Low-Power Wireless Data Acquisition System

Sergiu Nimara, Mihnea Nandra and Razvan Bogdan, *Member, IEEE*

***Abstract* — State-of-the-art electronics being used by different consumers are increasingly requiring low power modes of operation and extended battery life. In this paper, the low-power component is integrated in a data acquisition system (DAQ), which can read important data about temperature, humidity and light intensity from the environment. The goal of the project is to design a DAQ that uses low-power and can be further integrated in other domain specific applications such as agriculture, sport and health. The obtained results demonstrate that the low-power desideratum can be attained by a specific set of actions.**

***Keywords* — data acquisition system, low-power, environmental sensors, wireless.**

I. Introduction

LOW-POWER data acquisition systems have become more and more popular since technology started to focus on energy consumption.

This domain is very wide and the problems that can be solved with the usage of a DAQ are varied. Those systems can be used to measure the level of CO_2 in the room and can also help keeping track of someone's healthiness. Some of the domains that can be improved by the usage of a data acquisition system are: medicine and home care, agriculture, building safeness, sport.

As all other domains, medicine has evolved in time. Robots and machines have taken control over the medical field. More and more precise measurements are made with the help of machines. To make those measurements precise, some equipment have integrated data acquisition systems [1]. For example, in [2] it is presented a remote monitoring system that uses a surveillance camera for receiving critical information about the patient by analyzing and storing sounds, video images and even temperature and afterwards processing the data and deciding if an alarm is needed or not.

Agriculture has been and is still going to be one of the most important industries in the world. As estimated in [3], Earth should be prepared for the 9.6 billion people that will be living on this planet by the year 2050. With this number of inhabitants, the world should be prepared for an increase of 70% in the need of food supply by 2050 [3]. The solution for this problem can be the implementation of Data Acquisition Systems in the agriculture fields. With the help of the DAQ, precision farming or smart farming can evolve and can help the world by providing faster growing seeds, which has lower need of water and nutrients but has higher yield [4].

DAQ systems are currently used in different areas of sport activities; wearable devices that can track your movement, heart rate, burned calories are becoming increasingly popular over the years [5]. To help the athletes regain their strength, recover faster from injuries or even avoid them, some medical systems have integrated a data acquisition system to measure some parameters such as fatigue degree, the explosion power (response velocity) or even the electrical activity of the muscles and its efficiency [6].

Taking into account the studies above, it can be easily acknowledged that a DAQ system can help in various domains but a low-power DAQ is actually the step-forward that needs to be implemented. To provide the low-power component to a DAQ system, research has been made and it is presented in this paper.

The rest of the paper is structured as follows. Chapter II brings an overview of the whole system and some comparisons between different types of MCU's and wireless communication systems which can be used for building the DAQ. The 3rd Chapter presents the proposed solution and implementation of the system. Chapter IV depicts the results that have been obtained, while the final chapter is dedicated to conclusions and some directions in which the project can be further developed.

II. System Overview

The designed Wireless DAQ (Data Acquisition System) has four main parts:

- Sensors;
- Microcontroller;
- Wireless Communication;
- Server.

To make this data acquisition system work with low energy consumption, the right components need to be chosen. A multi-objective analysis regarding price, energy consumption and required resources and a comparison between some development boards and wireless transmission modules has been made.

This paper was funded under the Saguaro Technology Bachelor Diploma Project 2016-2017 and with the help of Deian Cosaș.

Sergiu Nimara is with the Department of Computer and Information Technology, Politehnica University of Timisoara, Bd. Vasile Parvan 2, 300223 Timisoara, Romania (phone: +40-256-403272; e-mail: sergiu.nimara@cs.upt.ro).

Corresponding authors, Mihnea Nandra and Razvan Bogdan, are with the Department of Computer and Information Technology, Politehnica University of Timisoara, Bd. Vasile Parvan 2, 300223 Timisoara, Romania (phone: +40-256-403275; e-mail: nandra.mihnea@gmail.com, razvan.bogdan@cs.upt.ro).

