Low Cost Soil Moisture Monitoring System: A Capstone Design Project

Jeng-Nan Juang and R. Radharamanan
School of Engineering, Mercer University, Macon, GA 31207
junag_jn@mercer.edu; radharaman_r@mercer.edu

Session: 6

Abstract

Environmental monitoring is a significant driver for wireless sensor communication. Its potential to provide dynamic real-time data about monitored variable will enable to measure properties that have not previously been observable. A low cost consumer version soil moisture monitoring system was built using a gypsum block to take moisture readings, a peripheral interface controller (PIC) with a built-in transmitter as sensing unit, and a transmitter for wireless communication. The design of the overall system is based on: the system must provide consistent soil moisture measurements at low cost; the system must interface with an irrigation system to allow for automatic watering of the soil; and the measurement units must be unobtrusive to everyday activity. The system was tested so that it could be implemented with existing sprinkler systems. This system would conserve more water than the traditional timers that are in place on most irrigation systems today. In cases where the homeowner or user does a large amount of watering, there can be a substantial savings in water consumption with the low cost soil moisture monitoring system. While the prototype realizes all the goals that were set forth, the addition of other options would be beneficial to the marketability of the system. One option should be the implementation of other sensors such as a barometer and temperature sensor. These will allow the microcontroller to determine more accurately the optimum watering times. Also, reverting back to the original design that used a PIC with an integrated transmitter would reduce both the cost and the size of the sensing unit. While the current implementation works, a more user friendly interface, such as a PC interface, might be more desirable for some users.

Introduction

Environmental monitoring is a significant driver for wireless sensor communication. Its potential to provide dynamic real-time data about monitored variable will enable to measure properties that have not previously been observable. However, there are significant problems to be overcome to implement this concept in working systems. This paper describes a PC controlled irrigation monitoring and controlling system with wireless sensor communication. The design of the overall system is based on: the system must provide consistent soil moisture measurements at low cost; the system must interface with an irrigation system to allow for automatic watering of the soil; and the measurement units must be unobtrusive to everyday activity. Research performed to determine the feasibility of a moisture monitoring system indicated that the cost of similar systems was astronomical, due to their typical use in commercial applications. It was determined that a lower cost consumer version should be available that could be implemented with existing sprinkler systems. This system would conserve more water than the traditional timers that are commonly used on most irrigation systems today. The timer will always water the garden or lawn at a predetermined time, regardless of the current moisture content in the soil. It can also contribute to the poor health of plants and grass, from over watering. There can be a substantial savings in water consumption using the developed soil moisture monitoring system in cases where the homeowner or user does a large amount of watering [1].

Methods and Materials

A. Sensor Unit:

1. Sensor: The analysis indicated that the gypsum block is a viable choice to take soil moisture readings. The gypsum block, shown in Figure 1, is a cylindrical block of gypsum in which two electrodes are inserted. The gypsum is porous and allows water to move in and out of the block as the soil wets and dries. When the block is excited electrically, ions move to the respective electrodes establishing an effective block resistance. A greater amount of water in the block equals more ions and a lower resistance to electrical current flow. Based on documentation provided by the manufacturer of the gypsum block, it was decided that an oscillator circuit should be used to prevent polarization. The signal generated by the oscillator was used in conjunction with a voltage divider to obtain measurements from the sensor. As the effective resistance of the sensor increased, the voltage across the limiting resistor in the voltage divider circuit decreased. During testing, it was determined that this was not a viable method for reading the sensor. The gypsum block sensor acts like a variable resistor for a specific frequency. However, the range of this resistance was too great to use a single frequency. It was determined to be too difficult to have a variable frequency oscillator.

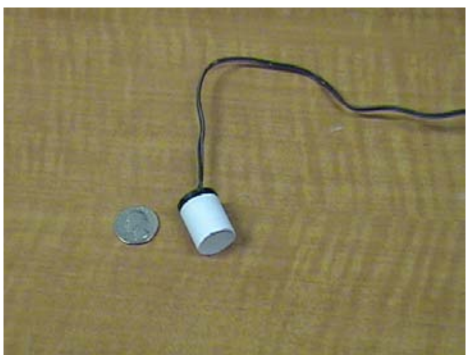

Fig. 1: A gypsum block for moisture reading

A solution for this changing frequency problem is to measure the varying capacitance of the sensor. First, the sensor was charged for a short duration with a 5V output from the sensing unit PIC to accumulate charge on one of the plates [2]. The sensor was then discharged through a resistive circuit to ground. Several readings were taken during this discharge process until the charge was at a specified value. Each reading was taken a preset amount of time after the previous reading. The quantity of readings determined the amount of time for discharge. The time required for discharge is directly related to the size of the capacitor. This method allows for acquisition of a sensor value over its entire range with little chance of polarization.

