Instrumentation and control development for ISEP water supply management system

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***Abstract*—This article is based on the response found for the optimization of the ISEP water supply management system. Along with the explanation of the solution found and the chosen sensors (humidity, level and flow) focus will be given to the conditioning circuit and the continuous current source developed for test and simulation purposes. Pspice simulation studies, Monte Carlo analysis and variation with temperature are also covered in this article.**

Keywords—signal conditioning; humidity sensor; flow sensor; level sensor; intrumentation; microcontroller.

I. Introduction

Efficiency, Ecological thinking and cost reduction is at the top of agenda and were taken in to account in the system developed for the ISEP water supply management system on the context of the Instrumentation system subject .

The current water supply system installed consists in two cisterns of 30000 liters each which are supplied by a water drill, water table and company water. The water stored in the cisterns is used for watering the gardens (11 sectors) and to be used in case of fire. The current management of the water supply and watering is archaic and requires a higher level of optimization taking into to account economic and ecological issues. The levels are currently taken sporadically and the management of the drill, water table and company water are made manually.

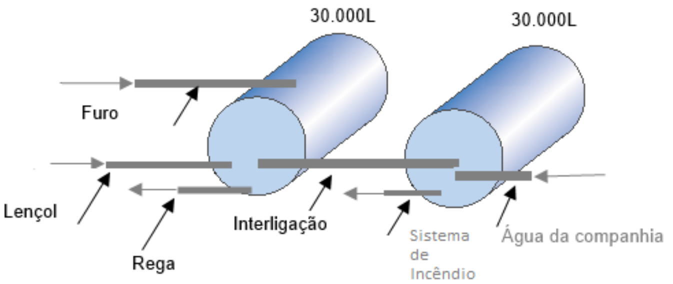

Figure 1 – ISEP's Cisterns installation scheme.

The solution found consists in the development of an automatic system that would potentiate the available resources, limiting the use of company water and provide data regarding the drill and water table levels for the use of the ISEP's geotechnical department.

II. Solution

The management system comprises one microcontroller with Ethernet based device (Atmega 328p + ENC 28J60) which controls the watering time and sectors, cistern levels, water table and drill levels, fire situation and allows data to be sent to a database.

The system has two modes of functioning, offline and online, and two status, manual and automatic. On the automatic status the company water electro valve is activated when needed while manual mode requires the user to activate or status change. The online mode has priority over offline mode and allows the user through a website to set the values of humidity, sectors to be watered and watering time. Although it was not implemented in this solution an lcd and simple system can be added to the cisterns site so local management such as reset or change parameters (e.g. humidity levels or watering time) could be changed on site.

A. Watering system

For the watering system humidity sensors were implemented in each sector. The sensors measures the humidity in each sector hourly in the event of the humidity level decreasing more than the specified by the user the respective sector will be identified and watered by activating the respective electro valve at the specified watering time.

B. Cistern level management

Cistern levels measurements are made by a position sensor and it is considered low water level below 25% (15 000 L) and the highest 55000 l. The system works so that all available water in the water table and drill is transferred to the cistern as soon as possible ensuring that the cistern is always with the highest volume of water possible and that ecological minimum levels from the drill and water table are maintained. The water table has priority over the drill due to expected higher volume than the drill. This feature also ensures that the cisterns have the necessary amount of water for watering and to fill the needs of the Robotics laboratory tank. When the water level in the cistern is lower than the water needed for watering the system sends a warning to the website and opens the electro valve from the company water (last one only on automatic status). This check is made three times (spaced for 30 minutes between each check) before watering time so the company water is gradually used in case more water becomes available on the other resources.

C. *Fire Alarm and leak monitoring*

In case of fire an interruption is set and all electro valves are open so all water is made available for fire control. All other functionalities are cancelled until the fire alarm goes off. Also through the flow sensors eventual leaks can be detected once an interruption is set by the microcontroller when it detects an A/D conversion while outside the watering time sending a warning to the user. The flow sensor among with the levels sensors can be used to confirm values of debits and volumes to improve accuracy in the measurements and detect eventual malfunctions of the system or equipment.

