Computer

Figure 1. Project Block Diagram

II.   Introduction to GPS

The NAVSTAR system (Navigation Satellite Timing and Ranging) is the official U.S. Department of Defense name for GPS (Global Positioning System). There are three segments of the GPS system: a space segment (satellites), a control segment (ground stations), and a user segment (GPS receiver).

The space segment consists of at least 24 satellites that are arranged in their orbits, approximately 12,000 miles above the Earth's surface, so that a GPS receiver can receive a signal from at least four of them simultaneously. Each satellite transmits low power, approximately 20-50 watts, on several frequencies. Civilian GPS receivers "listen" at a frequency of 1575.42 MHz in the UHF band. The control segment tracks the satellites and provides them with corrected orbital and clock information.

The GPS receiver picks up three kinds of coded information from each satellite. The first is a pseudo-random code that is simply identification for the specific satellite. The second is called "almanac" data and contains the approximate position of each satellite. This data is continuously transmitted and stored in the GPS receiver so that it knows where each satellite is supposed to be. The third is called "ephemeris" data and contains the corrected orbital information about each satellite. Together, the "almanac" and "ephemeris" data provide the GPS receiver with the position of each satellite.

The distance between the GPS receiver and each satellite is determined by measuring time. The GPS receiver compares the pseudo-random code it receives from the satellite with the same pseudo-random code it generates. Based upon the time shift between the two codes, the GPS receiver automatically calculates distance.

Once the satellite position and distance are determined, the GPS receiver can calculate its position. If at least four satellites are used, the three-dimensional position (latitude, longitude, and altitude) of the GPS receiver is found.[2]

III.   GPS Sensor

The GPS sensor that was used in this project was a Garmin sensor.[3] An external GPS antenna was also connected to the sensor.[4] Detailed information about the sensor can be found within the technical specifications.[5] The GPS sensor is WAAS (Wide Area Augmentation System) enabled. WAAS capable systems provide potential position accuracy within three meters, 95% of the time.[2] They are able to determine such a precise orientation by using 25 ground reference stations in the United States. Each reference station is linked to a master station, which determines and broadcasts a correction message. This message accounts for satellite orbit and clock drift errors caused by the atmosphere. The message that is transmitted is compatible with the basic GPS signal structure; therefore no added decoding is necessary.

Additional features regarding this sensor are shown below.
- 12-channel GPS receiver tracks and uses up to 12 satellites for determining position.
- User initialization is not required. Once installed, it will automatically transmit data every second continuously.
- Flexible input voltage levels of 3.3 to 5.0 V DC with 100mA peak current.

III.A   Hardware interfacing Requirements

The following section provides information about the electrical interface characteristics of the sensor.
- True RS-232 compatibility for the input and output pins on the COM 1 port.
- Standard null modem configuration required with no hardware handshaking connections.
- DC voltage on power input pin.
- Default bit rate of 4800 bps with no parity bit and 2 stop bits. User selectable bit rates (300, 600, 1200, 2400, 4800, 9600, 19200, 38400).

III.B   Software interfacing Requirements

The interface protocol is based on NMEA (National Marine Electronic Association) 0183 ASCII interface specification.[6]
- Sentence start delimiter is the character "$" and the termination delimiter is the carriage return and line feed (<CR><LF>).
- The checksum *hh is used for parity checking and is included just prior to the <CR><LF> characters. The parity bytes (hh) are the ASCII representation of the exclusive-or sum of all the characters between the "$" and "*" characters, non-inclusive.

- ASCII output sentences are:
    - GPALM (GPS Almanac Data)
    - GPGGA (GPS Fix Data)
    - GPGLL (Geographic Position)
    - GPGSA (GPS Dilution of Precision and Active Satellites)
    - GPGSV (GPS Satellites in View)
    - GPRMC (Recommended Minimum Specific GPS/TRANSIT Data)
    - GPVTG (Track Made Good and Ground Speed)

Two output sentences were used for this project: GPGGA and GPRMC.