2. Wireless Communication System: After doing extensive research during the initial design phase, a PIC microcontroller with a built in transmitter was selected for the sensing unit. This PIC had many useful features such as a built in analog to digital converter (A/D), a built in oscillator, and the built in transmitter. However, a proven wireless system that was already implemented was found on an evaluation board in the instrumentation lab. This wireless system was produced by Linx and included several different transmitters and receivers available at different ranges and frequencies. The Linx system uses Amplitude Modulation (AM) to transmit data. Amplitude Modulation sends the signal by varying the output power and the data is transmitted at the center signals frequency. The system transmits when it receives a logical high and does not transmit when it receives a logical low. The Linx chip, pictured in Figure 2, that was incorporated, was the TXM-315-LR. A steel welding rod measuring 24 cm was used as the antenna. This length was determined using the ¼ wavelength formula to minimize transmission loss [3, 4].

Fig. 2: A Linx transmitter

3. Microcontroller: As stated above, a microcontroller with a built in A/D converter, an internal oscillator, and a DIP configuration was desired. Based on these specifications, the 16F88 was selected as the final sensing unit PIC. Figure 3 shows the relative size of the PIC [5]. In order to take a sensor reading, a plate is charged for a short amount of time. Charging one of the plates for four milliseconds would not polarize the sensor. After the sensor is charged, the A/D converter takes a reading and compares this value to a preset cutoff value. If the value the A/D converter takes is higher than this preset value, it will wait a set amount of time and then repeat this process. The total time it takes for the sensor to discharge and reach this value correlates to the soils moisture level. Soil with less water content takes a shorter amount of time to reach this preset cutoff value.

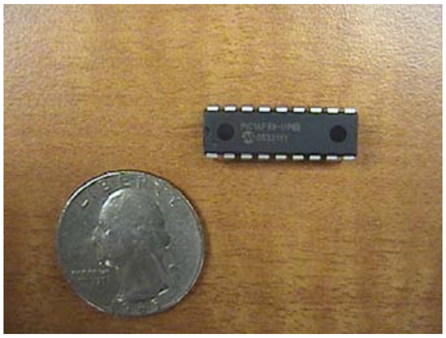

Fig. 3: The PIC16F88's built-in A/D converter

Initially, the PIC powers up the transmitter by driving a pin high. Prior to sending the data, an identifier sequence is transmitted. This sequence serves two purposes: identify the specific sensor; assist the receiver in distinguishing valid data from noise.

4. Power Supply: The power supply of the sensing unit consists of four AA batteries as shown in Figure 4. These batteries are connected in series and provide a total of 6 volts to the microcontroller. This voltage is within the operating voltage range as specified by the manufacturer. Based on calculations performed during the design phase these batteries will last well over two years. After completing the initial prototype, actual power consumption was calculated. During sleep there was a draw of less than 40µA. During the transmission cycle, the sensing unit drew just under 20mA. Assuming a sleep cycle of two hours and a transmission cycle of thirty seconds, the average current was calculated at 123µA per hour. Given that double AA batteries supply 2850 milliamp hours of current, ignoring the limits of battery shelf life and environmental effects, the sensing unit should not require battery replacement for over two and a half years [6].

