Wireless Sensors without Batteries

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Researchers have worked on various ways to reduce the power consumption in wireless sensors.

Introduction

Wireless sensor networks have been the subject of numerous research and development activities in the past decade. Despite all this attention, their widespread deployment is yet to be realized. The main hurdle is power consumption requirements and limited on-board battery capacities. Researchers at the University of Maine, Wireless Sensor Networks (WiSe-Net) laboratory have worked on various ways to reduce the power consumption in wireless sensors including: efficient compression and coding techniques [1], power optimized routing [2], and cooperative relaying [3]. All these techniques combined with coordinated sleep-wake algorithms developed by other research groups [4] pushed wireless sensors toward efficiency limits with, most recently, only marginal improvements. This calls for a paradigm shift to take wireless sensors networking to the next level in order to unleash its true potential. In this article, we present a novel approach to wireless sensing in which batteries are completely eliminated from the sensor boards, while networking and multiple-access are still feasible. In this new class of battery-free or passive sensors, power is emitted to all sensors using high frequency radio beams and their response is read by a sophisticated interrogating unit employing several digital signal processing techniques.

The rest of this article is organized as follows. Device operation principles are presented first, followed by orthogonal code design, and application scenarios.

Device Operation Principles

The concept of passive sensors is much like Radio Frequency Identification (RFID), with the difference being that RFIDs will only send a number (Tag ID) back to the reader. Passive sensors can be designed to measure physical parameters such as temperature, humidity, pressure, and strain and send those values back in addition to the sensor tag number. RFIDs are read one at a time like barcodes, while passive sensors can be read in groups at the same time. The responses are then separated using signal processing techniques.

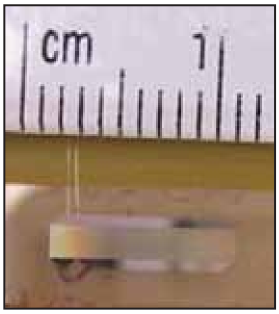

Figure 1 • Prototype sensor device fabricated at UMaine.

Building such devices requires knowledge of microwave and acoustic waves as well as coding theory and information theory. This section covers the former analog aspects, followed by the next section, which studies the latter coding.

It all starts with depositing micron-sized metallic “fingers” on a piezoelectric substrate using direct writing or photolithography in a clean room. An electromagnetic signal that impinges on the metallic interdigitated “fingers” is transduced to acoustic waves, which travels on the surface of the substrate crystal. These metallic fingers are designed in such a way that they can add phase shift to each smaller portion of received RF signal independently. These phase-shifted smaller portions travel with different velocities in the substrate. Physical changes in the environments changes these velocities and phase shifts making a distorted signal that is reflected back to the interrogator. Figure 2 depicts a schematic

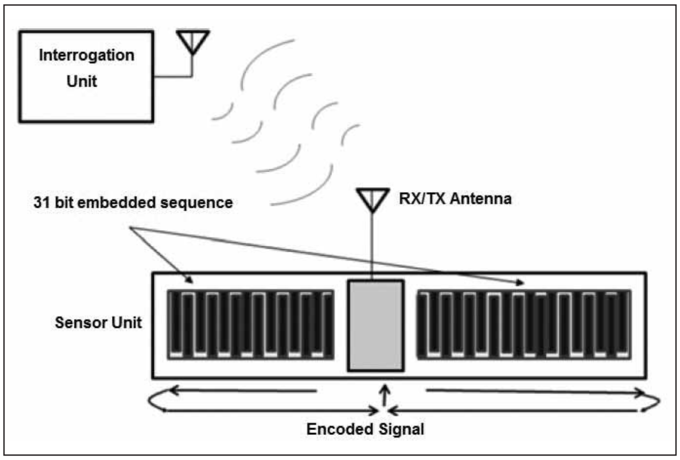

Figure 2 • Sensor Device with 31-bit code.

diagram for a sensor device with 31-bit code. For more info refer to [5].

