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Implementation of Compressive Sensing Algorithm for Wireless Sensor Network Energy Conservation

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Abstract: Huge data processing contributes many factors in wireless sensor network such as network traffic and energy constraint. Using compressive sensing a new technique in data acquisition which reduced the required sampling rate to reconstruct the original signal will therefore lessen the power consumption. This paper will implement the compressive sensing algorithm of the wireless sensor network installed in the greenhouse. The primary objective of the design is to reduce the power consumption on wireless system network by maximizing the data packet payloads while minimizing the transmission activity of the Wireless Sensor Network. The sensor and receiver node consumes more power when transmission of data is taking place. The main contributions of this paper are to apply the compressive sensing algorithm in the greenhouse monitoring system to lessen the power consumption of the WSN, to serve as a reference for the new design of analog to digital converter using sampling rate lower than the traditional Nyquist rate and to give ideas to other researchers that compressive sensing can be applied to other WSN applications. This study will do the compression of the measured data in the sensor node and transmit it over a specified time. Matlab will be used to simulate and recover the original signal for verification of the results.

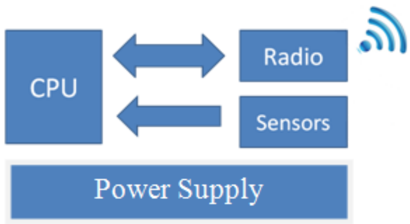
Keywords: compressive sensing; power consumption; digital signal processing; WSN

1. Introduction

Compressive Sensing (CS) is a new paradigm in signal processing particularly for data acquisition [1][2]. This theory opposed the traditional Shannon-Nyquist which states that in order to recover the original signal the sampling rate should be twice as the signal being measured [3][4]. In compressive sensing it needs fewer samples or measurements. It will only process the large coefficients and disregard the zero coefficients. This type of compression algorithm reduces the size of data sent and decreases the storage requirements of the system. Moreover, this will also lessen the transmission activity of the sensor node.

Wireless Sensor Network (WSN) is composed of distributed sensors use to monitor different parameters for many applications such as environmental, health care, industry, automation and transportation. Data that are being processed in the network is so huge that can cause network traffic, packet loss and more power consumption. The power consumption limits the lifetime of the WSN. All the components in the WSN as shown in Figure 1 need power to function. The sensor node measures physical conditions in the environment such as temperature, humidity and light intensity. It digitizes the inputs and transmits it to the server, which will be needed for collecting and monitoring the physical conditions. In a wireless sensor network environment which is composed of different sensor nodes interconnected with each other, the amount of data that is being processed is so huge. This huge amount of data is one of the factors that can cause power dissipation. Once the sensors are deployed, the batteries cannot be replaced at any time. According to Donoho [1] "Why go to so much effort to acquire all the data when most of what we get will be thrown away? Can we not just directly measure the part that will not end up being thrown away?" In the paper [5] it stated that the wideband signal in most of RF applications contain small information rate. This only proved that not all the signals that are being processed are useful.

Figure 1. Sensor Node Block Diagram.



2. Compressive Sensing Background

Compressive sensing deals with acquiring the signal with a few numbers of measurements. Collect massive amount of data and do the compression by neglecting most of the samples. It disregards the zero coefficients in a sparse signal representation. It only focuses on large or non-zero coefficients. The first consideration in a compressive sensing algorithm is the sparsity of the signal. In order to recover the signal in its original form the signal should have sparse representation. In this paper, the sensor readings represent the data vectors wherein $x \epsilon \mathbb{R}^N$. Assuming that the signals are sparse, the representation of the compressible signal can be expressed as:

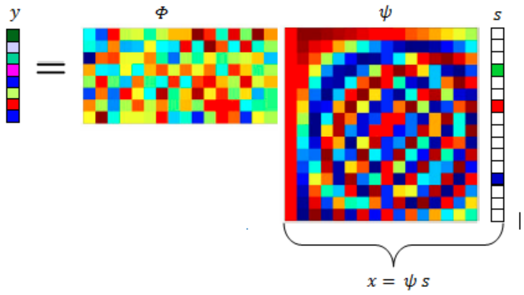
$$x = \sum_{i=1}^{N} s_i \psi_i \qquad (1)$$

where $\boldsymbol{\psi}$ is the transformation basis $\boldsymbol{\psi} = \{\boldsymbol{\psi_1}, \boldsymbol{\psi_2}, \boldsymbol{\psi_3} \ldots . \boldsymbol{\psi_N}\}$ and $\boldsymbol{s}$ is a K-sparse representation of x. The sensing matrix $\phi = \{\phi_1, \phi_2, \phi_3, \ldots . \phi_N\}$ is an $Mx\ N$, wherein it has far fewer rows than column $M \ll N$. The compress signal can be represented in the form of:

$$y = \Phi x \qquad (2)$$

y is now an M×1 column vector and x is an N×1 column vector. Since y is M×1, therefore it is easier to transmit the data over the network. As presented in the paper [6] Figure 2 illustrated the description of the matrix dimensions.

