CES Research Report
Sothern Illinois University Carbondale
Adaptive compressive sensing techniques for low power sensors
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Project Description

This project investigates novel adaptive approaches to more effectively apply compressive sensing technique [1, 2] in low-power sensor design. Recently, compressive sensing emerged as an attractive technique in low-power sensor development [3, 4, 5], because of its capability to allow sensor signals to be sampled at rates lower than Nyquist rate. Currently, low-power sensor circuits using compressive sensing techniques typically have pre-fixed sampling rates during the entire sensing operations. This approach works well in the cases that the sparsity of sensor signals does not experience dramatic changes. However, in applications that the sparsity of sensor signals exhibits large changes, adaptive sampling approach can potentially further reduce the power consumption of the sensor devices. This motivates the proposed research.

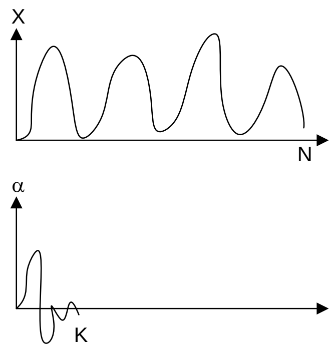

Figure 1: A compressible signal

Assume vector X contains N sampled sensor outputs in time domain as shown in the top panel of Figure 1. By operation of $X = \psi \cdot \alpha$, where ψ is an $N \times N$ matrix, vector X is projected into another domain and the projected values are contained in vector α, whose size is also N. If α contains only K significant terms and the rest of N-K terms are zero or insignificant as shown in the bottom panel of Figure 1, sensor signal X is called sparse or compressible (the sparsity refers to the value of K compared to N). For compressible signal X, the compressive sensor produces compressed output Y using matrix operation $Y = \phi \cdot X$, where Y is a vector with the size of M and ϕ is an $M \times N$ matrix. For sensor signal X, if its corresponding α projection has only K significant terms, and ψ and ϕ are incoherent, the value of M that enables the receiver to reconstruct X from Y is $M = \mathrm{O}(K \cdot \log\frac{N}{K})$. If $K \ll N$, then $M < N$, implying that the sensor outputs can be potentially sampled at rates less than Nyquist rates.

The project investigates the feasibility, potential benefits and circuit techniques to adaptively apply compressive sensing techniques in low-power sensor systems. The basic hypothesis is that the sparsity of sensor signals may vary over the time or under different operating conditions. Therefore, the number of samples of sensor signals to be transmitted or sensed can be adaptively adjusted according to the variations of signal sparsity. This adaptive approach potentially results in further power reduction for compressive sensing circuits.

Objectives

The objectives of the project are to: 1) validate the hypothesis by examining realistic biomedical sensor signals from Multi-parameter Intelligent Monitoring in Intensive Care (MIMIC II) database (http://physionet.org); 2) study potential power saving achieved by adaptively adjusting compressive sensing scheme; and 3) develop circuit techniques that enable low-power sensor nodes to detect when sampling rates should be adjusted.

Industrial Relevance

Low power sensors, including biomedical sensors, have emerged as an important sector of semiconductor and embedded electronic industries, which not only poses significant future growth but also has the potentials to dramatically change various aspects of human life. Recently, compressive sensing has been demonstrated as an attractive low-power technique to implement various biomedical sensor circuits. The proposed research is to further advance the knowledge and techniques in this area and potentially helps industrial companies develop more power efficient sensor devices.

Project Outcomes

By analyzing various real sensor signals, including ECG, EEG, blood pressure (BP), etc., obtained from MIMIC database, we observed that signal sparsity does fluctuate over the time, which validates the feasibility of adaptive compressive sensing approach. Accordingly, the measurement sizes for these sensor signals can be adaptively adjusted over the time without violating the signal recovery accuracy requirement. The variations of measurement sizes for various signals are shown in Figure 2 [6].

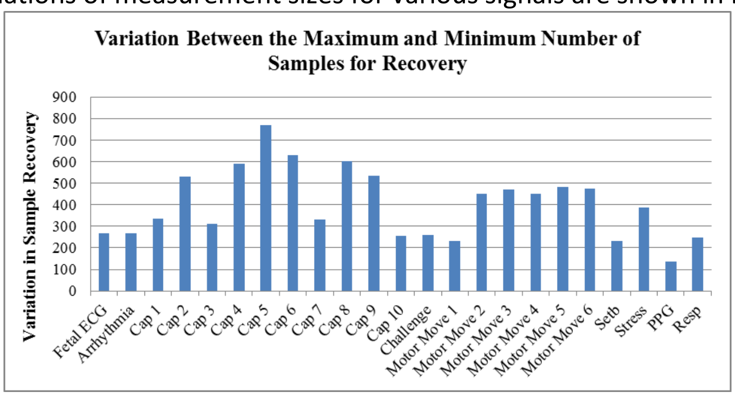

Figure 2: Variation between the maximum and minimum number of samples

The potential power savings by adaptive compressive sensing operations are also investigated. The results demonstrate that significant power saving can be achieved as shown in Table 1. To facilitate this study, high-level power estimation models for a generic wireless sensor topology as shown in Figure 3 are developed [6]. The developed power models also benefit other research in the field of low-power sensor or sensor networks.

Table 1. Potential Power Saving by ACS

Signal	Conv. CS	ACS	Power Savings
Fetal ECG	3.08 mW	2.31 mW	25%
Cap	4.57 mW	3.75 mW	17.2%
Stress	2.98 mW	1.57 mW	47.3%
PPG	1.55 mW	1.27 mW	18.1%

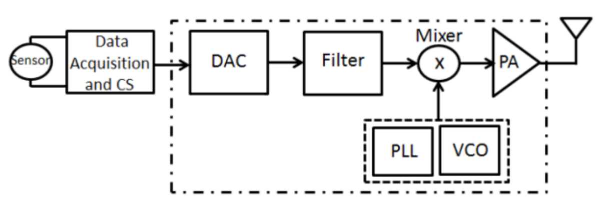

Figure 3: wireless sensor block diagram

The research also leads to a promising approach to detect signal sparsity variations and subsequently adjust the sampling rate at the sensor node. This is one of the important issues that need to be addressed in the implementation of adaptive compressing sensing operation. We proposed to use a low-power analog (continuous-time) wavelet transformation (WT) circuit to monitor the signal sparsity during sensor operation and to adjust the sampling rates according to the output of the analog WT circuit. The relation between the optimal sampling rate and the WT circuit output is stored in a lookup table. The procedure to establish the relations are sketched in Figure 4. Currently, we are investigating the effectiveness of the proposed method.

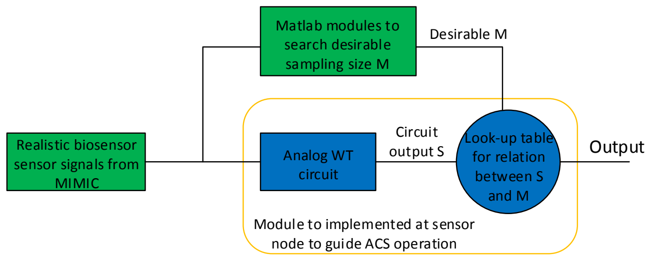

Figure 4: Establishing the relation between signal sparsity and the output of analog WT circuits

Research Team

The research team is led by Drs. Haibo Wang and Spyros Tragoudas, who are both with the SIU ECE department. Two highly motivated Ph. D. students Naresh Mudhireddy and Adam Watkins are also working on the project.

References

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