Undergraduate Research Experiences in Wireless, Powerless Sensor Technology

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Abstract *— This document describes three undergraduate research projects in which students from the University of Puerto Rico at Mayagüez developed wireless sensor circuits designed to monitor the health condition of mechanical components. In the first project, a circuit to measure strain was developed. In the second, students developed a circuit that uses a capacitive transducer and an oscillator to sense and transmit temperature information. In a third project, students developed a circuit that replaces the oscillator with an ultra-low power microcontroller. Our main objective is to provide students with the opportunity to learn about sensors and instrumentation by performing a meaningful research experience. The prototypes developed by the students can be the first steps in the development of a technology that integrates sensors into composite structures to allow for performance and health monitoring during operation.*

Index Terms *— Undergraduate research, sensor education, multidisciplinary education*

INTRODUCTION

Undergraduate research projects often provide a way of complementing traditional engineering education by allowing students to explore areas that are either too new to be formally integrated in their curriculums, or too specific to be covered by the broad nature of traditional courses. One of such areas is wireless, powerless sensor technology.

During the last year, a group of students at the departments of Electrical and Computer Engineering and Mechanical Engineering of the University of Puerto Rico at Mayagüez, have been working on a series of small, interrelated research projects on wireless microsensor technology. This paper describes three of such projects developed as part of the Industrial Affiliates Program (IAP) [1].

The projects focus on the integration of sensors into mechanical components. A technology that accomplishes this objective is of interest because it would allow monitoring the condition of mechanical components while they are in operation. Thus it can be use to detect damage, prevent accidents, or to optimize preventive maintenance. Some requirements for these devices are:

- Mechanical characteristics must be compatible with those of the mechanical component;
- Small size because they may have to be placed in difficult to reach places;
- Data transmission must be wireless, since the mechanical components may be in motion while the devices are used and the use of wires directly connected to the sensor circuit might not practical;
- Should avoid the use of batteries;
- Should be low-cost and maintenance-free.

Related research works have been performed by [2], [4], and others.

The projects described here explore the development of micro-sensors to monitor strain and temperature. The projects can be summarized as follows:

- Project 1: To integrate a semiconductor strain sensing element into a Dupont Kapton® thick film layer; to develop and test a wireless strain micro-sensor and associated electronics.
- Project 2: To monitor the temperature variation of a bearing cage during bearing operation using a batteryless, wireless sensor.
- Project 3: To incorporate a microcontroller of the MSP430 family as the main component in a battery-less wireless temperature sensor interface, and evaluate methods of wireless data transmission.

STRAIN SENSOR

The wireless strain sensor developed in this project was based on a semiconductor strain sensing element integrated into a resistor bridge, shown in Figure 1. Commercially-available resistive strain gages made by Micron Instruments were used.

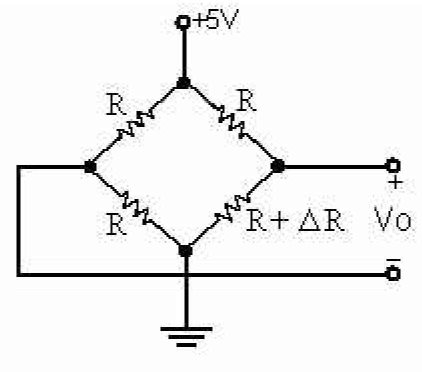

FIGURE 1
WHEATSTONE BRIDGE USED FOR STRAIN MEASUREMENT.

The activities performed as part of this project were:

1. *Design of the sensor's electronic interface* : Students designed and implemented the strain gage measurement circuit, shown in Figure 2. The circuit contains a difference amplifier, an AD654 voltage-to-frequency converter, and a TX-2 RADIOMETRIX transmitter. A RADIOMETRIX receiver was used to wirelessly detect the signal. The signal frequency was measured with a handheld multi-meter. Printed circuit board fabrication methods and surface mount technology (SMT) were used to construct the circuits. Figure 3 shows a picture of the test assembly on a steel beam on which the stress measurements were to be performed.