978-1-5386-3073-0/17/$31.00 ©2017 IEEE

A. *Comparison between microcontrollers*

For this experiment, three microcontrollers have been selected for a short evaluation of current consumption measured in mA, price represented in USD and the needs for the project.

The first microcontroller on the list is ATMEGA328p, being included in the Arduino UNO v3 development board. The ATMEGA microcontroller operates at voltages between 1.8V and 5.5V with a maximum frequency of 20MHz. The microcontroller can be set to work on three different modes [7]: (i) active mode consumes 0.2 mA, (ii) power-save mode consumes 0.75 µA, (iii) power-down mode consumes 0.1 µA. The Arduino UNO v3 is cheap and has a lot of resources which make it one of the most used boards nowadays.

The second development board on the list is the Raspberry Pi 3 Model B SBC. The ARM microprocessor present on this board is not low-power, actually being the biggest energy consumer, but is the most powerful microprocessor from our study. The resources of this board are very impressive in spite of its size. With 4xARM Cortex-A53 CPU's it can work on frequencies up to 1.2 GHz. It also has 1GB of RAM. As already mentioned, this microprocessor is not low-power and it consumes a lot of energy to deliver the high performance. In Boot mode, the RPi 3 consumes an average of 0.35 A and a maximum of 0.75 A. While in IDLE, 0.3 A are consumed by the processor. For a working frequency of 1.2 GHz the Raspberry Pi 3 consumes up to 1.34 A with an average of 0.85 A under stress [8]. This already is a clear sign that the Raspberry Pi 3 is not a good choice for a low-power project.

The last system on the list is the MSP432P401R from Texas Instruments Inc. (TI). The MSP432 is the forerunner of the MSP430. It has a voltage range between 1.62V and 3.7V. The power consumption for the different types of working modes is [9]:

- Active mode consumes 80 µA;
- LPM3 consumes 660 nA;
- LPM3.5 consumes 630 nA;
- LPM4 consumes 550 nA;
- LPM4.5 consumes 25 nA.

In Table 1, a brief comparison between MSP432 and MSP430 is shown.

TABLE 1: COMPARISON BETWEEN MSP430 AND MSP432.

	MSP430	*MSP430X*	*MSP432*
Address space (bits)	16	20	32
Memory address space	64 kB	1MB	4GB
Clock speed (MHz)	25		48
Typical Dhrystone 2.1 (DMIPS/MHz)	None		IEEE754 32-bit FPU
Floating Point	0.288		1.196
ULPBench Low Power score	120		167.4

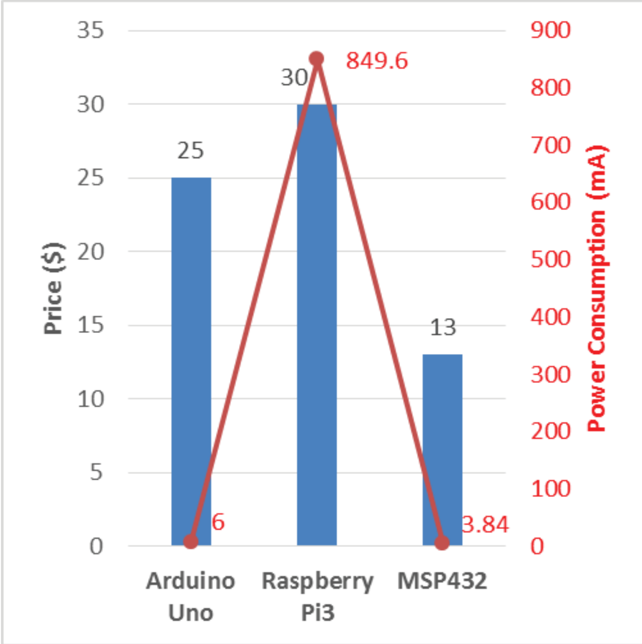

Fig. 1 - Comparison between different microcontrollers

As presented in Table 1, it can be seen that the MSP432 is more performant than its predecessor, the MSP430, because it has more powerful resources and it uses less power.

