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Embedded System Platform for Real Time Monitoring applied to Solar Collector ⋆

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Abstract: The implementation of data loggin platforms is an important stage in validating theoretical models, to finally propose a suitable description of a process. The system to log data have to be reliable and consistent to avoid including noise and offset to signal, affecting final conclusions. This paper describes the development of an embedded plaform to get the parameters from multiple thermo resistor analog sensors in order to validate the model of a solar collector.

Keywords: Embedded systems, Temperature Measurement, System on Chip, Transducer, Data Logger, Ethernet

1. INTRODUCTION

Existing systems used to log data are broadly based in two technologies: Embedded systems, and PLC (programmable logic controller) based. Each alternative is adequate to different applications depending on the precision and reliability needed. Embedded systems are mostly used projects with single sensor reading and low resolution and doesnt include industrial communication protocols.

Nowadays, there are systems with capacities that meet a wider set of requirements: high precision, communication compatibility and high resolution. A system presented in Siddhartha Baruah (2010) and Cai (2009) is capable of collecting high precision measurements and publish it to a web server with MODBUS compatibility, and in Shriram K (2013) a health care system was designed to collect health parameters and communicate it with high transmission rate using robust and recurrent system.

In this project, an embedded system has been developed to measure the variables needed to validate the model of heat transfer in a solar collector, applied to cocoa drying. To meet the requirements, two technologies have been implemented, and their description is presented in section III.

The next section presents a description of the principles of solar collector, so as to understand the considerations made in the system design. Section IV and V explain the measurement principle of the sensor system and the validation of results with industrial sensor transmitters. Finally section VI describes the implemented system and results.

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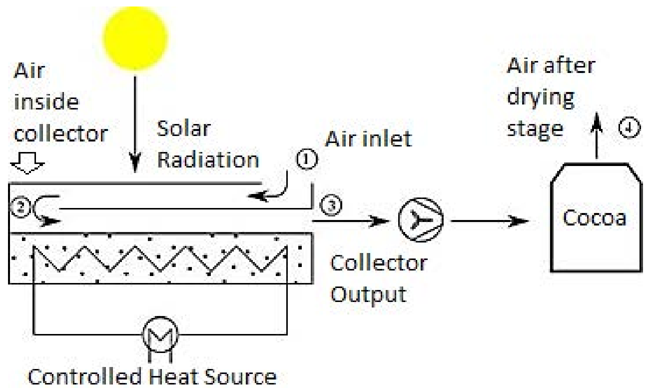

Fig. 1. Solar Air Heater Scheme

2. SOLAR COLLECTOR

The prototype used for the drying process is a solar air heater, harnessing solar radiation and green house effect to raise the temperature of an air flow transferring thermal energy.Air flow will help to dry fruits without modifying most sensible characteristics of products. The collector consists of a pipeline made of two glass covers, which establish an energy trap increasing the temperature of air current, and generating flows induced by solar radiation (greenhouse effect). Under the glass covers there is a second duct(made of black metal plate to absorb solar heat radiation), and a concrete block is at the bottom working as heat storage system. The concrete block suppplies thermal power to the air flow in absence of solar radiation. See figure 1

Validation of mathematical model developed for this collector requires temperature measurements in glass and plate for different positions, and speed of airflow for input and exit(assuming that the airflow speed is constant inside collector).

Fig. 2. Solar Collector with RTD Sensors

To set the temperature model based on Dilip Jain (2004), three points are measured on covers and in absorber plate. Measurements were taken at periods of 3 days to studty the behavior of transmitted thermal power and heat transfer coefficients. Scheme in figure 1 shows the flow of air during the heating process, so to obtain a reliable model of the process, measurements of air temperature variation are required. Image on figure 2 shows the solar collector with sensors mounted in order to measure the variation of temperature during the experiment.

3. CONCEPTS AND COMPONENTS

3.1 System on Chip Technology

Describes the tendency of using manufacturing technologies that integrate the system design based on digital, analog, mixed and radio frequency signal circuits in an integrated circuit or chip. See Furber (2000).