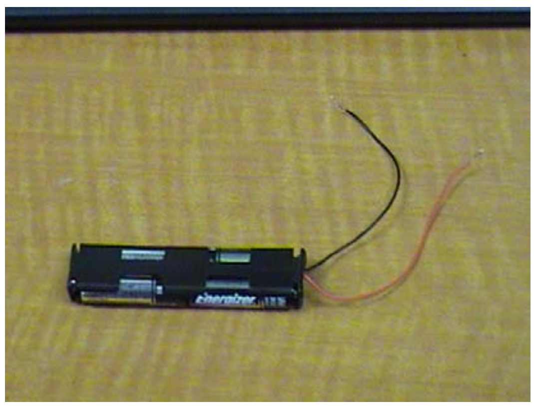

Fig. 4: The sensing unit powered by four AA batteries

5. Construction: The sensor case is constructed from a 12” section of 3” diameter schedule 40 PVC pipe. The circuit board is held inside by cutting two rings from the same material and cutting sections of the ring out. This allowed the rings to be compressed enough to enter the pipe. The rings then expand to stay in place. The circuit board is inserted between these two rings. Figures 5 and 6 show the case and the location of the circuit board. A ¼” hole is drilled three inches from the top to allow for the sensor wiring. After sensor wiring is inserted, the hole sealed with silicone to prevent water penetration. The battery pack is attached to the side of the case with Velcro strips. An end cap is permanently attached to the bottom of the sensing unit. A threaded fitting is installed on the top of the sensing unit to allow for the replacement of batteries and sensor [7, 8].

B. Main Station:

1. Wireless Communication System: The receiver used is also made by Linx technologies and is the companion to the transmitter, the RXM-315-LR. An identical ¼ wavelength antenna was used at this station. This receiver is always on sending information to the PIC. The PIC then determines which part of this information is noise and which part is the actual data that is transmitted.

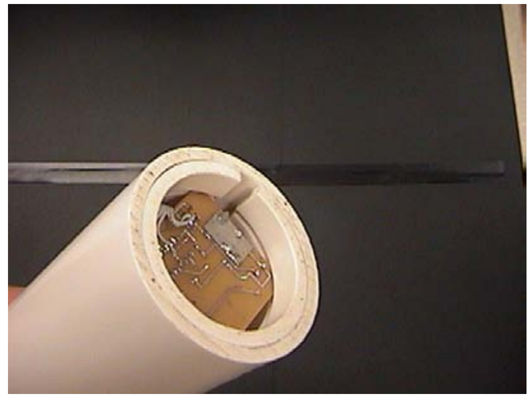

Fig. 5: Sensor case of 3”diameter PVC

Fig. 6: Compressed slotted rings to hold circuit board

2. Microcontroller: The main station microcontroller needs to have several I/O pins, a large amount of memory, a DIP configuration, and a local knowledge base. Based on these specifications the 16F74 was selected. Figure 7 shows a size comparison of the PIC16F74.

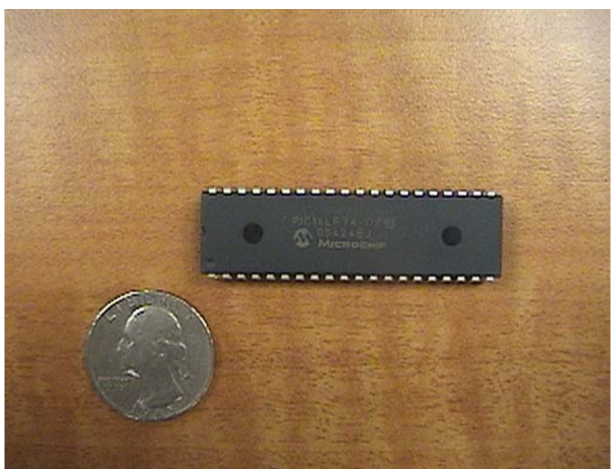

Fig. 7: The PIC16F74

3. Power Supply: The power supply consists of an AC-DC converter and a power regulator. The converter was a 9V DC output converter. The power regulator was a standard 7805 5V DC regulator. This regulator provides over 1A of output current with up to 15V DC input.

4. Construction: The main station circuit board was wire wrapped as opposed to etching as the sensing unit was. A ¼” hole was drilled in the top of the case for the antenna. The LCD is installed in the case by cutting a rectangle in the front and gluing it in place. Two ¼” holes are also drilled in the front of the case on the right side of the LCD to allow for the user interface buttons (Figures 8 and 9). Standoffs are installed on the main controller circuit board to keep it off the bottom of the case. A small square is cut out of the bottom back panel to allow for the power cord [9].