III.B.1 Global Positioning System Fix Data (GPGGA)

The format for the sentence structure is shown below.
$GPGGA,<1>,<2>,<3>,<4>,<5>,<6>,<7>,<8>,<9>,M,<10>,M,<11>,<12>*hh<CR><LF>

Table 1 lists the information contained within the sentence structure format.

Table 1. Sentence structure format description for GPGGA

Reference	Description
<1>	UTC time of position fix, hhmmss format
<2>	Latitude, ddmm.mmmm format (leading zeros will be transmitted)
<3>	Latitude hemisphere, N or S
<4>	Longitude, dddmm.mmmm format (leading zeros will be transmitted)
<5>	Longitude hemisphere, E or W
<6>	GPS quality indicator, 0=Fix not available, 1=Non-differential GPS fix available, 2=Differential GPS (DGPS) fix available, 6=Estimated
<7>	Number of satellites in use, 00 to 12 (leading zeros will be transmitted)
<8>	Horizontal dilution of precision, 0.5 to 99.9
<9>	Antenna height above/below mean sea level, -9999.9 to 99999.9 meters
<10>	Geoidal height, -999.9 to 9999.9 meters
<11>	Differential GPS (RTCM SC-104) data age, number of seconds since last valid RTCM transmission (null if not an RTCM DGPS fix)
<12>	Differential Reference Station ID, 0000 to 1023 (leading zeros will be transmitted, null if not an RTCM DGPS fix)

III.B.2 Recommended Minimum Specific GPS/TRANSIT Data (GPRMC)

The format for the sentence structure is shown below.
$GPRMC,<1>,<2>,<3>,<4>,<5>,<6>,<7>,<8>,<9>,<10>,<11>,<12>*hh<CR><LF>

Table 2 lists the information contained within the sentence structure format.

Table 2. Sentence structure format description for GPRMC

Reference	Description
<1>	UTC time of position fix, hhmmss format
<2>	Status, A=Valid position, V=NAV receiver warning
<3>	Latitude, ddmm.mmmm format (leading zeros will be transmitted)
<4>	Latitude hemisphere, N or S
<5>	Longitude, dddmm.mmmm format (leading zeros will be transmitted)
<6>	Longitude hemisphere, E or W
<7>	Speed over ground, 000.0 to 999.9 knots (leading zeros will be transmitted)
<8>	Course over ground, 000.0 to 359.9 degrees, true (leading zeros will be transmitted)
<9>	UTC date of position fix, ddmmyy format
<10>	Magnetic variation, 000.0 to 180.0 degrees (leading zeros will be transmitted)
<11>	Magnetic variation direction, E or W (westerly variation adds to true course)
<12>	Mode indicator (only output if NMEA 0183 version 3.00 active), A=Autonomous, D=Differential, E=Estimated, N=Data not valid

IV.   Cellular Telephone

A Motorola V120C cellular telephone was connected to the RS-232 port of the remote PC. In order to interface the cellular telephone to the PC, a Motorola serial data connectivity kit was required. The cellular telephone was utilized as a wireless modem to upload the data collected by the GPS sensor to the local PC. A detailed listing of the AT command set for data communication over the telephone network is available for reference.[7,8,9]

Table 3 lists the AT commands used with the cellular telephone for this project.

Table 3. AT Commands used for the Cellular Telephone

AT commands	Description
at+gmi	Manufacturer
at+gmm	Model
at+cad	Service Type, 0=No service, 1=CDMA, 2=TDMA, 3=Analog
at+csq	Signal Quality Measure, 0=weakest, 31=strongest
at+cbc	Battery Charge, Percent of battery remaining
at&fdt	Set to factory-defined configuration, Dial tone
+++	Escape sequence to return to command mode
ath0	Hang-up