3.2 Mixed Signal Embedded Systems

An embedded system is a computer system with better reliability features than other computer systems and its designed to perform specific task (Noergaard (2005)). In our project this system is used to perform three important tasks, data acquisition, data processing, and communication of data to a central recording unit. The mixed signal architecture integrates the tools to manage analog signals accurately and develop signal processing.

3.3 Programmable System on Chip

Programmable System on Chip (PSoC) is a family of microcontrollers integrated circuits developed by Cypress Semiconductor that include a wide range of modules with different functions in a single chip, and fully programmable blocks. Their main applications are consumer electronics, telecommunications, power control and medical instruments
PSoC family consists of four blocks: Core PSoC that includes the processor, analog configurable resources (like opamps, analog multiplexer, analog filters, and signal amplificators), and digital configurable blocks. Cypress get this by taking advantage of mixed signal architecture. See Ashby (2005) for more details.

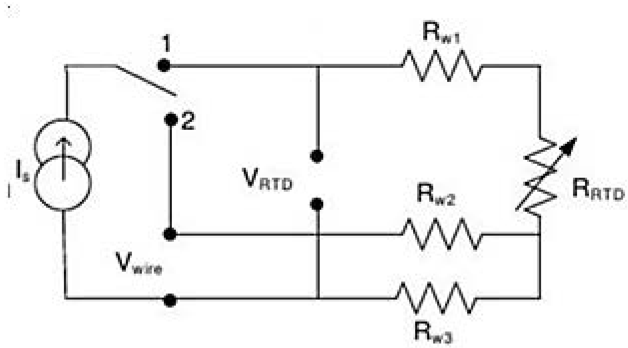

Fig. 3. Mixed Signal Architecture Diagram

3.4 Single Board Computer, Raspberry Pi

Raspberry Pi is a low cost single board computer that includes a Broadcom System on Chip BCM 2835 with ARM1176JZF-s running at 700 MHz, and a video processor (GPU) VideoCoreIV and 512 MHz of ram memory. The default operating system, Raspbian, is a modified version of Debian to Raspberry Pi and brings all the APIs to control the peripherals of the platform. With all this features this SBC is used to control the interaction of the nodes in the platform and record all the gathered data from sensors send it to a remote computer.

4. INSTRUMENTATION AND ACQUISITION SYSTEM

The purpose of this project is the development of a system to measure multiple RTD (Resistance Temperature Detector) sensors and monitor them in real time. Embedded systems are the perfect choice to accomplish these requirements, because it presents the possibility to perform signal processing algorithms with high reliability. The calibration procedure is necessary to avoid bias due to inaccurately current generation in PSoC, circuit system errors and RTD wire resistance mismatch estimation.

RTD sensors have different presentations, depending on the number of wires, with the difference of better compensation of measurement errors added by the resistance of wires. For economical purposes we choose three wires RTD sensors modeled like a variable resistor with fixed resistor in one side and two parallel resistors in the other one.

According to this RTD model we use equation (1) and equation (2) to find the R_{WIRE} value, assuming that the wire resistance is similar and the circuit model appears on figure 3. (This assumption is valid only when wires have same length).

$$V_{RTD} = I_S(R_{W1} + R_{RTD} + R_{W3}) \tag{1}$$

$$V_{Wire} = I_S(R_{W2} + R_{W3}) \tag{2}$$

Reference resistor method was implemented to known value of real current inserted in the circuit and then calculate real R_{RTd} value based on high precision resistor. In our design the calibration procedure is made inserting an initial current by a reference resistor and measuring the voltage across it. This voltage and high precision resistor