Fig. 8: The front layout of the case holds a LCD screen and two buttons

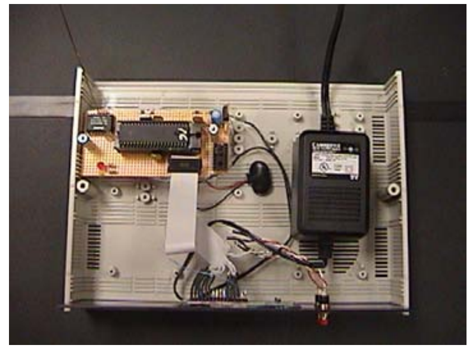

Fig. 9: The main case contains a circuit board and power supply

Results and Discussion

After further consultation with the manufacturer, another method for measuring the moisture content was implemented and tested. During the original design phase it was thought that the sensor required an AC signal so as not to polarize the plates inside the gypsum. While this is true, it is possible to use an extremely short DC pulse. The final design utilizes a short DC pulse to actually charge one of the plates. It is then discharged through a current limiting circuit to ground. The time it takes to discharge will be directly proportional to the capacitance value of the sensor. This method was found to produce consistent and accurate values. It is also effective over the entire moisture sensitivity range of the sensor. Implementation was also more compact and forgiving, as the component values do not need to be as precise. This method also allows for differences in sensors due to manufacturing differences and possible erosion of gypsum over time [10].

The original design called for a microcontroller that had a wireless transmitter built in. While this is considered the best method for a mass produced product, it was not the best for an initial prototype. There were too many aspects that were new and that could not be tested separately. There was also not enough local experience or hardware support to facilitate the original design. The initial assumptions of the capabilities of the hardware available for construction were found to be false. The available programmers could not program the specific microcontroller, without designing an additional interface unit or purchasing a very expensive surface mount programmer. The original programmer that was available could only program 16 series PICs. The original microcontroller in the sensing unit was a 12 series PIC. After comparing the requirements to available 16 series PICs, the 16F88 was chosen for the sensing unit. This is already a proven microcontroller with a wide knowledge base. The main station had different requirements and as such the 16F74 was selected for it. This PIC is also widely used in industry and in the academic environment.

Changing the microcontrollers also forced the redesign of the transmission schemes. Several different options were considered. A Linx system and demonstration boards from the instrumentation lab at Mercer University were used. The demonstration boards allowed observation and testing of this system. Another appealing aspect of the Linx system was the low cost as compared to similar systems [11].

Conclusions and Recommendations

Even with a good design, there are several problems that always seem to occur that cause changes in the design. One particular problem that occurred was the abundance of noise that was present in the transmission medium. An anticipated benefit of using the Linx transmitter and receiver combination was the assumption that noise would be minimized because of the built-in coding and decoding schemes of these products. The cause of this problematic noise was the receiver's very low noise floor. An unorthodox solution to this problem was the use of software to minimize noise during transmission. Another problem that was encountered was the implementation of two different transmitter and receiver frequencies. This turned out to be a problem because the main station PIC cannot poll two lines at the same time to see if a data transmission is about to start. This problem was resolved by having one receiver and two transmitters at the same frequency. To prevent signal corruption the sensing stations were configured to transmit at different time intervals. The early assumption of measuring the change in resistance of the gypsum block to determine water content was found to be unreliable. Instead, measuring the time constant of the varying capacitance is a much more reliable way of obtaining consistent moisture measurements. Based on these changes, the current design and prototype meet all the feasibility criteria. However, there are more aspects that should be included in the design prior to full production.

While the prototype realizes all the goals that were set forth, the addition of other options would be beneficial to the marketability of the system. One option should be the implementation of other sensors such as a barometer and temperature sensor. These will allow the microcontroller to determine more accurately the optimum watering times. Also, reverting back to the original design that used a PIC with an integrated transmitter would reduce both the cost and the size of the sensing unit. Another possible option would be the improvement of the user interface. While the current LCD implementation works, a more user friendly interface, such as a PC interface, might be more desirable for some users. Professional installation is recommended because of various soil types and environmental conditions. The user menu still allows the user to choose the moisture level that initiates the watering process.

References

[1] Skinner, A., Hignett, C., and Dearden, J., "*Resurrecting the Gypsum Block for Soil Moisture Measurement*", Australian Viticulture, October/November 1997. (http://www.sowacs.com/sensors/gypsum.txt).