V.   Remote LabVIEW program

The LabVIEW program at the remote site was designed to first read the GPS sensor data from the RS-232 port. Then the software was designed to read data from the cellular telephone after it

is connected to the same RS-232 port. The software dialed the local site and automatically uploaded the complete information. A flowchart for the program is shown in Figure 2.

```
          ┌─────────┐
          │  Start  │
          └────┬────┘
               │      ┌──────────────────────────────────────────────┐
               │      │                                              │
    ┌──────────▼──────────┐   ┌──────────────────┐      ┌──────────────────────┐
    │ Initialize Serial   │   │ Reinitialize     │      │ Hang-up Cellular     │
    │ Port                │   │ Serial Port      │      │ Telephone            │
    └──────────┬──────────┘   └────────┬─────────┘      └──────────┬───────────┘
               │                       │                           │
    ┌──────────▼──────────┐   ┌────────▼─────────┐      ┌──────────▼───────────┐
    │ Connect GPS         │   │ Collect Cellular │      │ Close Serial Port    │
    │ Receiver            │   │ Telephone Data   │      │                      │
    └──────────┬──────────┘   └────────┬─────────┘      └──────────┬───────────┘
               │                       │                           │
    ┌──────────▼──────────┐   ┌────────▼─────────┐             ◇ Re-loop ◇── YES
    │ Collect GPS Data    │   │ Dial Local Modem │                 │
    └──────────┬──────────┘   └────────┬─────────┘                NO
               │                       │                           │
    ┌──────────▼──────────┐   ┌────────▼─────────┐            ┌─────▼─────┐
    │ Close Serial Port   │   │ Upload GPS and   │            │   Stop    │
    └──────────┬──────────┘   │ Cell Phone Data  │            └───────────┘
               │              └────────┬─────────┘
    ┌──────────▼──────────┐   ┌────────▼─────────┐
    │ Connect Cellular    │   │ Receive Control  │
    │ Telephone           │   │ Information      │
    └─────────────────────┘   └──────────────────┘
```
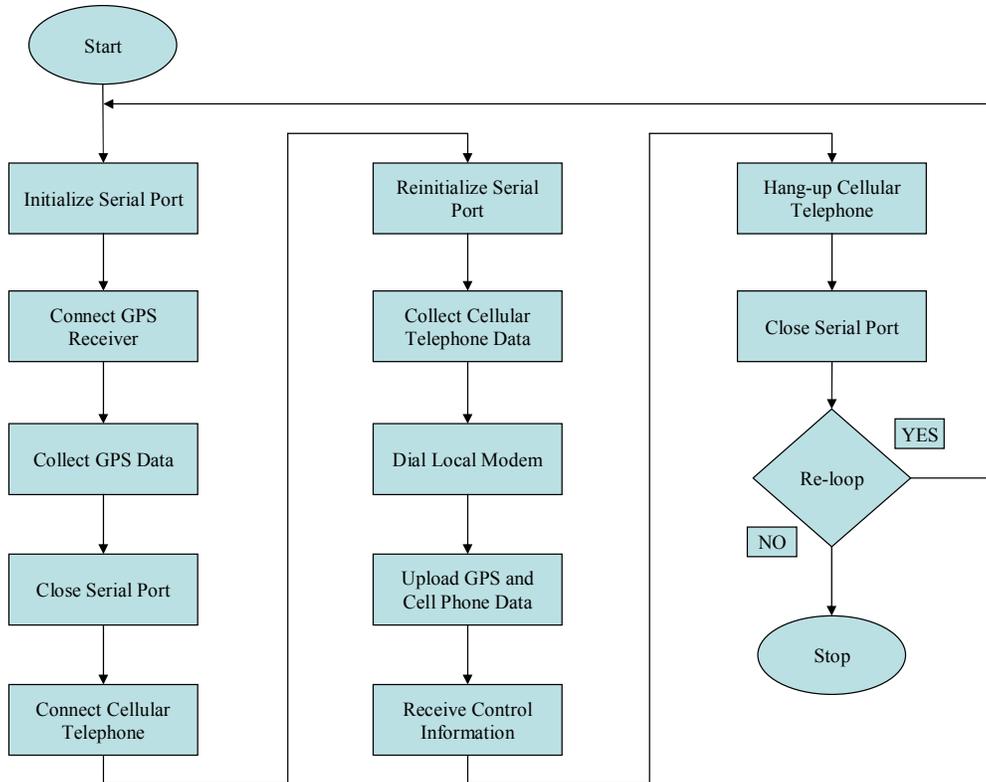
Figure 2. Remote LabVIEW Program