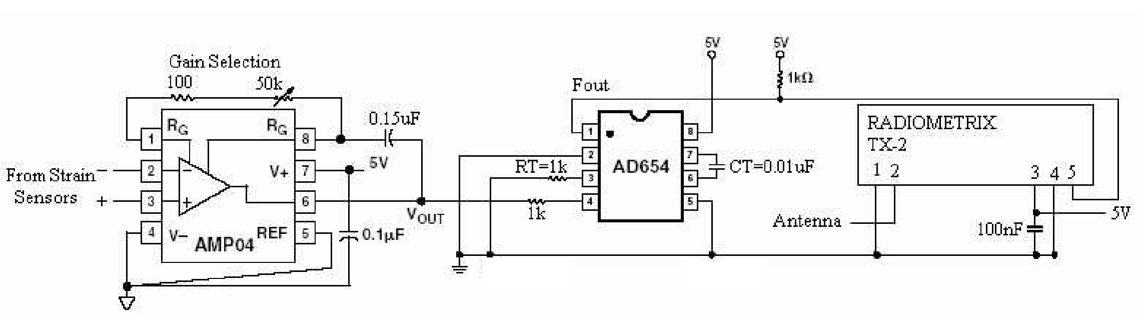

FIGURE 2
SCHEMATIC FOR WIRELESS STRAIN MEASUREMENT CIRCUIT

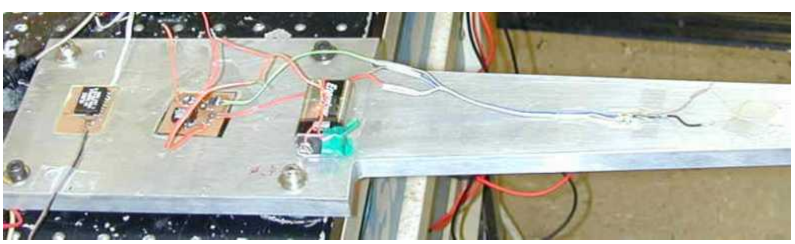

FIGURE 3
PHOTOGRAPHY OF THE SENSOR, TRANSMITTER AND RECEIVER

2. *Structural analysis* : A structural analysis of the beam provided values of the strain generated due to the applied force at a known location.

3. *Testing and calibration* : Students calibrated the wireless strain sensor using a cantilever steel beam with a thin rectangular section instrumented with the wireless strain sensor, shown in Figure 4. The beam was rigidly supported at one end and force was applied at the other end using deadweights. The application of deadweight at the free end produced strain at the sensor location and hence changed the sensor frequency. The output frequency was recorded as a function of the applied load on the beam. as shown in figure 5.

FIGURE 4
CALIBRATION SETUP.

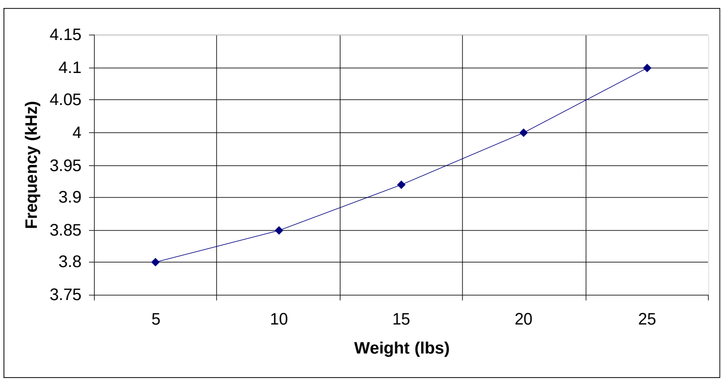

FIGURE 5
RESULTS FROM THE RIGID BEAM CALIBRATION EXPERIMENT.

OSCILLATOR-BASED TEMPERATURE SENSOR

This project explores the development of a batteryless, wireless sensor for bearing-cage temperature measurement. The device is based on the incorporation of temperature-sensitive capacitors into an oscillator, making the frequency of oscillation temperature-dependant. The four students that participated in this project performed the following activities:

1. *Design of the oscillator* : A Colpitts oscillator was employed as a telemeter circuit [5]. Figure 6 shows a schematic diagram of the oscillator. Inductor L and the capacitors C_{s1} and C_{s2} form an LC tank that determines the oscillation frequency.
2. *Design of a radio -frequency (RF) power -supply*: remote power for the sensor operation was supplied via RF energy remotely irradiated into coil L_2. Exciter coil L_3 is placed in the vicinity of inductor coil L_2. A sinusoidal voltage applied to L_3 excites L_2. The resulting alternating voltage is rectified and filtered, producing the dc voltage to power the oscillator.
3. *Sensor testing and calibration* : Calibration was performed immersing the sensor in a temperature controlled oil bath. The sensor setup is shown in figure 8. The calibration was performed by monitoring the oscillator frequency with a small antenna and an oscilloscope while the oil bath was heated. A thermocouple was used to obtain an independent temperature measurement. Figure 9 shows the temperature, measured by the thermocouple, and the detected shift in frequency.