A simplified diagram from the solution is showed in the following diagram

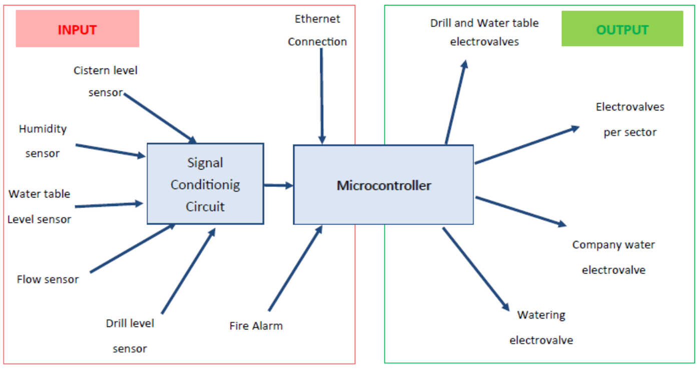

Figure 3 – Solution Diagram.

III. CONTROL

In order to develop a user interface, as well as an automatic control of the system there's a need for a microcontroller. In the initial project design, the choice was an integrated board that contained:

A. *Microcontroller Amega 328p*

The Atmega328p is an 8-bit microcontroller and internal frequency clock set to 8Mhz. According to manufacturer the ADC is provided with a dedicated clock domain. This allows halting the CPU and I/O clocks in order to reduce noise generated by digital circuitry. This gives more accurate ADC conversion results [1]. The ADC is connected to an 8-channel Analog Multiplexer that allows eight single-ended voltage inputs constructed from the pins of Port A.

B. *Embedded Ethernet module ENC28J60*

The ENC28J60 is and Stand-Alone Ethernet Controller with SPI™ Interface used as Ethernet network interface and meets all of the IEEE 802.3 specifications as well as compliant with MAC logic and a Physical Layer module that encodes and decodes the analog data that is present on the twisted pair interface. It also incorporates a number of packet filtering schemes to limit incoming packets and among these features the module also has a dual port RAM buffer for received and transmitted data packets [2].

Figure 2 - Atmega328p+ENC28J60 integrated board.

Due to Ethernet connection issues:

1. Internet protocol libraries not working or not making the ip-address connection;
2. Socket connection option too difficult and too time consuming.

The initial idea was dropped, since there was very few examples and support during our research. Also there were easier and more capable microcontrollers. The second choice was:

C. *Arduino MEGA 2650*

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 (datasheet). It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

Figure 4 - Arduino MEGA 2560.

Since Atmega328p and the ENC28J60 where already internally interconnected through the board, there was no possibility to take advantage of the initial microcontroller option, because we couldn’t connect the ENC28J60 to the Arduino through SPI™ Interface.

Therefore the webserver/webclient idea was dropped and the Arduino MEGA 2560 was solely programed to operate offline.

The Arduino MEGA 2560 is also capable to create a webserver through Serial connection, but that would implicate a PC always associated with the microcontroller, making it cost ineffective.

IV. SENSORS

The aspects taking into account when choosing sensors were the analog output range, cost, accuracy and susceptibility to noise. These aspects will be covered in the following topics.

A. *Level sensor*

The sensor for the level measurements used is a LT9000 which is a continuous level transmitter that detects the level of an electrically conductive liquid in a tank. According to the manufacturer the LT9000 can sense the level of an interface such as oil or water[3]. The conductance method of liquid level measurement is based on the electrical conductance of the measured material that can conduct a current with a low-voltage source. Conductance is a relatively low-cost, simple method to detect and control level in a tank [4]. The analog output range from 4 to 20 mA. The following figure represents the schematic of the referred sensor.

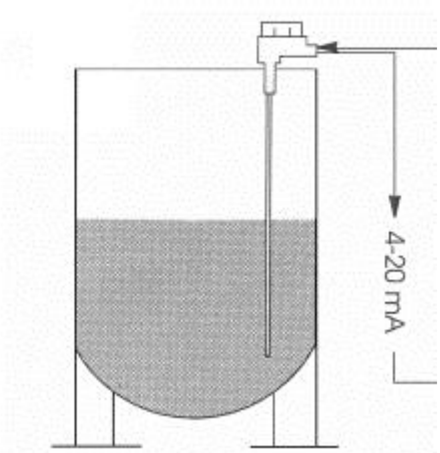

Figure 5 - LT9000 assembly scheme.