For making things even clearer, Fig. 1 presents the best choice regarding the type of the microcontroller that can be used in this project. The blue pipes represent the price in USD of each component, while the red line represents the current consumption measured in mA for each board.

Regarding the analysis that was done and with the help of the resulting table, the system used for the project was the MSP432 development board from Texas Instruments.

B. *Comparison between different wireless transmission modules*

To provide the best results, three performant wireless transmission modules were chosen.

The first module is ZigBee RF4CE. It is widely used for home automation, remote-control units or smart meters because it introduces the mesh networking to the low-power wireless space. On the other hand, ZigBee is not suited for applications that need to function on a low-power regime for a long period of time because of its complexity and power requirements. The ZigBee has a range of 100m and a power consumption of 178mW, that is pretty high because it uses Wi-Fi protocol to transfer the data.

The second component is the Bluetooth LE. It is the best solution for low-power devices which have the need to always be connected to the internet because it was specially designed to do that. They use little power, usually 49 µA at 3V for transferring 20 bytes of data / packet.

The last wireless technology that was reviewed is Wi-Fi. The pros for using the Wi-Fi are that is a very efficient wireless technology because it can transfer large packets of data with a speed up to 40 GB/s and it has a working range of up to 1.5 km. The cons are that, because it can transfer big chunks of data, it consumes very much energy and it is not suitable for a CR2032 battery-powered system.

In Table 2 are presented the characteristics of some of the wireless technologies that could have been used in the project. The technologies that are compared are LE (Bluetooth Low-Energy), A (Ant), A+ (Ant), Wi-Fi, Nike+, IR (InfraRed) and NFC.

TABLE 2: COMPARISON BETWEEN WIRELESS TECHNOLOGIES.

	LE	*A&A+*	*Z*	*WIFI*	*NIKE+*	*IR*	*NFC*
Transfer Rate (bits/sec)	960	256	192	40GB	272	121	208
Power Consumption (mW)	0.15	0.183	178	210	0.675	5.844	159
Range (m)	280	30	100	1500	10	0.1	0.05
Throughput (kbps)	305	20	100	6000	272	1 GB	424
CR2032 OK?	YES	YES	NO	NO	YES	YES	NO

Table 2 also presents the differences between these wireless technologies, regarding transfer rate speed measured in bits/sec, power consumption measured in mW, the working range measured in meters, throughput measured in kbps and the possibility to be sustained by a simple CR2032 battery.

Fig. 2 emphasizes the best type of wireless data transfer technology, based on a comparison between price and current consumption. The blue pipes from Fig. 2 represent the current consumption measured in mA and the red lines the price in USD for the three wireless technologies that were compared.

After this analysis was reviewed, the chosen technology was the Wi-Fi (ESP8266 module) for academical, cost and infrastructure reasons.

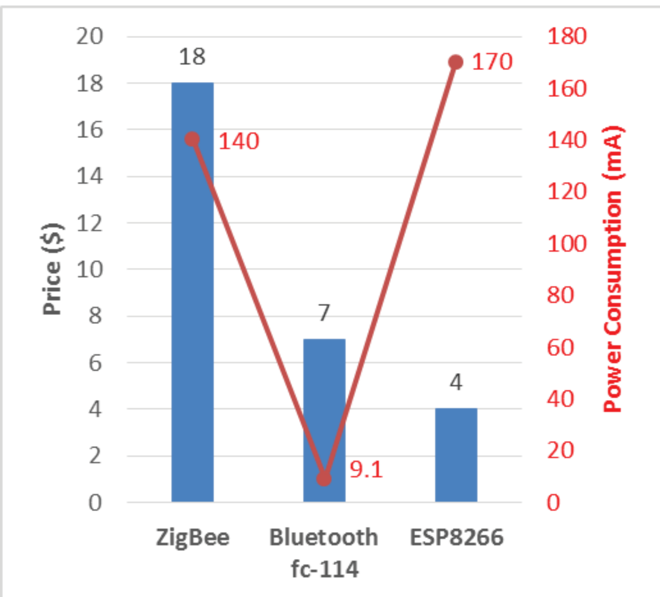

Fig. 2 - Comparison between different Wireless technologies

III. IMPLEMENTATION

To solve the problems described, we have implemented a system that acquires important data about temperature, humidity, and light intensity and sends the data through a Wi-Fi module to a server. The server receives the data and saves it to a hard-disk in a .csv file format.