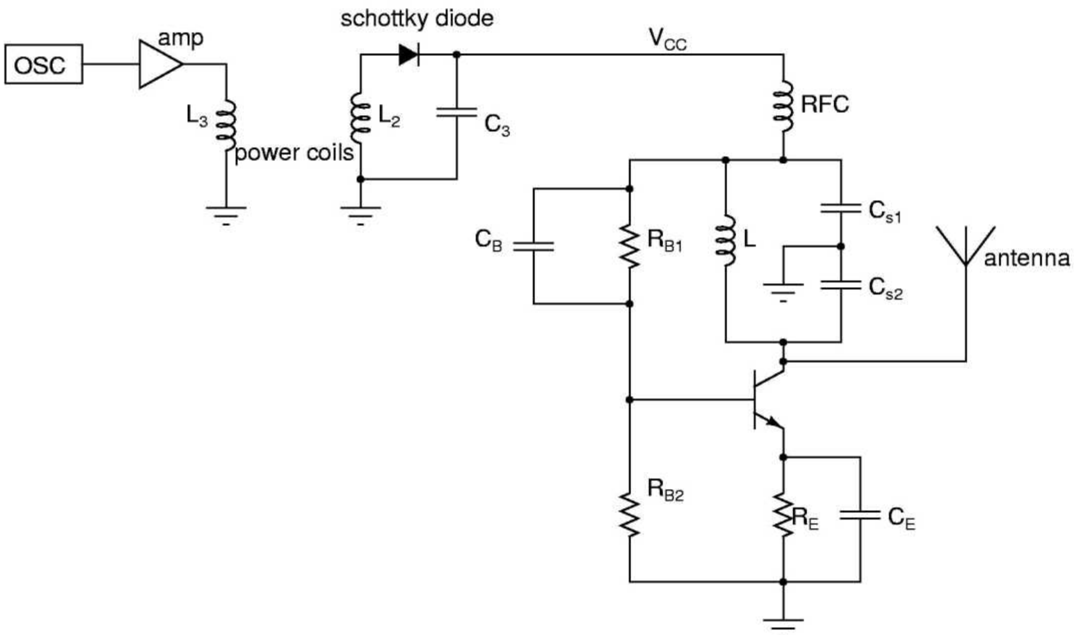

FIGURE 6
WIRELESS SENSOR CIRCUIT SCHEMATIC.

MICROPROCESSOR-BASED, SMART, WIRELESS TEMPERATURE SENSOR

The objective of this project is to incorporate a microcontroller into the sensor circuit, enabling the simultaneous use of multiple transducers and allowing the deployment of addressable sensor networks.

The tasks to be completed: (i) Developing a wireless temperature sensor interface using the MSP430 as the main component, (ii) demonstrate the microcontroller operation with an RF power source, and (iii) to evaluate wireless data transmission by modulating the reflected impedance seen by the reader. Figure 7 shows a block diagram of the system..

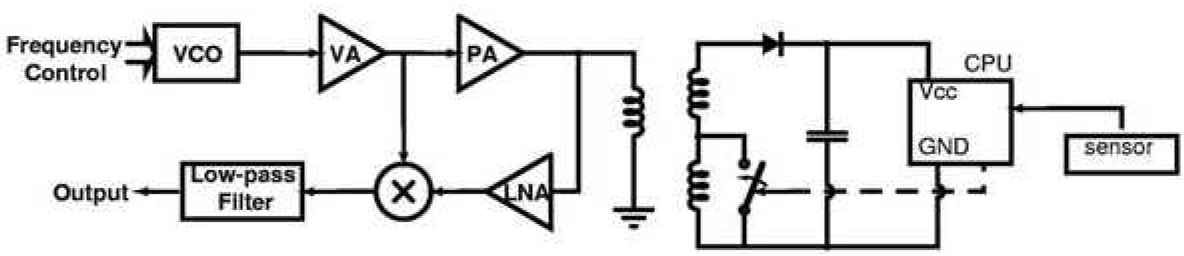

FIGURE 7
MICRO-PROCESSOR BASED WIRELESS SENSOR INTERFACE.

Power to the microcontroller side is remotely supplied by means of a radio frequency signal. Due to the magnetic coupling between the coils an alternating voltage is generated and induced into the other coil on the sensor. This ac voltage is further rectified into a dc voltage that powers the sensor unit.

Several schemes for data transmission were considered, being the selected one based on reflected impedance. Here, a switch connected in parallel to the power receiving coil changes the impedance reflected in the reader. Driving the switch with a microcontroller I/O line allows for transmitting digital data.

