Use of SCADA Principles to Simplify Pool Ownership

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***Abstract*—A system was designed to decrease the amount of work required to own a pool. The system performs pH readings and adds chemicals to keep pH in a desired range; owners could be alerted via email when chemical levels are low. Any concerns of children falling in the pool were mitigated with the SplashAlert feature.**

Two high-impedance pH electrodes are amplified to provide a voltage with a 1:1 correspondence to the 0-14 pH range. That voltage is converted to a digital signal by an Outdoor RTU and communicates via Zigbee to the Indoor RTU. The indoor RTU's sole purpose is to pass the pH level to the HMI on a pool owner's personal computer for trend data and alert notifications. The outdoor RTU has multiple output functions dependent on pH input readings, including opening valves and operating pumps to add and circulate pH corrective chemicals. National Instruments' LabView serves as a HMI and provides trend data, as well as email alerts when chemical additive levels were low. A SplashAlert feature uses a magnetic float to monitor water levels and alert owners of any unexpected fluctuation in water level that may indicate a child falling in a pool.

***Index Terms*—Analog Circuits, Zigbee, SCADA Systems, Microcontrollers, Computerized Instrumentation, Telemetry.**

I. Nomenclature

Aquatic Peace of Mind – Pool water Monitoring, Control, and Alerting System developed by Skinners' Skimmers
HMI – Human Machine Interface
Indoor RTU – PIC18F4620 microcontroller serving as a communications relay between the Outdoor RTU and HMI
Outdoor RTU – PIC18F4620 microcontroller acting as an RTU by converting analog signals to digital data and a PLC by using that digital data to control various aspects of the system
PLC – Programmable Logic Controller
RTU – Remote Terminal Unit
SCADA – Supervisory Control and Data Acquisition
SplashAlert – Feature that detects unexpected waves that could be caused by a child falling in the pool

II. Introduction

Owning a pool is a much more arduous endeavor than many realize. To avoid damages to the very expensive pump, filter, and the pool itself, a pool owner must keep several water characteristics in desired ranges. pH is one of the most important quantities to monitor. Pool water that is too acidic or basic can cause eye and skin irritation and will lead to cloudy water. The Aquatic Peace of Mind project tackles the observation and management of the most difficult water quality to monitor. A similar system could easily monitor other water quality characteristics utilizing the principles displayed by Aquatic Peace of Mind.

Beyond keeping water safe and sparkling, pool owners with children must exercise constant vigilance to ensure children are only near the pool when proper supervision is available. Drowning is the leading cause of accidental death for children under age 5, and while there are several existing products that alert pool owners of an unexpected person entering the pool, none thus far have been integrated in an autonomous chemical dispersion product.

III. Technical Work Preparation

The Aquatic Peace of Mind test apparatus consists of a 55-gallon drum that serves as mock pool, which is connected to an elevated 5-gallon mixing chamber. Each of these containers has a pH electrode mounted inside to monitor the pH. The readings from the two electrodes are fed into a pH metering circuit that corrects the raw values to produce a voltage value that directly reflects the pH. This reading is then sent to the Outdoor RTU, which is responsible for interpreting the readings and comparing them to stored set points. Using Zigbee, the Outdoor RTU communicates wirelessly with an Indoor RTU. This Indoor RTU is hooked directly to a pool owner's PC, which has an end-user version of LabView installed to serve as a HMI. LabView is responsible for displaying trend data, SplashAlert on/off settings, and email alerts for low chemicals and SplashAlerts.

As previously mentioned, the Outdoor RTU is responsible for pH correction. Two containers hold chemicals to increase and decrease pH separately. Small AC pumps are used to dispense the chemicals. When the Outdoor RTU senses a pH

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beyond factory-set boundaries, it uses digital outputs that interface with a ULN2003A Darlington pair IC to control several relays. These relays pump water into the mixing chamber and correct the pH by reading the 5-gallon sample pH and pumping in the proper chemical and then releasing that water back into the 55-gallon pool. A pump in the pool runs constantly to circulate water and give better chemical dispersion as well as providing more accurate pH readings. An overall view of the Aquatic Peace of Mind project is included as Fig. 1.