Figure 2. Schematical description of matrix dimensions with 3s-sparse vector [6].



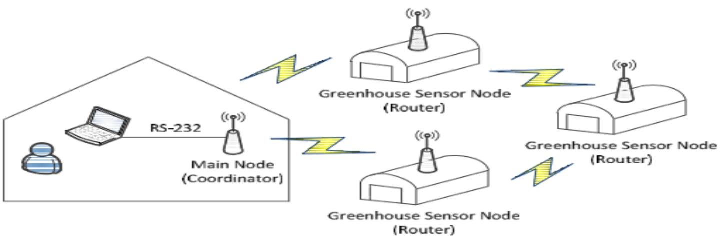
3. Discussion and Methodology

Data transmission is the most consuming activity in the WSN. In order to save the energy, the reduction of data transmission over the network is the primary importance. In this paper the theory of compressive sensing will be used to monitor the temperature in a greenhouse. Sensor nodes are deployed in the greenhouse and the main coordinator transmits the temperature values directly to the server.

3.1. Existing Greenhouse Monitoring System

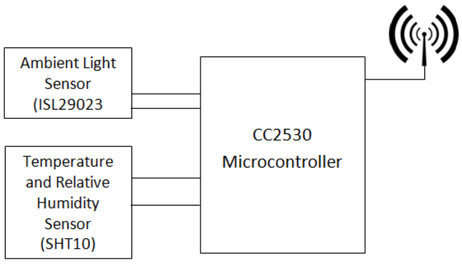
The wireless sensor node was installed in the greenhouse that is used to collect environmental parameters such as temperature, humidity and light intensity [7]. Three greenhouses were monitored as depicted in Figure 3. The actual installation of the WSN took place at Da-yun Organic vegetable farm, Taoyuan County, Taiwan.

Figure 3. Architecture of Greenhouse Monitoring [7].



The sensor node comprised of CC2530 as the microcontroller, SHT10 humidity sensor, DS18B20 temperature sensor and ISL29023 for the light ambient sensor. Figure 4 illustrated the block diagram of the sensor node. SHT10 is a commercially available capacitive sensor element that used for measuring the relative humidity while the temperature is being measured by the band-gap sensor. It has a 14-bit analog to digital converter and serial interface circuit. The CC2530 is a low power system-on-chip (SoC) compliant with IEEE 802.15.4 Zigbee standard. It uses 8051 microcontroller, programmable flash memory and 8KB RAM. It has power management module that prolongs the battery life.

Figure 4. Block Diagram of Greenhouse Sensor Node.



3.2. Power Consumption

Based on the measurement setup in the Application Note of CC2530 [9] the current consumption of the microcontroller can be estimated using the mode of operation of the microcontroller. For Operation 1, there is no sending of data to the receiver node therefore the microcontroller will immediately go to sleep mode. For Operation 2, there is a message sending and therefore the receiver will wait for the message and will return an acknowledgement signal to the sending node. In Operation 3 it is the same as Operation 1 but instead of transmitting the MAC data request it transmit the Toggle command. Operation 4 is the same as Operation 2 but while waiting for the message to receive a Default Response command was sent. The current consumption of each mode is summarized in Table 1.

Table 1. Current Consumption of CC2530[8].

Mode of Operation	Time (ms)	Consumption (mA * mS)
Operation 1	6.5825	100.5775
Operation 2	23.865	388.4335
Operation 3	7.2025	120.4175
Operation 4	13.01	245.669

Assuming that the existing greenhouse monitoring system sense the temperature every 5 seconds and transmit the data 20 times a day. The total current consumption of the CC2530 can be computed as:

$$CC_{Total} = CC_{Sleep} + CC_{Op1} * 17{,}260 + CC_{op3} * 20 + CC_{op4} * 20$$

$$CC_{Ave} = \frac{(86400 + 100.5775 * 17260 + 120.4175 * 20 + 245.669 * 20)}{84600} = 21.17uA$$

If the capacity of the battery is 2000mAh, therefore the battery life can be calculated as 2000mAh / 21.17uA = *92165.9h* or equivalent to *3840 days*. Please refer to the Application Note[8] for the detailed discussion on the measurement setup of CC2530.