At the moment of writing this document, this project was still in its early stages of development. Student efforts have been concentrated in designing the sensor interface, Characterizing the microcontroller power requirement, developing the RF powering, and understanding the data transmission method. Preliminary measurements indicate that detectable impedance changes reach the primary coil. Also, the power consumption characterization is pointing to a feasible operation with the energy picked by the antenna.

STUDENT FEEDBACK

Upon completion of the first year, students were requested to provide feedback about their experience through an exit survey. Below we summarize their answers.

- **Question 1:** *Participating in the project was ___________ (1. not effective/ 2. somewhat effective/ 3. effective/ 4. very effective) in providing me with experience in __________ (see subjects below)* .

Table 1 summarizes the student answers to question 1, which were averaged to obtain the average effectiveness. This have the effect of producing a low score for a subject like *micro-controllers* since only the students that participated in the third project had to deal with it. Most students felt this project gave them more experience in electronics, presentations skills, and sensor technology.

Subject	Average Effectiveness
Sensor Technology	3.5
Sensor Characterization	3.2
Wireless Communications	3.1
Electronics	3.7
Mechanical Measurements	2.7
Applied Electromagnetism	2.3
Microcontrollers	2.5
Working with others	4
Public presentations	3.7

TABLE 1
ANSWERS TO QUESTION 1.

- **Question 2:** *After participating in the project, I am ____________ (1. not interested in/ 2. less likely to/ 3. more likely to/ 4. very enthusiastic about) ____________ (see alternatives below).*

Table 2 summarizes the student answers to this question. It can be observed that participation in the project helped the students feel more reasured about the carrer field the wanted, and inclined to pursue graduate studies. Paradojically, they did not feel as enthusistic about getting a job in research and development.

Alternative	Average score
Go to graduate school	3.2
Seek R&D job	3
Undergraduate project participation	3.1
Select right career field	3.4
Improved classroom learning	3

TABLE 2
ANSWERS TO QUESTION 2

- **Questions 3 to 5:** In the third question we asked the student to rate if their experience was (negative, neutral, positive, or very positive). All answers were “very positive”. The fourth questions asked them to indicate wether the above projects were a good complement to classroom learning, to which they all answered “yes”. Finally, in the fifth quetion we requested their opinion about the impact of their participating in the project in their future career, and all of them replied that they expect it to have a positive impact.

CONCLUSION

This article summarizes our experience using research projects to introduce undergraduate students to wireless sensor technology. The multidisciplinary nature of the projects presented here provided us with an effective, hands-on approach to expose undergraduate students to practical problem solving in several areas of electrical engineering, that include: sensor technology, sensor characterization and calibration; wireless communications; mechanical measurements; electronics; applied electromagnetism; and microcontrollers. From the way the students rated their learning experience, we can conclude that the projects provided an effective educational tool in the areas of sensor technology, electronics, sensor characterization, wireless communications and mechanical measurements. The area of microcontrollers was an effective learning experience only for the students participating in the third project, which was expected since the other two projects lacked this component.

Besides improving their knowledge of the technical and scientific aspects of this subject, the projects, being part of the Industrial Affiliates Program, provided the students with an opportunity to improve their report writing and public speaking skills.

REFERENCES

[1] M. Toledo-Quiñones and J. Colom Ustáriz, Industrial Affiliates Program At UPRM: An Undergraduate Research Program. In Proceedings of the International Conference on Engineering Education. Valencia, Spain, 2003..

[2] D.G. Krantz, J.H. Belk, Remotely Queried Wireless Embedded Microsensors in Composites, In Proceedings of SPIE - The International Society for Opti-cal Engineering, v.3044, 1997, pp.219-226

[3] D. Krantz, J. Belk, P.J. Biermann, J. Dubow, L.W. Gause, R. Harjani, S. Mantell, D. Polla, P. Troyk. Project Update: Applied Research on Remotely-queried Embedded Microsensors. In Proceedings of SPIE - The International Society for Optical Engineering, v.3673, 1999, pp.157-164

[4] C. Hautamaki, S. Zurn, S.C. Mantell, D.L. Polla. Embedded Microelec-tromechanical Systems (MEMS) for Measuring Strain in Composites. In Journal of Reinforced Plastics and Composites, v.19, no.4, 2000, pp.268-277

[5] A.S. Sedra And K.C. Smith. Microelectronic Circuits. New York; Oxford University Press, 1997. ISBN 0-19-511663-1.