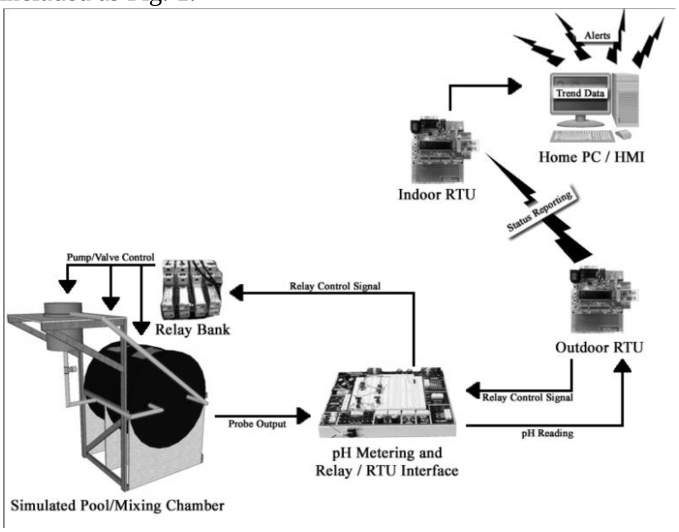

Fig.1. Aquatic Peace of Mind project overview

A. pH Meter

The pH metering circuit consists of an amplification and summing circuit that converts the -420 to 420 mV signal given by the pH electrode into a voltage of 0 to 14, with a pH of zero being 0V and a pH of fourteen being 14V. The conversion table from electrode output voltage to pH meter output voltage is included as Table I.

TABLE I
pH METER CIRCUIT INPUT AND OUTPUT VOLTAGES

pH	Electrode Reading (Input)	Output Voltage
0	0.42	0
1	0.36	1
2	0.3	2
3	0.24	3
4	0.18	4
5	0.12	5
6	0.06	6
7	0	7
8	-0.06	8
9	-0.12	9
10	-0.18	10
11	-0.24	11
12	-0.3	12
13	-0.36	13
14	-0.42	14

This amplification is accomplished using three LM741 National Semiconductor Operational Amplifiers [1] for each probe and a single TL082 Texas Instruments Dual JFET Operational Amplifier [2] for both probes. Both probes are connected to the sole TL082 opamp to overcome the extremely high impedance inherent in all pH electrodes. The amplification schematic is included as Fig. 2.

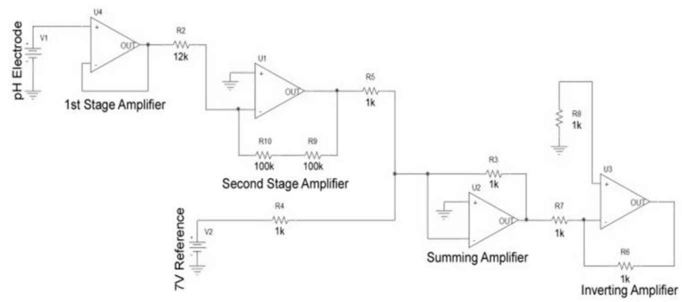

Fig. 2. Probe amplification schematic

The Outdoor RTU uses the output voltage of the inverting amplifier of each probe to measure the pH in that respective container. A photograph of the physical implementation of this circuit is included as Fig. 3.