VI.   Local LabVIEW Program

The LabVIEW program at the local site was designed to download and display the data collected at the remote site by the GPS sensor and the cellular telephone. Also, the software sent control information back to the remote site to control the amount of data obtained by the GPS sensor during the next data collection iteration. A flowchart for the LabVIEW program is shown in Figure 3.
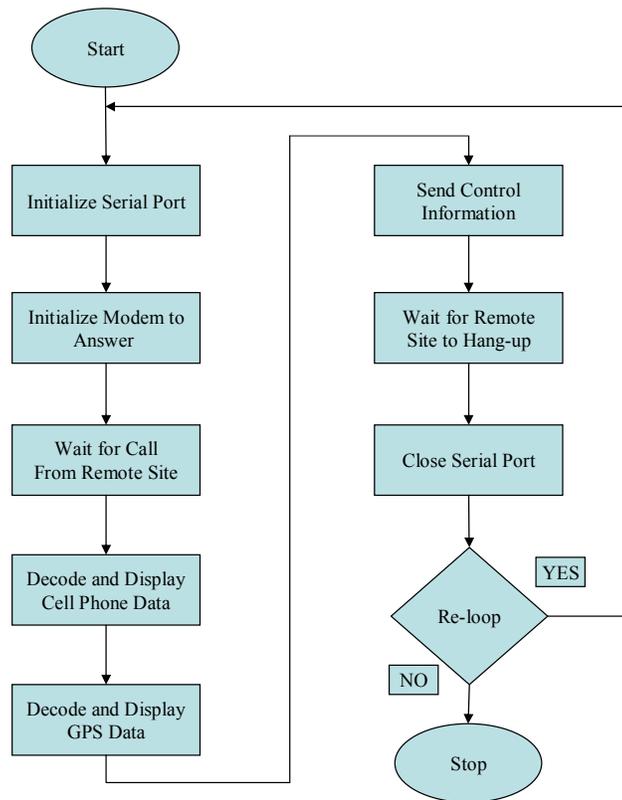
Figure 3. Local LabVIEW Program

VII.   Results

Results were taken while the GPS receiver and cellular telephone were connected to a laptop PC placed within a moving vehicle. The local site was within a laboratory facility on campus. The results shown are images of portions of the front panels of the LabVIEW programs.

The students on this project were asked to assess the quality of the project. Results from this assessment form are also presented.

VII.A LabVIEW Results

In Figure 4, a portion of the front panel for the Remote LabVIEW program is shown. In this figure, a sample of data obtained from the GPS receiver is presented. Interpretation of the results is based upon Tables 1 and 2. Figure 5 contains data from the cellular telephone and the GPS sensor that was automatically downloaded to the local site. The data from the cellular telephone was decoded and displayed in various indicators in Figure 6. The GPS data was also decoded and displayed in a spreadsheet format. A portion of this data is shown in Figure 7. In Figure 8, statistical analysis of some of the GPS data is presented. Finally, the latitude and longitude