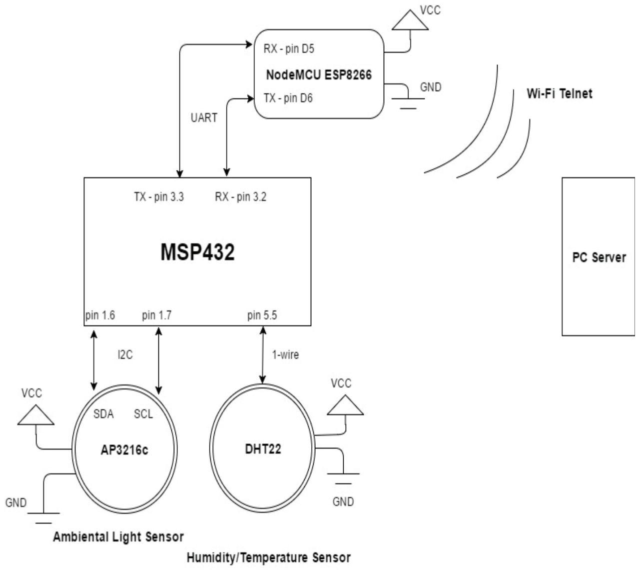

Fig. 3 – The system block diagram

Fig. 3 presents the system's block diagram. The data is read through the AP3216c Ambiental Light Sensor (ALS) and the DHT22 Humidity and Temperature sensor. The DHT22 has an 8-bit single-chip DSP, which is connected to its sensing elements and it features a calibration chamber for accurate readings and temperature compensation.

The ALS communicates with the main board, the MSP432, through a I2C protocol, while the DHT22 communicates through a special 1-wire protocol. After the data is received by the microcontroller, it is sent further to the Node MCU ESP8266 wireless module through UART. The wireless module is the interface between the microcontroller and the server and it is used to send the data to the server through the Wi-Fi protocol. The data is received by the Telnet server and it is stored on the hard-disk.

The server is working on the local IP of the machine and the desired port can be defined by the programmer. The server side has been programmed using C# and the TCP protocol. The functioning of the system relies on the configuration of a Wi-Fi local network, with a certain SSID and password, which facilitate the connection of the NodeMCU ESP8266 wireless module.

To make the system work with low energy consumption, the system is running in sleep mode and only wakes up to read and send data every minute. For this purpose, the Real Time Clock (RTC) module of the microcontroller has been used. The Calendar mode of the RTC module of the MSP432 is configured to wake up the device from deep-sleep once every 60 seconds.

IV. RESULTS

After implementing the system, some tests were performed in order to check the functionality of the system and also to test in which ways the system could be optimized towards low energy.

The Low Power Mode 3 (LPM3) and the Normal working mode of the MSP432 board were chosen to be the references while doing the tests. For minimizing the power consumption, the unused GPIO pins of the MSP432 board were powered down. The measurements were done using the Energy Trace™ feature that can be found in Code Composer Studio 6, which is a development environment released by Texas Instruments. Energy Trace is available for MSP430 and MSP432 microcontrollers and represents an energy-based code analysis tool that measures and displays the application's energy profile and helps to optimize it for ultra-low-power consumption, according to TI [9].

The first test was done to find the difference between the two working modes when doing the data acquisition. The result of the test have shown that in a 300 seconds time span, the energy consumed without the usage of the LPM3 has been 2123.71 mJ and an estimated battery life of 3.9 days, while the usage of LPM3 to read the sensor data has led to a power consumption of only 1656.42 mJ and an estimated battery life of 5 days.