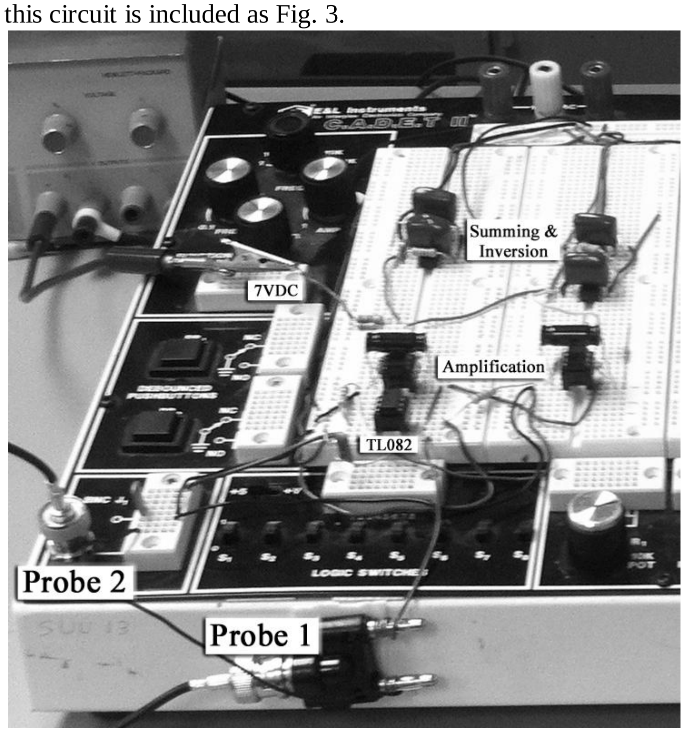

Fig. 3. Implementation of pH Metering circuit

B. Outdoor RTU

The Outdoor RTU is responsible for monitoring pH, sending status readings to the Indoor RTU, and activating pumps and valves to correct the pH when needed. Port A was initialized to be analog inputs (probe voltage readings), Port B as digital inputs (magnetic floats), and Port C as all digital outputs (relay control signals). All analog-to-digital conversion was done on Port A. The 55-gallon pH probe serves as the main pH acquisition device and is selected by initializing the A/D multiplexer to Probe 0. The RTU then begins A/D conversion and polls the A/D “Done” flag until conversion is complete. The first 8 bits of the resulting A/D conversion are stored in register pH55. The pH55 register is updated with each polling cycle. Next, the value stored in ph55 is compared to the two limits of the desired pH defined as HTEST (7.6) and LTEST (7.2). When the microcontroller senses an undesired pH, subroutines PHPLUS or PHMINUS are called to bring the pH back into the desired range. The only difference in the two subroutines is which chemical they add, thus the variation in names.

The corrective cycle begins as the 55-gallon pH reading is stored in pH 5, the register designated for the second pH probe. This assumes that the pH of the sample pulled into the 5-gallon mixing chamber will have the same pH reading that required corrective action in the 55-gallon pool. Next, the A/D mux is changed to Probe 1, so that the A/D converter can take readings from the 5-gallon-chamber's pH probe. The solenoid valve is closed by the RTU as the lift pump is turned on. An indication that the desired amount of water has been added to the mixing chamber is given by a magnetic float, and this indication leads the RTU to shut off the lift pump. Depending on the subroutine, either the pH plus or minus pump is turned on for 5 seconds and then shut off. A minute delay is added after the pump shuts off to allow the recently added chemicals to disperse throughout the mixing chamber. A subroutine titled CONVERT is called to poll the second probe for another reading. If the reading is still not within the desired range, the subroutine adds another round of chemicals. Once it is within the desired range, a solenoid valve is opened and the push pump located in the mixing chamber is turned on. After running for 90 seconds to clear the mixing chamber, it is turned off and the A/D mux is changed back to the main probe in the 55-gallon pool.

C. Physical Control

Water is circulated in the system by two 12VDC submersible pumps. One is located in the main holding tank while the second one is located in the elevated mixing chamber. Chemicals to raise and lower pH are stored in two separate containers and are dispensed through two 120VAC fountain pumps. A 12VDC solenoid valve is located in-line with the mixing chamber drain to isolate the balanced solution from the rest of the system. The four pumps and one valve are actuated through five 12VDC relays. The Outdoor RTU turns on each individual relay through a Darlington paired transistor inside a ULN2003AN IC chip [3]. The ULN2003A allows the RTU to turn on the relay by providing a higher driving current taken from a 12VDC power supply.

When the pool pH requires corrective action, water is pumped from the pool to the mixing chamber until a magnetic float signals the 5-gallon chamber is full. The valve remains open unless until the pH needs correction. Once the overflow float is tripped, the RTU will switch both pumps off and close the valve. Depending on the pH condition, the RTU will turn either one of the small fountain pumps to correct the system imbalance. Once the chemicals are dispensed, the system will resume normal circulation in order to uniformly distribute the pH.

D. Indoor RTU

The Indoor RTU serves as a communications relay between the Outdoor RTU and the HMI running on a PC. The RTU reads PORTA, where the PICtail Zigbee chip is located, and routes it to a serial output that is connected directly to the HMI.