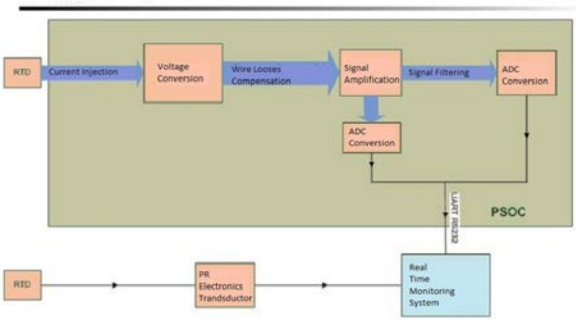

Fig. 4. Data Measuremente Validation Process Scheme

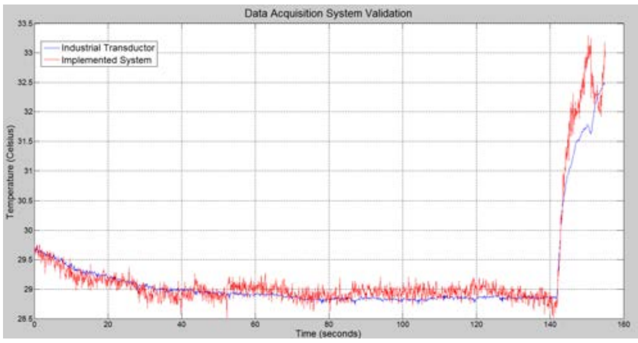

Fig. 5. Response in validation process with exposition to a heating source at 140°C

value define real current value in the system. The fifference between I_S and I_{Real} is that I_S corresponds to theoretical current deilvered by microcontroller and I_{Real} is actual current in circuit. Under these considerations the current value is calculated using equation (3).

$$I_{Real} = V_{AcrossRref}/R_{Ref} \tag{3}$$

So assumming that both R_{Wire} resistances have the same value we can express them as a function ov V_{Wire} and I_{Real}.

$$R_{Wire} = V_{Wire}/(2 * I_{Real}) \tag{4}$$

Finally R_{RTD} was calculated from total resistance value and R_{Wire}.

$$R_{RTD} = V_{RTD}/I_{Real} - 2R_{Wire} \tag{5}$$

4.1 System with raw signal without filtering

To perform the validation of the proposed systems, data gathered from designed embedded solution and the R/I transmitter (PR Electronics) are sampled at the same time and compared. Also both systems were configured to operate between 10 and 100 Celsius degrees (PSoC system have an RTD linearization algorithm included). Data was collected and stored in comma separated value format (CSV) for analysis purposes and flexibility. Figure 4 shows signal analysis scheme.

In test exposed to external heating source both signals reach the same temperature but had different responses to temperature changes. A change in temperature was applied after 140 seconds using an external source, and the response to this variation is observed in figure 5. This change presents a delay in PR Electronics transmitter, and thats because it has a signal processing stage, to suppress noise in signal input but this feature inserts a lag in response to temperature changes (blue signal in figure 5). Nevertheless, data collected reflects a tendency to similar behavior for both systems in stationary response, but presents noise in developed system, so a signal processing stage is needed.

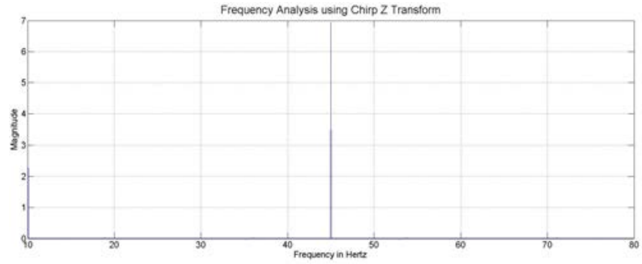

Fig. 6. Frequency Analysis of signal between 10 Hertz and 80 Hertz using Chirp Z Transform