coordinates of the GPS receiver were plotted on a digital image of Erie County. This map is shown in Figure 9.
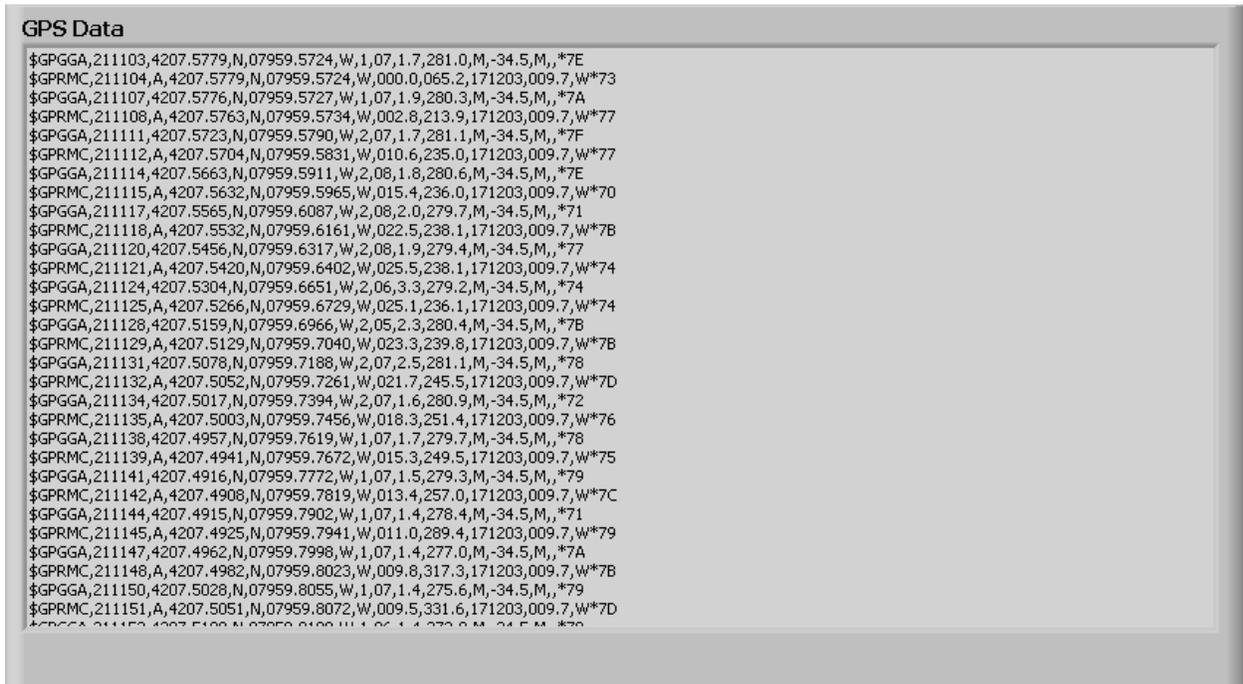
GPS Data
```
$GPGGA,211103,4207.5779,N,07959.5724,W,1,07,1.7,281.0,M,-34.5,M,,*7E
$GPRMC,211104,A,4207.5779,N,07959.5724,W,000.0,065.2,171203,009.7,W*73
$GPGGA,211107,4207.5776,N,07959.5727,W,1,07,1.9,280.3,M,-34.5,M,,*7A
$GPRMC,211108,A,4207.5763,N,07959.5734,W,002.8,213.9,171203,009.7,W*77
$GPGGA,211111,4207.5723,N,07959.5790,W,2,07,1.7,281.1,M,-34.5,M,,*7F
$GPRMC,211112,A,4207.5704,N,07959.5831,W,010.6,235.0,171203,009.7,W*77
$GPGGA,211114,4207.5663,N,07959.5911,W,2,08,1.8,280.6,M,-34.5,M,,*7E
$GPRMC,211115,A,4207.5632,N,07959.5965,W,015.4,236.0,171203,009.7,W*70
$GPGGA,211117,4207.5565,N,07959.6087,W,2,08,2.0,279.7,M,-34.5,M,,*71
$GPRMC,211118,A,4207.5532,N,07959.6161,W,022.5,238.1,171203,009.7,W*7B
$GPGGA,211120,4207.5456,N,07959.6317,W,2,08,1.9,279.4,M,-34.5,M,,*77
$GPRMC,211121,A,4207.5420,N,07959.6402,W,025.5,238.1,171203,009.7,W*74
$GPGGA,211124,4207.5304,N,07959.6651,W,2,06,3.3,279.2,M,-34.5,M,,*74
$GPRMC,211125,A,4207.5266,N,07959.6729,W,025.1,236.1,171203,009.7,W*74