The measured current consumption of the existing system is shown below:

$$60 * 60 * 24 = 86400\ s\ (per\ day)$$
$$CC_{ave} = CC_{normal} + \ CC_{sendstatus})/86400$$
$$CC_{ave} = \frac{32mA * 86400 + 36mA * 5760}{86400} = 34.4\ mA$$

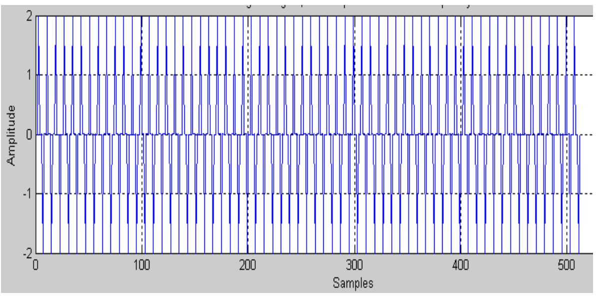
The battery life = 2000mAh / 32.27mA = 61.98H or equivalent to 2.58 days

4. Present Work

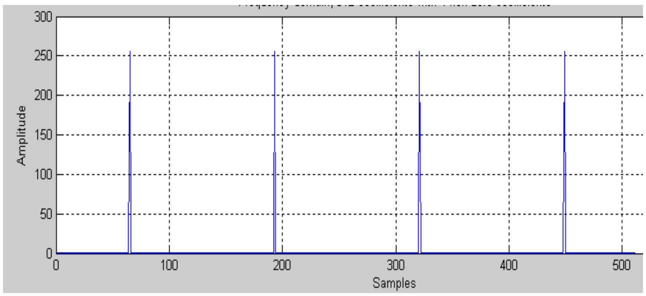
The primary objective of this paper is to lessen the transmission activity of the WSN but not sacrificing the quantitative measurement results. For a single transmission of data packet, several measurements are compressed. In doing so, the compressive sensing algorithm will used to compress several temperature measurements in a single transmission. The compressive sensing algorithm was simulated using MATLAB software to verify if the signal can be recovered to its original form.

Discrete Fourier transform was used to acquire the large coefficients of the signal. The sensing matrix $\phi = \{\phi_1, \phi_2, \phi_3, \dots . \phi_N\}$ is an M x N matrix, where M « N. In order for the CS algorithm to recover the signal, the original signal should have sparse representation. The program used 512 samples and used the operating frequency of the temperature sensor. The reference frequency was based on the datasheet of the SHT10 humidity and temperature sensor. After running the program, the 512 sample signal can be represented with only four large coefficients. It also recovered the original signal using only the four large coefficients. Based on Figure 5 the signals can be reconstructed below the Nyquist rate. This proved that from 512 samples, the signal can be recovered using few measurements.

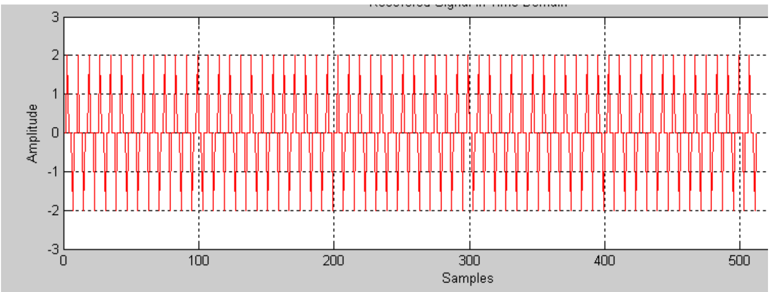
Figure 5. (a) Original Signals with 512 Samples. (b) Four Large Coefficients after Four Fourier Transform. (c) Recovered Signal



a.



b.



4. Conclusions

In doing this, it will reduce the resources needed to process the data in the wireless sensor network environment. Instead of transmitting all the sensed data, it can be stored in the memory for a specified time. The stored data is compressed and transmitted over the network. Therefore, if several data are packed together in a single transmission this will limit the transmission activity of the WSN. Moreover, this compression can also be applied to any WSN applications.

Acknowledgment

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