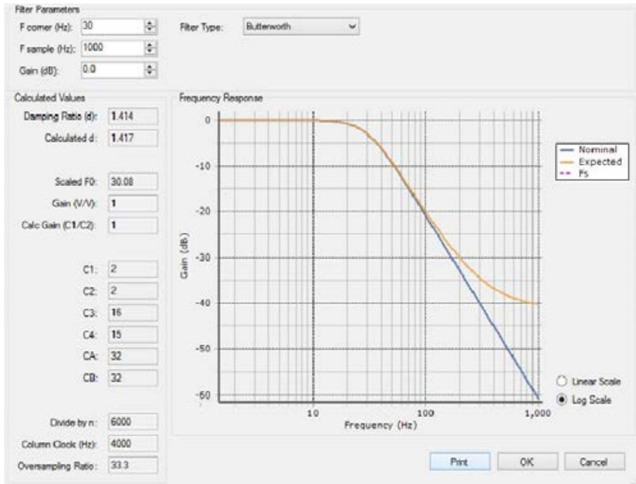

Fig. 7. Butterworth filter design using PSoC Designer

4.2 Signal Processing System

Signals provided by sensor presents white noise added in all channels. The signal processing for this system can be made in two ways, performing recursive filters on Single Board Computer, Raspberry Pi, or by using switched capacitor filters included in PSoC1 chips. This last one allows us to develop an analog filtering layer that doesnt consume processor power and have a real time response. See Ess (2009) and David Van Ess (2011)

In this design we used two microcontrollers of Cypress family. PSoC 1 brings configurable analog components, including switched capacitor low pass filters, and PSoC 5 family has a powerful 32 bit processor, high precision digital to analog converter module and high resolution Delta-Sigma converter, so by using both capabilities it has been developed a solution to address the requirements. See Nidhim (2012) and Ess (2009)

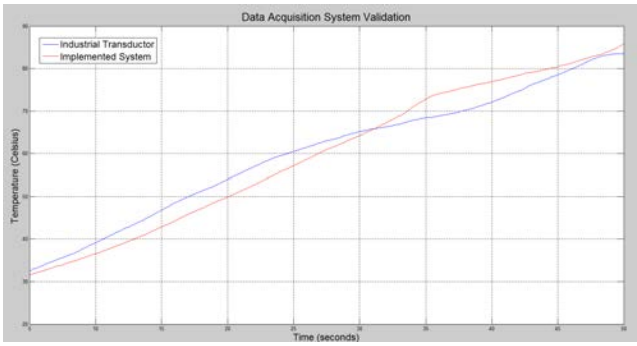

Fig. 8. Response of both systems after signal processing stage with low pass filter with 100 hertz cut-off frequency

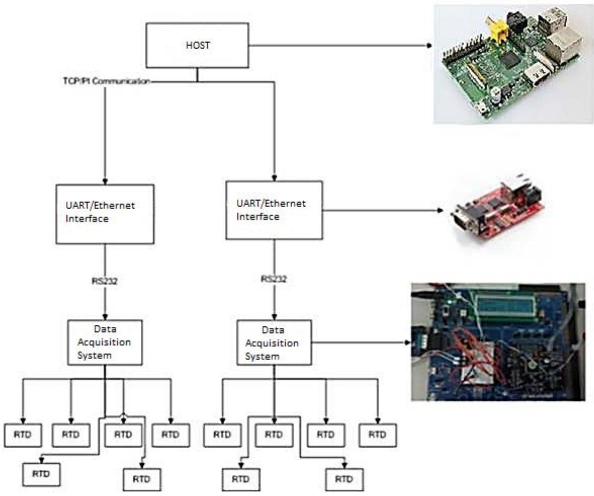

Fig. 9. System communication diagram

Figure 6 shows the frequency analysis of signal using Chirp Z Transform (CZT)to perform a zoom view with high resolulction of Fourier Transform. Studying CZT we can notice that noise frequency is next to 45 Hz so we have to design a low pass filter to reject it.

A Butterworth second order filter was chose to filter the signal with 100 Hz cutoff frequency using PSoC LPF2 Configuration Wizard with no gain. The operation principle of PSoC filters is switched capacitors technology to modify the filter conditions at programming level. The filtered signal is shown in figure 8. For programming and configurations details see Ess (2009) and Corporation (2012).

5. IMPLEMENTED SYSTEM

The system has been implemented to monitor the temperature to validate a mathematical model based on physical laws in heat transfer and to study the performance of collector and the relation with sun radiation.