Orthogonal Code Design

Single wireless sensors without a battery DC supply operating in a passive fashion were introduced back in the late 1970's. However, due to multi-sensor requirements in most industrial applications, this sensor technology was not widely used. Available spectrum for this type of application was scarce, and consideration of alternate frequency bands seemed prohibitively expensive. The introduction of battery-free wireless sensor networks enables a wide array of applications allowing for communicating with multiple sensors simultaneously in time and within the same frequency band. The distinguishing factor between sensor responses is the orthogonal codes embedded in their design. The metallic phase shifting portion of the sensors from the previous section is designed in such a way that each sensor response is orthogonal to all other sensor responses. This is in contrast to the digital orthogonal code design that led to code division multiple access (CDMA) systems. Each sensor response is a multi-pulse analog signal that is detected using matched filters and neural networks at the receiver side [6]. The sequence of phase shifters is called a code that needs to have high auto-correlation and low cross correlation with other codes. These codes, if designed properly, allow for usage of multiple sensors within a reasonable distance from each other covering a specific area. For more info refer to [7].

There are two ways to interrogate these sensors. The first method is called time reversal which transmits a signal that is a time-reversed version of a specific sensor code, causing only that sensor to respond. This is used for selective sensor readings with higher reliability in noise dominant regime. The second method starts with broadcasting an ultra-wide band pulse to "ping" all sensors and receive all responses superimposed on each other. This method allows for faster reading of many sensors at the expense of lower reliability in an interference-dominant regime.

Application Scenarios

There is a broad array of applications that one can imagine for the battery-free wireless sensors introduced in this article. Passive sensors can be used wherever embedding sensors in objects, structures or vehicles is desired for a long period of time, making battery replacement hard or costly to perform if not impossible. Temperature monitoring in industrial plants, machines, and rotating blades such as wind turbines or helicopter blades; structural health monitoring using strain sensors; and shape monitoring of inflatable bridges or habitats are some examples of these applications.

Inside its Wireless Sensing Lab, the University of Maine hosts the first inflatable lunar habitat module built by NASA Johnson Space Center. This module was built in 2009 and delivered to UMaine to be outfitted with passive wireless sensors for structural monitoring. Figure 3 presents outside and inside views of this module that is outfitted with 124 passive wireless sensors for shape detection, leak detection, and impact localization. We have developed localization methods for sensors built at UMaine at 107

Figure 3 • NASA's Inflatable Lunar Habitat Module at UMaine.

MHz, as well as other types of sensors operating at 900 MHz with a communication range of 16-18 ft using 20 mW power [8]. Other applications include bridge load monitoring and jet engine age monitoring.

About the Author:

High Frequency Electronics Editorial Advisor Ali Abedi received his Ph.D. in Electrical and Computer Engineering from the University of Waterloo in 2004. He serves currently as Associate Professor of Electrical and Computer Engineering and Director of the WiSe-Net Lab at the University of Maine, Orono. He held visiting professor appointments at the Maine Institute for Human Genetics and Health (2010-11) and the University of Maryland at College Park (2012). His research works include analytical performance evaluation of block codes; new methods for performance and convergence analysis of Turbo-codes; and applications of error correction codes in wireless sensor networks for structural monitoring, space exploration and biomedical applications. His research on wireless sensing of lunar habitats was featured on the “NSF Science360” website in 2012. Dr. Abedi is the co-author of two books on Propagation Engineering published by Springer, and over 60 peer-reviewed journal and conference proceedings papers. He has received a number of awards and honors from the Natural Sciences and Engineering Research Council of Canada (NSERC), the Japan Society for the Promotion of Science (JSPS), the Canadian Space Agency (CSA), NASA, IET, and IEEE. He has been a senior member of IEEE since 2007 and currently serves on several IEEE committees. He has served on Technical Program Committee (TPC) of the following conferences: IEEE Globecom 2012 (Anaheim), ICCNC 2012 (Hawaii), ICEED 2011 (Malaysia), ACC 2011 (India), IEEE FBW 2011 (Montreal), IEEE Globecom 2011 (Houston), IEEE CCECE 2011 (Canada), IEEE Wireless Communications and Networking Conference 2010 (Australia), IEEE Queen’s Biennial Symposium on Communications 2010 (Canada), IEEE/ACM International Wireless Communications and Mobile Computing Conference 2009 (Germany), IEEE GCC 2009 (Kuwait), IEEE Canadian Workshop on Information Theory 2009 (Canada), IEEE Wireless Telecommunication Symposium 2009 (Czech Republic), IEEE Vehicular Technology Conference 2009 (Alaska), World Academy of Science International Conference on Wireless Networks 2009 (Las Vegas).

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