$GPGGA,211128,4207.5159,N,07959.6966,W,2,05,2.3,280.4,M,-34.5,M,,*7B
$GPRMC,211129,A,4207.5129,N,07959.7040,W,023.3,239.8,171203,009.7,W*7B
$GPGGA,211131,4207.5078,N,07959.7188,W,2,07,2.5,281.1,M,-34.5,M,,*78
$GPRMC,211132,A,4207.5052,N,07959.7261,W,021.7,245.5,171203,009.7,W*7D
$GPGGA,211134,4207.5017,N,07959.7394,W,2,07,1.6,280.9,M,-34.5,M,,*72
$GPRMC,211135,A,4207.5003,N,07959.7456,W,018.3,251.4,171203,009.7,W*76
$GPGGA,211138,4207.4957,N,07959.7619,W,1,07,1.7,279.7,M,-34.5,M,,*78
$GPRMC,211139,A,4207.4941,N,07959.7672,W,015.3,249.5,171203,009.7,W*75
$GPGGA,211141,4207.4916,N,07959.7772,W,1,07,1.5,279.3,M,-34.5,M,,*79
$GPRMC,211142,A,4207.4908,N,07959.7819,W,013.4,257.0,171203,009.7,W*7C
$GPGGA,211144,4207.4915,N,07959.7902,W,1,07,1.4,278.4,M,-34.5,M,,*71
$GPRMC,211145,A,4207.4925,N,07959.7941,W,011.0,289.4,171203,009.7,W*79
$GPGGA,211147,4207.4962,N,07959.7998,W,1,07,1.4,277.0,M,-34.5,M,,*7A
$GPRMC,211148,A,4207.4982,N,07959.8023,W,009.8,317.3,171203,009.7,W*7B
$GPGGA,211150,4207.5028,N,07959.8055,W,1,07,1.4,275.6,M,-34.5,M,,*79
$GPRMC,211151,A,4207.5051,N,07959.8072,W,009.5,331.6,171203,009.7,W*7D
```