To achieve this, the setting of measurement nodes was designed to gather the information required in the mathematical model. Each node has a client direction and reports data to a TCP server placed on a Raspberry Pi SBC using RS232/Ethernet module.

Collected data is visualized in a display using the video

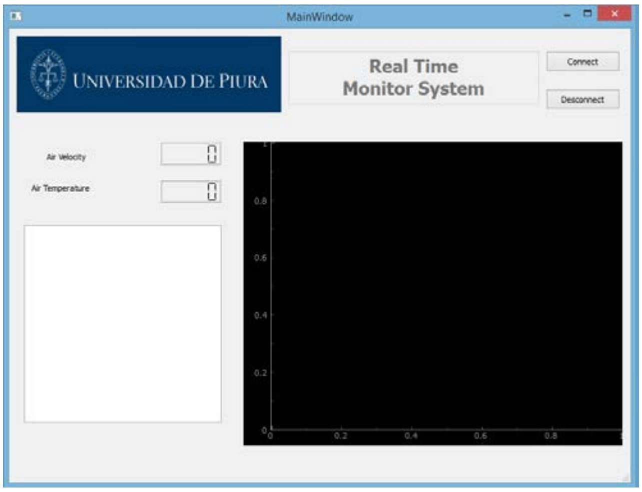

Fig. 10. Graphical User Interface implemented in Raspberry Pi

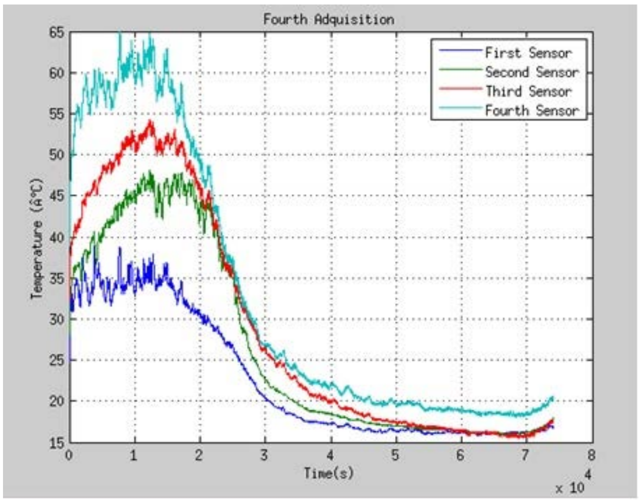

Fig. 11. Data collected from one acquisition data node

processor included in Raspberry Pi SBC with an interface developed using Qt Libraries (these libraries have a good response time with real time signals, thanks to its event based programming). Figure 10 shows the interface with signals of four RTD sensors. Data collected is transmitted to a remote computer and stored in a database.

6. RESULTS

Figure 11 and figure 12 show the data collected by the system, and reflect the variation of air temperature in collector platform. Measurements of three sensors in different positions across second glass in collector (cyan signal corresponds to sensor near to the output of collector, red signal corresponds to sensor in the middle of glass and green signal is from sensor in the beginning of second glass) and air inlet (blue signal) are shown in figure 11.

Data collected from two nodes, each one with 4 sensors is integrated and plotted using Matlab and showed in figure 12. Signals in yellow and magenta correspond to input and output of airflow collector respectively. The second day of measurement presents a different behavior because