B. *Humidity sensor*

For the soil humidity the selected sensor was the MAS-1 which determines the volume water content (VMC). It works by measuring the dielectric constant of the surrounding soil using capacitance/frequency domain technology. The sensor uses a 70 MHz frequency, which minimizes salinity and textural effects, making the MAS-1 accurate in almost any soil[5]. It has an output current from 4 to 20 mA which is proportional to the VWC on the soil [0-100%]. This sensor has an accuracy of ±6% VWC with generic calibration and can be improved if calibrated according to the soil and is suitable to implement with cable longer than 75 meters improving its resistance to noise.

Figure 6 – MAS – 1 humidity sensor.

C. *Flow sensor*

The water flow measurements the sensor chosen is the Kobold DPE model. The device works through the blade wheel principle where the blade is set on motion by the flowing water and the magnets that are embedded in the end of the blades generate electrical pulses[6]. The analogue output is 4 to 20 mA proportional to the measuring range 5 to 30 l/min. The measuring accuracy is ±2.5% of the full scale.

Figure 7 – Kobold DPE flow sensor.

V. SIGNAL CONDITIONING

Signal conditioners are measuring system elements that start with an electric sensor output signal and then yield a signal suitable for transmission, display, or recording, or that better meet the requirements of a subsequent standard equipment or device[7]. The circuit developed allows to converts current from the sensor to voltage that that can be interpreted by the microcontroller. The circuit is represented in the following picture and will be divided and explained in next topics:

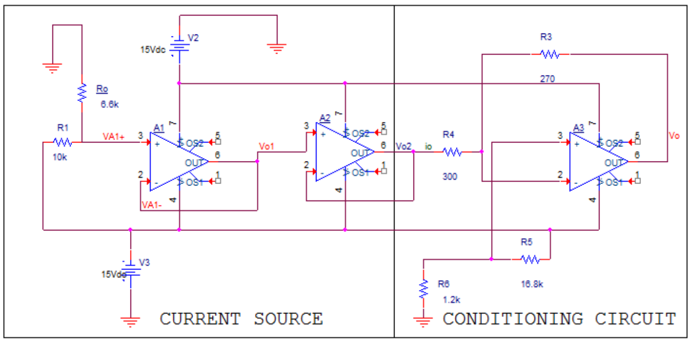

Figure 8 – Signal Conditioning circuit

A. *Current source*

The current source finality is to mimic the conversion of a physical to another physical form (in this case the amount of water passing through a pipe within a given period of time to electrical current). The variation of the current values is the result from the variation of a variable resistance *Ro*. Resistive elements are inexpensive and relatively easy to interface with signal conditioning circuits and complex physical phenomena can be measured such as fluid or mass flow[8].The current values determined range from [6 to 16 mA so accuracy and sensibility could be improved. The values found for the minimum *Ro*=2.2 kΩ and maximum *Ro*=6.6 kΩ. Implied is also that this an active sensors, once most of the output signal power comes from an auxiliary power source.

For the measure of *Ro* a voltage divider has been used which method consists one of the resistors is known, a single voltmeter reading allows us to calculate the unknown resistor [7]. Adding an op amp to the voltage divider yields a circuit whose output voltage is inversely proportional to the unknown resistance and allows measuring the current through the circuit (on *R4* the value of 300 Ω was determined to approximate values to the desired range). The current source developed has an output (*Io*) of [-5.67 mA to -16.54 mA] at the output of op amp *A2* as shown in the following theoretical analysis, therefore an inverted buffer circuit has been added to the output of the current source resulting in positive current values.