Figure 4. GPS Data Collected at Remote Site

Data Sent
```
CELL_INFOMotorola CE, Copyright 2000&Motorola CDMA 707 Modem&1&0,99&0,60&$GPGGA,211103,4207.5779,
N,07959.5724,W,1,07,1.7,281.0,M,-34.5,M,,*7E
$GPRMC,211104,A,4207.5779,N,07959.5724,W,000.0,065.2,171203,009.7,W*73
$GPGGA,211107,4207.5776,N,07959.5727,W,1,07,1.9,280.3,M,-34.5,M,,*7A
$GPRMC,211108,A,4207.5763,N,07959.5734,W,002.8,213.9,171203,009.7,W*77
$GPGGA,211111,4207.5723,N,07959.5790,W,2,07,1.7,281.1,M,-34.5,M,,*7F
$GPRMC,211112,A,4207.5704,N,07959.5831,W,010.6,235.0,171203,009.7,W*77
$GPGGA,211114,4207.5663,N,07959.5911,W,2,08,1.8,280.6,M,-34.5,M,,*7E
```
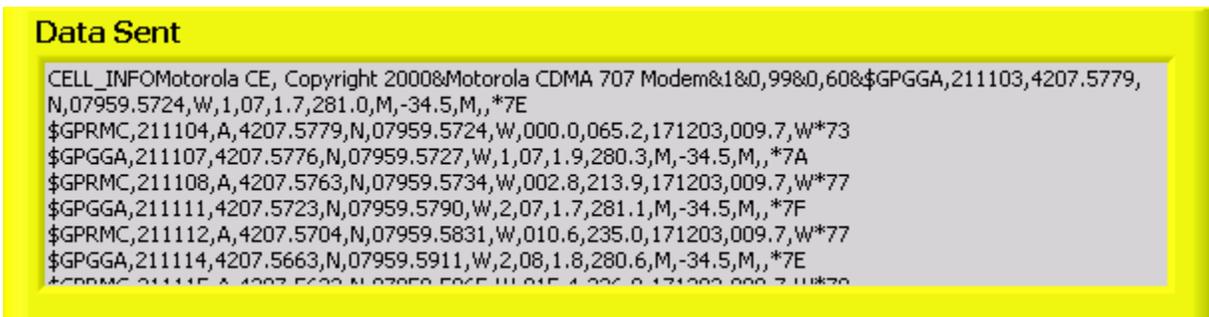
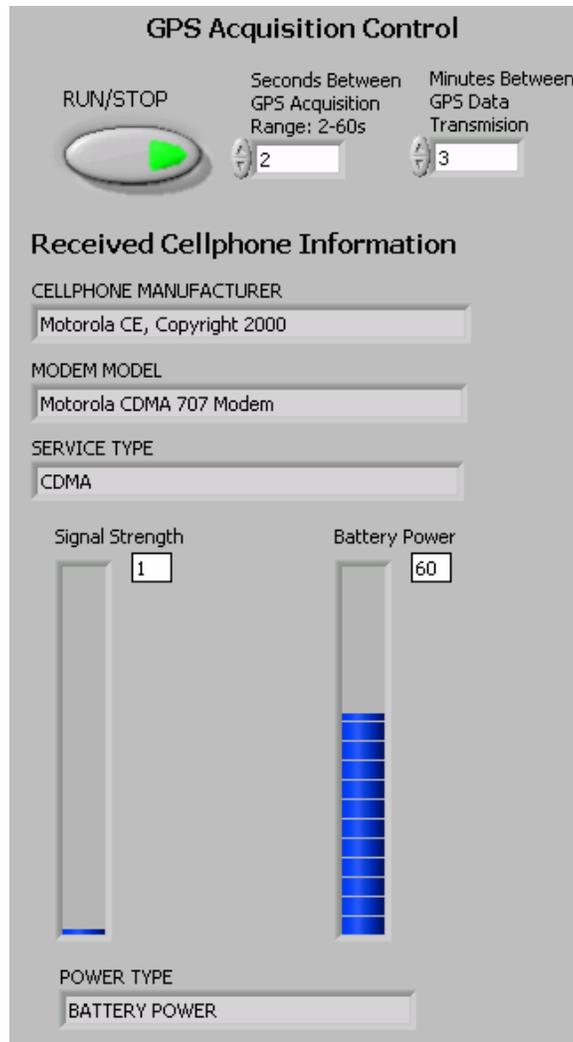Figure 5. Data Received at Local Site

Figure 6. Displayed Cellular Telephone Data at Local Site

Data Spreadsheet

	Time	Hemisphere	Hemisphere	Altitude	Number Of Satellites Used
0	Standard Time 9 : 11 : 2 PM	North	West	281.000000	7
0	Standard Time 9 : 11 : 7 PM	North	West	280.300000	7
	Standard Time 9 : 11 : 11 PM	North	West	281.100000	7
	Standard Time 9 : 11 : 13 PM	North	West	280.600000	8
	Standard Time 9 : 11 : 16 PM	North	West	279.700000	8
	Standard Time 9 : 11 : 19 PM	North	West	279.400000	8
	Standard Time 9 : 11 : 24 PM	North	West	279.200000	6
	Standard Time 9 : 11 : 28 PM	North	West	280.400000	5
	Standard Time 9 : 11 : 30 PM	North	West	281.100000	7
	Standard Time 9 : 11 : 33 PM	North	West	280.900000	7
	Standard Time 9 : 11 : 38 PM	North	West	279.700000	7
	Standard Time 9 : 11 : 41 PM	North	West	279.300000	7
	Standard Time 9 : 11 : 43 PM	North	West	278.400000	7
	Standard Time 9 : 11 : 46 PM	North	West	277.000000	7
	Standard Time 9 : 11 : 49 PM	North	West	275.600000	7
	Standard Time 9 : 11 : 53 PM	North	West	273.900000	6