The second test aimed to see the difference between the energy consumed by transmitting the data through UART protocol. In a 300 seconds time span, the energy consumed by the UART, while not using LPM3, has been 1827.79 mJ and the estimated battery life has been 4.5 days. On the other hand, the energy consumed by the UART while using LPM3 has been 1043.59 mJ and the estimated battery life has been 7.9 days.

After processing those results and knowing that the Wi-Fi module current consumption is estimated to be 825 mA in 300 seconds [10], the entire system current consumption can be estimated.

TABLE 3: TOTAL CURRENT CONSUMED BY THE SYSTEM

Total current consumed while using LPM3 in a 300 seconds time span	***Total current consumed without using LPM3 in a 300 seconds time span***
825mA + 502.11 mA = 1327.11 mA	825mA + 643.77 mA = 1468.77 mA

From Table 3, it can be concluded that using the Low-Power Mode helps the system consume less energy, while having the same expected results.

V. CONCLUSIONS AND FUTURE WORK

The presented research demonstrated how a low-power acquisition system can be implemented, taking into consideration different trade-offs between price, power consumption and performance. In order to attain this target, a detailed comparison between state-of-the-art microcontrollers and wireless transmission modules has been made. The power consumption of the implemented system has been monitored, using both the normal working mode and the low power mode of the MSP432 microcontroller. The measurements show that the LPM3 mode of the MSP432 brings significant battery life expectance increase for a DAQ system which reads temperature, humidity and ambient light intensity data.

Regarding the future directions, the project can be extended in different ways. First of all, the project can be upgraded to work with ultra-low-power consumption. Next thing that can be done is to integrate the system into the real-world, helping in the domains described in the introduction. After the system is integrated, the data from the environment is stored and the processing of the data is going to be the next step. The processing of data means that the stored data is going to be analyzed and, based on the results, some actions (external or internal) can be taken.

REFERENCES

[1] Carlos Abellan, Jean-Pierre Cachemiche, Frederic Rethore, "A Data Acquisition System for Medical Imaging" – *Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA)*, 2013.

[2] T. Medjeldi , D. Moreau, J. C. Morissette, "Smart Acquisition of medical data" - *Sciences of Electronics, Technologies of Information and Telecommunications (SETIT),* 2012.

[3] F. Guerrini, "The Future Of Agriculture? Smart Farming," 2015. [Online].Available: http://www.forbes.com/sites/federicoguerrini/2015/02/18/thefuture-of-agriculture-smart-farming/#338e9d6e337c.

[4] Rob Dolci, "IoT solutions for precision farming and food manufacturing," *Computer Software and Applications Conference (COMPSAC),* 2017.

[5] Marko Kos, Iztok Kramberger, "A Wearable Device and System for Movement and Biometric Data Acquisition for Sports Applications," *IEEE Access (Volume: 5), pp. 6411 – 6420,* March 2017.

[6] A. P. Vinod, Chai Yee Da, "An Integrated Surface EMG Data Acquisition System for Sports Medicine Applications," in *Medical Information and Communication Technology (ISMICT),* 2013.

[7] ATMEGA 328p datasheet. [Online]. Available: http://www.atmel.com/images/Atmel-8271-8-bit-AVR-Microcontroller-ATmega48A-48PA-88A-88PA-168A-168PA-328-328P_datasheet_Complete.

[8] Raspberry pi 3 datasheet. [Online]. Available: http://docs-europe.electrocomponents.com/webdocs/14ba/0900766b814ba5fd.pdf.

[9] MSP432P401R datasheet. [Online]. Available: http://www.ti.com/product/MSP432P401R.

[10] Talk2, "Temp. and Humidity Sensor with CR2032 for over 1 year!". [Online]. Available: https://www.hackster.io/Talk2/temp-and-humidity-sensor-with-a-cr2032-for-over-1-year-580114.