- For *Ro*=2.2 kΩ:

$$V_{A1+} =.(-15)\frac{R_o}{R_o+R_1} = \frac{2.2}{2.2+10} = -2.7\,V \qquad (1)$$

$$V_{A1+} = V_{A1-} = -V_{o1}$$

$$V_{o1} = 2.7\,V$$

$$V_{o2} = -V_{o1} = -2.7\,V$$

$$I_o = \frac{V_{o2} - V_{in3}}{R4} = \frac{2.7-(-1)}{300} = 5.67mA \qquad (2)$$

$$V_3 = \frac{R6}{R5+R6} \times 15 = \frac{1.2}{16.8+1.2} = -1 = V_2 \qquad (3)$$

$$V_o = V_2 - I_o \times R3 = (-1) - (-5.67) \times 270 = 530\,mV \quad (4)$$

- For *Ro*=6.6 kΩ

Applying the same calculations for *Ro*=6.6 kΩ

$$V_{o1} = 5.96\,V$$

$$I_o = 16.54\,mA$$

$$V_o = 3.46\,V$$

B. *Conditioning circuit*

For determination of optimum values were found taking in mind the A/D converter from the microcontroller selected. The ADC as a range from 0 V to 3.3V and so some flow variations might have changes in millivolt range which need to be conditioned before they are applied to the ADC. Once the output needed is voltage we need to add a current-to-voltage converter. The R6 and R5 have been determined to achieve linearity between current and voltage values.

C. *The analog-to-digital converter*

The ADC from the ATmega328p converts an analog input voltage [0-3.3V] to a 10-bit digital value through successive approximation. This gives 1024 levels [0 to 1023] where the minimum value represents GND (0V) and the maximum value represents the voltage on the AREF (3.3V) pin minus 1 LSB. Accuracy could be improved by choosing a microcontroller with higher analog input range. Therefore the resolution (Q) of ADC can be obtained through the following equation.

$$Q = \frac{V_{refHI} - V_{refLO}}{2^M} = \frac{3.3-0}{1024} = 3.22mv \qquad (5)$$

By default, the successive approximation circuitry requires an input clock frequency between 50 kHz and 200 kHz to get maximum resolution for 10 bits. For this we need to

$$f_{clkADC} = \frac{f_{clk}}{Division\,factor} = \frac{8MHz}{32} = 250\,KHz \qquad (6)$$

VI. Analysis and Results

A. *Pspice simulation*

Pspice simulation studies have been carried out to scrutinize the performance of the proposed signal conditioning circuit.

Although Pspice is computational software, it takes into account the characteristics of practical devices. Hence the results obtained using Pspice can be expected to be realistic enough to reveal the feasibility of actually implementing the scheme envisaged and also its performance [9]. The results obtained in the time domain analysis are registered on the following table.

TABLE 2. PSPICE TIME DOMAIN RESULTS.

Ro	Time Domain (transient)	
	io	*vo*
2.2 kΩ	5.68 mA	534.3 mV
6.6 kΩ	16.30 mA	3.46 V

B. *Temperature variation*

For temperature analysis a performance test was carried using the Pspice Temperature simulation. The range of temperatures was set from -12^{0}C to 60^{0}C. The results are summarized for the purposes of the referred circuit.

TABLE **2**. PSPICE TEMPERATURE VARIATION SIMULATION RESULTS.

Ro	**Temperature (sweep)**		
	Range	**io**	**vo**
2.2 kΩ	-12ºC	5.68262 mA	534.284 mV
	60ºC	5.86253 mA	534.261 mV
6.6 kΩ	-12ºC	16.54545 mA	3.46722 V
	60ºC	16.54521 mA	3.46716 V

The temperature variation resulted in a linear function that resulted in no real concerns, since the output current and voltage variation was so low. Also the temperature maximum and minimum values tested were far beyond the expected ones for the real application.

C. *Monte Carlo*

The Monte Carlo analysis is used for simulations with a given error on different components. This test is very useful for visualizing how the circuit will run with imperfect components as are used in reality[10].