[2] "*PIC 16F87/88 Data Sheet*", Microchip Technology Inc., 2005.

[3] "*LR Series Transmitter Module Data Guide*", Linx Technologies, January 14, 2005.

[4] "*LR Series Receiver Module Data Guide*", Linx Technologies, January 14, 2005.

[5] "*PIC 16F7X Data Sheet*", Microchip Technology Inc., 2002.

[6] Juang, J., Ekong, D.U., Carlson, C., Longsdorf, W., and Miller, M., *"A Computer-Based Soil Moisture Monitoring and Hydrating System"*, Proc. Thirty-Ninth Southeastern Symposium on System Theory (SSST'07), March 4-6, 2007.

[7] Morris, M., *"Soil Moisture Monitoring: Low-Cost Tools and Methods"* NCAT Energy Specialist, ATTRA Publication #IP277, 2006.

[8] Suda, T., Hirai, K., Sako, K., and Fukagawa, R., *"Soil-Moisture Monitoring Using Ultrasonic Wave for Prediction of Slope"*, IEICE Tech., vol.108, no. 410, 2009.

[9] Borthan, M., and Parsons, L.R., *"Evaluation of Low Cost Capacitance ECH20 Soil Moisture Sensorfor Citrus in a Sandy Soil"*, 25^{th} International Irrigation Show, November 2004.

[10] Cardell-Oliver, R., Smettem, K., Kranz, M., and Mayer, K., "*A Reactive Soil Moisture Sensor Network: Design and Field Evaluation*", International Journal of Distributed Sensor Networks, pp. 149–162, Volume 1, Number 2/April-June 2005.

[11] Cardell-Oliver, R., "*ROPE: A Reactive, Opportunistic Protocol for Environment Monitoring Sensor Networks"*, EmNets 05, Sydney, May 2005.

JENG-NAN JUANG

Dr. Juang received the B.S. degree in Electrical Engineering from National Taiwan Ocean University, Keelung, Taiwan and the M.S. and Ph.D. degrees from Tennessee Technological University, Tennessee. He has been a faculty member of the Electrical and Computer Engineering at Mercer University since 1987. He organized and chaired the "International Workshop on Future Aerospace Maintenance & Technology" at Taipei in Taiwan. He also served as a prime consultant for Fiber Optic Rate Gyroscope Development Program (A grant from Wright-Patterson Air Force Base, Ohio, USA). He has received one teaching award, and two research fellow awards from NASA Langley Research Center, Virginia, USA. He has organized the International Conference on Manufacturing and Engineering Systems 2009 at National Formosa University during December 17-19, 2009 in Taiwan. His professional affiliations include: ASEE, IEEE, AIAA, NATPA, NSPE, CAPASUS, and AAUP.

Contact Information: Associate Professor, Electrical Engineering Department, School of Engineering, Mercer University, 1400 Coleman Avenue, Macon, GA, 31207-0001; Phone: (478) 301-2574; Fax: (478) 301-2732; E-mail: juang_jn@mercer.edu

R. RADHARAMANAN

Dr. R. Radharamanan is currently working as Professor of Industrial Engineering and Director of Mercer Entrepreneurship Engineering Education Program (MEEEP) at Mercer University in Macon, Georgia. He has thirty seven years of teaching, research, and consulting experiences. His previous administrative experiences include: President of International Society for Productivity Enhancement (ISPE), Acting Director of Industrial Engineering as well as Director of Advanced Manufacturing Center at Marquette University, and Research Director of CAM and Robotics Center at San Diego State University. His primary research and teaching interests are in the areas of manufacturing systems, robotics and automation, quality engineering, and product and process development. He has organized and chaired four international conferences, co-chaired two, and organized and chaired one regional seminar. He has received two teaching awards, several research and service awards in the United States and in Brazil. His professional affiliations include ASEE, IIE, ASQ, SME, ASME, and ISPE.

Contact Information: Professor of Industrial Engineering, School of Engineering, Mercer University, 1400 Coleman Avenue, Macon, GA, 31207-0001; Phone: (478) 301-2215; Fax: (478) 301-2331; E-mail: radharaman_r@mercer.edu