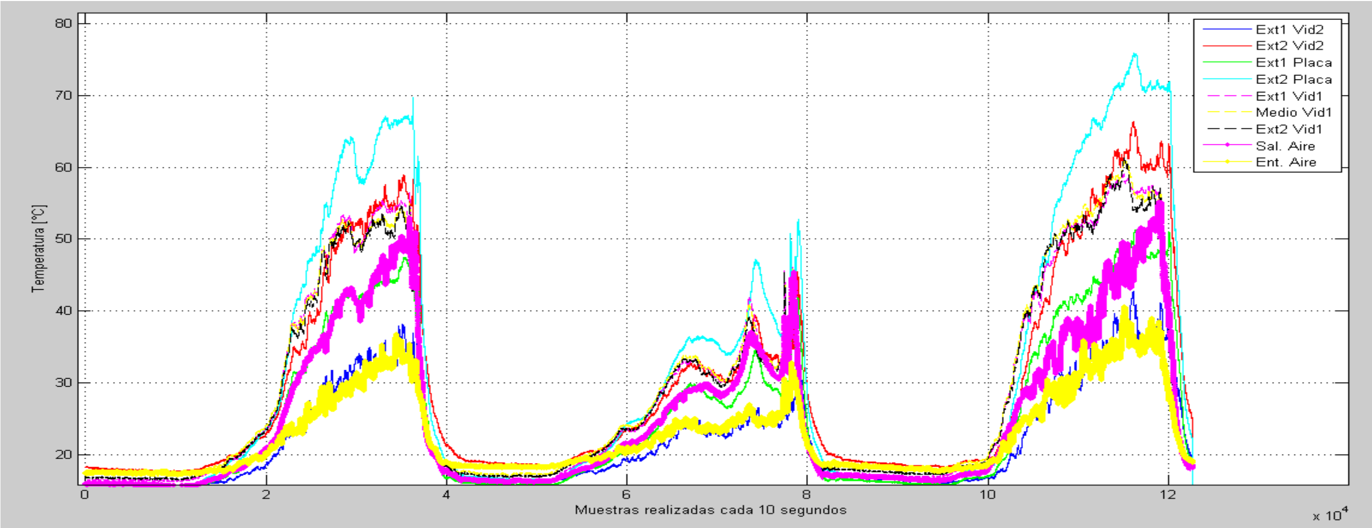

Fig. 12. Data collected from two nodes across three days.

Table 1. Battery Life Estimation based on average current draw

Battery Type	mAh	Hours	Days
AA	1500	53.7	2.2
AAA	1000	35.8	1.5
9V	1000	35.8	1.5
CR1212	18	0.6	0.0
CR1620	75	2.7	0.1
CR2032	220	7.9	0.3
2 AA	3000	107.4	4.5
4 AA	6000	214.8	9

rainy conditions appeared. Measurements were taken with 10 Hz frequency and the proposed model was validated with this data. For this test, the systems was powered by an arregement of three 9V batteries. The lifetime of batteries was estimated using PSoC Power Estimator Spreedsheet, and the results are in the next table. Batteries configuration used corresponds to 4 AA type in Table 1, so the estimated life is approximately 4.5 days but this results could me improved configuring PSoC module with sleep power modes. Raspberry Pi module was powered by an independent solar cell.

7. CONCLUSIONS

All measured data on the prototype should be sampled at the same time, due to the large variation of the atmospheric parameters, so this requires high processing power in the data acquisition system. This feature can improved without increasing power consumption, so the system its able to process higher data transmission rates.

Temperature changes across glass and plate length present high values (Figure 11), so the initial consideration of constant conditions had to be modified after the implementation of system in model validation.

PSoC devices have capability to receive and convert analog signals to digital in order to manipulate them without need of additional electronic devices to perform this task, so the final product doesnt depend on many different components. This feature is reflected in cost of system implementation. In signal processing stage, both nodes have low pass second order filters as an additional feature to manage signal noise without additional computer power consumption. This feature is very useful and enables the adaptation of systems in noisy conditions without additional requirements.

The implemented system only needs DC power, so is possible to use a battery or solar cells system. This feature is helpful in agricultural applications where electric power sources are limited. Comparing the performance of one of most used RTD transmitters in industrial applications with our systems, we can conclude that the implementation of embedded systems and low cost SBC brings the opportunity to develop reliable and accurate systems to signal acquisition and processing.

The resulting system has many advantages in cost, dimensions, communication compatibility as result of using embedded systems and SBC platforms. Also the system can be extended to a sensor network to monitor and integrate data from different sources in different locations with high precision

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