E. Zigbee Communications

The Zigbee communications module is highlighted in the picture of the microcontroller project board in Fig. 4.

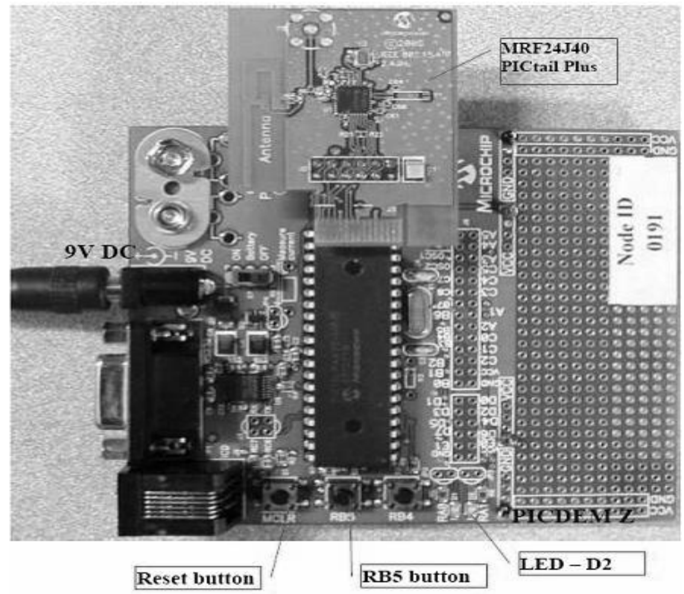

Fig. 4. PIC18F4620 project board with MRF24J40 PICtail Plus Zigbee module.

Zigbee is a communications protocol based on the IEEE 802.15.4-2003 standard [4] and is maintained and published by an association of companies known as the ZigBee alliance. In Aquatic Peace of Mind, Zigbee serves as a convenient means of wireless between an RTU directly connected to a home PC and an RTU that would be located outdoors to take readings and perform corrective actions. Fig. 1 shows the overall layout of this network. Zigbee eliminates the need for an end-user to set up a wireless router or perform the sometimes-difficult task of coordinating new devices with an existing Wi-Fi network. The Indoor RTU creates a Zigbee network and manages communications between the HMI and Outdoor RTU. These devices speak at all times so pH readings are up-to-date and any necessary alerts can be sent promptly.

A wireless network analyzer, Zena, was used to analyze network traffic and display the decoded packets being transmitted and received by the two RTUs. While Zena is not necessary to run the wireless function, it was integral in troubleshooting connectivity issues. In an end-user environment, it would be used to alert users that there is a communications error, and perhaps allow for basic communications troubleshooting. Fig. 5 shows an example of a typical Zena screenshot.

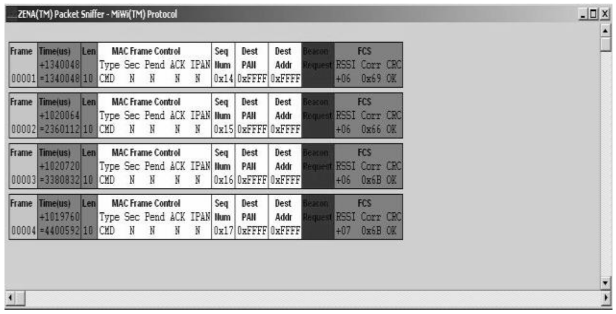

Fig. 5. Zena screenshot

F. LabView

The LabView portion of Aquatic Peace of Mind was designed to monitor pH trends and send alerts as well as serve as the HMI for the system. A channel is created via LabView's DAQmx to read digital signals from the Indoor RTU. The signals are then split to monitor the pH values, SplashAlert, and chemical levels. From the faceplate, LEDs display the status of each of these data points. A switch on the faceplate provides an override for the SplashAlert during times when splashes are expected, such as swimming or cleaning. While set, the SplashAlert LED will light up when a splash occurs until the alarm is acknowledged. The LabView control process is included as Fig. 6.