Figure 7. Select Portion of GPS Data Displayed at Local Site

Statistics

Max Speed	Max Number Of Satellites	Max Altitude
28.80	8	281.10
Min Speed	**Min Number Of Satellites**	**Min Altitude**
0.00	4	261.60
Average Speed	**Ave Number Of Satellites**	**Average Altitude**
11.46	7	272.78

Figure 8. Statistical Analysis of GPS Data at Local Site

Figure 9. Vehicle Location Map Displayed at Local Site

VII.B   Student Assessment Results

Each of the four members of the team was asked to complete an assessment form to evaluate this project. Table 4 includes the questions asked on the form and the responses from the students.

Table 4. Student Assessment Results

Question	Response
Approximate time in hours you worked on this project	10-20 → 1 student 20-30 → 1 student 30-40 → 1 student >50 → 1 student
Level of Difficulty	Very hard → 1 student hard → 2 students Moderate → 1 student
Areas of Difficulty	GPS Sensor → 1 student Cell Phone → 4 students Software → 1 student Map → 1 student (2 students choose multiple areas of difficulty)
Appropriateness of Project for the Telecommunications Course	Excellent → 4 students
The Number of Students on This Project for the Level of Effort Required	About Right → 4 students
Level of Interest in GPS and Cell Phone Technology as a Result of This Project	Significantly Improved → 2 students Improved → 2 students
Suggestions for Improvement	(Nothing mentioned)
Other Comments	Very good project to learn about cell phone and GPS technology. (No other comments provided)

VIII.   Conclusions

In this project, results were shown to successfully demonstrate a remote sensing application using a GPS sensor and a cellular telephone. Also, LabVIEW was used as the programming environment for implementing the software requirements.

Results from the student assessment form were very favorable. Each student felt that this was an excellent project for the course, and their level of interest in GPS and cell phone technology either improved or significantly improved as a result of this project.

Most students also agreed that this project was either hard or very hard, with the cellular telephone as the primary area of difficulty. One area of improvement would be to discuss data communications using the cellular telephone as an introductory topic within the telecommunications systems course. This would help to reduce the level of difficulty as well as the time required for the students to complete this project.

One potential change for this project would be to replace the laptop PC at the remote site with a microcontroller that has multiple serial ports and a display. Software development could be achieved by using assembly language or a higher-level programming language. This would

potentially enhance the portability of the equipment at the remote site and also integrate material from more courses into this project.

This project could also be expanded into a capstone design project by integrating the remote GPS sensor with remote data collection systems. This application would include collecting data from various sensors in mobile systems. The cellular modem would allow both GPS data and data from other sensors to be accessed at remote sites.

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4.   GARMIN International, Inc., Garmin GA27C Low Profile GPS Antenna, Part # 010-10052-05.
5.   GPS 15H & 15L Technical Specifications, web page
     http://www.garmin.com/manuals/237_TechnicalSpecifications.pdf.
6.   Web page http://www.nmea.org/pub0183/index.html.
7.   Web page http://www.globalvillage.com/support/pdfs/TelePort_K56_AT_Commands.pdf.
8.   Web page http://ridge.trideja.com/wireless/atcommands/.
9.   International Telecommunication Union, Telecommunication Standardization Sector (ITU-T)
     Recommendations, Series V.250, Data Communication over the Telephone Network, web page
     http://www.itu.int/rec/recommendation.asp?type=folders&lang=e&parent=T-REC-V.250.

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David R. Loker received the M.S.E.E. degree from Syracuse University in 1986. In 1984, he joined General Electric (GE) Company, AESD, as a design engineer. In 1988, he joined the faculty at Penn State Erie, The Behrend College, in the Electrical Engineering Technology program. His research interests include PC-based control systems, communication systems, and instrumentation systems.

RONALD P. KRAHE
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