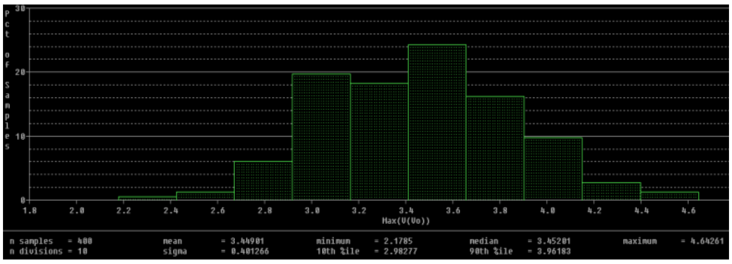

Figure 9 – Pspice Monte Carlo maximum output simulation.

Above is shown the Histogram for the maximum output voltage, for 400 samples. As shown, mean=3.45 V which mathematically is the most probable value. Since the expected value was 3.3 V, the relative error concerning the simulated mean is 4.35%, which was considered acceptable.

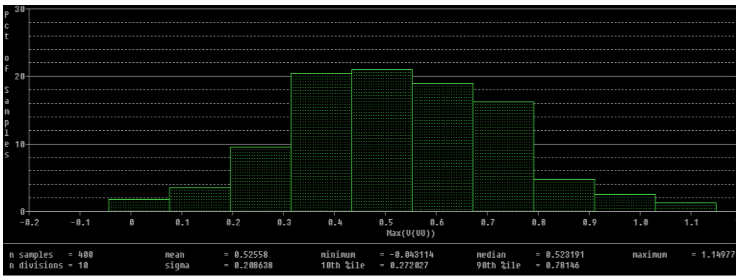

Figure 10 - Pspice Monte Carlo maximum output simulation.

In Figure 10 is shown the Histogram for the minimum output voltage, for 400 samples. As seen, mean=0.53V which mathematically is the most probable value. Since the expected value was 0 V, the absolute error concerning the simulated mean is 0.53V, which was considered acceptable.

CONCLUSIONS

A low-cost solution has been designed to meet the system requirements despite the problems referred along the article and alternatives/improvements have been researched. The signal conditioning circuit has been tested and its applicability demonstrated. The results from the various analyses were concordant including the prototype test.

This project not only allowed the authors to learn and improve knowledge regarding signal conditioning, ADC conversion and microcontroller programming but also to experience how much a project need to be carefully planned in terms of equipment and time frame as well as how small details can delay and put the project in risk.

As an overall appraisal the authors found this project very stimulating and positive.

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REFERENCES

[1] A. Corporation, *ATmega328p datasheet*. 2009, p. 448.

[2] Microchip Technology Inc., “ENC28J60 Data Sheet Stand-Alone Ethernet Controller with SPI ^{TM} Interface,” 2004.

[3] I. BABBITT INTERNATIONAL, “OMLT9000_level_sensor.pdf.” p. 2.

[4] Gabor Vass, “The Principles of Level Measurement,” 2000. [Online]. Available: http://www.sensorsmag.com/sensors/leak-level/the-principles-level-measurement-941.

[5] I. Decagon Devices, “MAS-1.” [Online]. Available: http://www.decagon.com/products/soils/volumetric-water-content-sensors/mas-1-4-20-milliamp-water-content-sensor/. [Accessed: 03-Dec-2014].

[6] K. M. Gmbh, *Turbine wheel flow meter*, vol. 49, no. 0. 2014, pp. 1–4.

[7] R. Palla and J. G. Webster, *SENSORS AND SIGNAL Second Edition*, 2nd ed. JOHN WILEY & SONS, INC, 2001, p. 25.

[8] W. Kester, “Sensor signal conditioning.” [Online]. Available: http://www.analog.com/library/analogdialogue/archives/39-05/Web_Ch4_final.pdf. [Accessed: 05-Jan-2015].

[9] N. Sanyal, B. Bhattacharyya, and S. Munshi, “An analog non-linear signal conditioning circuit for constant temperature anemometer,” *Measurement*, vol. 39, no. 4, pp. 308–311, May 2006.

[10] N. Kuyvenhoven, “Monte Carlo Analysis ORCAD PSPICE.” [Online]. Available: https://www.calvin.edu/~pribeiro/courses/engr311/samples/Neil/Monte_Carlo_Analysis.html. [Accessed: 15-Dec-2014].