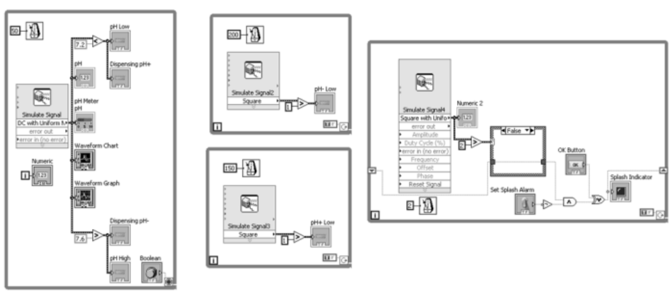

Fig. 6. LabView block diagram

pH values are read and graphed on intervals of 15 minutes. While pH values are out of range, chemicals are distributed and the LEDs for dispensing chemicals are lit. Signals from the floats, also received via the RTU, send the LabView system into an alert mode. In alert mode, the LED for a low chemical is lit and both an e-mail and a text message are sent to an end-user. This was accomplished by using Simple Mail Transfer Protocol (SMTP) to first e-mail the message to a Gmail account and then using the free Short Message Service (SMS) gateway to forward the text message. The alert process in LabView is included as Fig. 7.

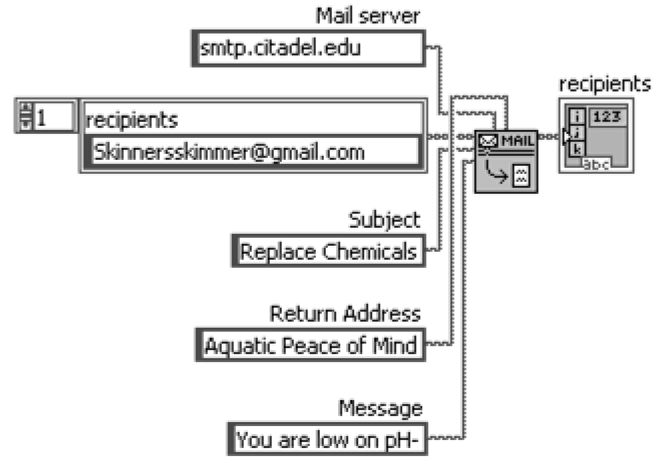

Fig. 7. LabView alert process

IV. Acknowledgment

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V. References

Datasheets:

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VI. Biographies

Susanmarie Durso was born in East Utica, NY on May 4, 1989. With Bachelor of Science in Electrical Engineering from the Citadel, she will be commissioned in the United States Navy as a Naval Flight Officer. Along with a naval career, she plans on Mastering in Aerospace Engineering.

Matthew William Hearl was born in Walhalla, SC on July 20, 1989. Upon graduation from The Citadel with a Bachelor of Science, he will be commissioned into the U.S. Navy as an Ensign, and head to Norfolk, VA to meet his first ship, the USS Oscar Austin. He eventually plans to try to work in the Nuclear Power field sometime after his time in the Navy as well as obtain a Masters in Engineering Management. As a member of the Corps of Cadets at The Citadel, he served as Regimental Supply Officer.

W. Brigman Kinard was born in Newberry, SC on October 2, 1989. Upon graduation from The Citadel with a Bachelor of Science, he plans to work in either the Power Systems or Defense Contracting fields in Charleston, South Carolina. He plans on working towards being classified a Professional Engineer and obtaining PMP certification. As a member of the Corps of Cadets at The Citadel, he served as Third Battalion Commander, overseeing 400 cadets.

Jaime A. Lugo-Castillo was born in Mayaguez, Puerto Rico on December 6, 1985. Upon graduation from The Citadel with a Bachelor of Science, he plans to work in the Electronic or Automation Control field in Charleston, South Carolina. He plans on working towards a Masters in Biomedical Engineering and having a Professional Engineer classification. He currently works as a motorcycle mechanic for Berkley Power Sports in Charleston.

Adam Daniel Murphy was born in St. Louis, MO on September 8, 1988. Upon graduation from The Citadel with a Bachelor of Science, he plans to work as a developmental engineer as a First Lieutenant in the United States Air Force. He plans on working towards a Masters in Project Management. Upon retiring from the Air Force, he plans to work in the Defense Contracting field. As a member of the Corps of Cadets at the Citadel, he served as Hotel Company Commander.