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Outlier Detection In Wireless Sensor Networks Using Compressive Sensing Algorithm

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Abstract

An outlier is a data value which is significantly deviated from the remaining data. A wireless sensor network is composed of a large number of sensor nodes that are deployed in the assigned area to perform particular functions in a system. In Wireless sensor networks (WSNs), outliers are the major issues that affect the inherent characteristics, such as flexibility, maintenance costs and scalability. The sources of an outliers include noise, errors, events and malicious attacks on the network. In this paper, we proposed a Compressive sensing algorithm (also known as compressive sensing, compressive sampling, or sparse sampling) to detect outliers in the images obtained from wireless sensors. The objective of this proposed method is to obtain an outlier degree of images in wireless sensors based on standard deviation, which provides the data quality for better selection process. Compressed Sensing theory is implemented to detect object through background subtracted images and the objects of interest which occupy a small portion of the camera view. Also we achieved good compression ratio of detected image.

Keywords: Compressive Sensing, Discrete Cosine Transformation, Outlier Detection, Wireless Sensor Networks.

Introduction

Wireless sensor networks comprised of a large number of small sensor nodes, integrated with sensing, computational power, and short-range wireless transmission capabilities, and have powerful resource constraints in terms of energy, memory, computational ability and communication bandwidth [1, 10]. Sensors concatenation into structures, machinery, and the environment, bounded with the efficient delivery of sensed images. The ideal wireless sensor is networked and scalable, consumes very little power, is smart and software programmable, efficient for fast data acquisition, reliable and accurate over the long term, costs little to purchase and install, and requires no real maintenance.

Architecture of Wireless Sensor Network

1. The tiny sensors are deployed all over the implemented background in WSNs.
2. The Networks are usually comprised of few sinks and large quantity of sensor nodes.
3. Sensor nodes are ordered into clusters.
4. Each node has a corresponding cluster header.
5. Each sensor node can sense different parameters such as temperature, smoke and relative humidity.
6. Nodes location details can be obtained by equipment such as Global Positioning System (GPS) or Bluetooth.

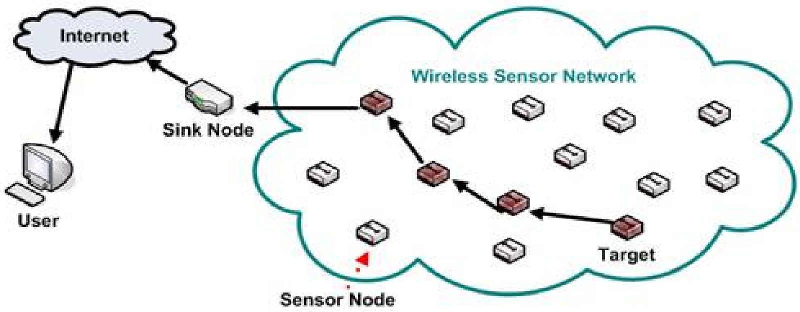

Figure 1: Block diagram of a Wireless Sensor Network

Sensor nodes can be used for continuous sensing, event detection, location sensing, and local control of sensors. We classify the applications in military, environment, health, home and many commercial areas. It is possible to expand this classification with more categories such as space exploration, chemical process industries and disaster relief. Most of the sensor network routing techniques and sensing tasks require the knowledge of location with high accuracy without losing information. Thus, it is important that a sensor node has a location finding system for outlier detection for gathering information safely [10].

Outlier

Outlier is defined by the author Hawkins formally defined as follows [2]:

"An outlier is an observation which deviates so much from the other observations as to arouse suspicions that it was generated by a different mechanism."

The value which differs substantially from other set of observations is referring to as *Outlier*. Outliers are also referred to as abnormalities, discordant, deviants, or anomalies in the data [6, 7].

Material and Methodology

Compressive Sensing Algorithm

Compressive Sensing is a signal processing technique for efficiently gathering and reconstructing a signal by finding solutions to underdetermined linear systems [5]. Image compression is processed to remove the unwanted information from the image to increase system efficiency [9]. The important information is extracted from DCT technique such that it can be reconstructed without losing quality and information of the image. Transform coding is the most efficient among all especially at low bit rate [3]. Transform coding is based on the principle that pixels in an image show a certain level of correlation with their neighbouring pixels. It shows a major role in many harsh applications, such as remote sensing (weather and earth applications), medical imaging, transmission, video-conferencing, military and space application.

Discrete Cosine Transformation

The discrete cosine transform (DCT) denote an image as a sum of sinusoids of varying magnitudes and frequencies. The *dct2* function computes the two-dimensional discrete cosine transform (DCT) of an image. The DCT has the property that, for a typical image, most of the visually significant information about the image is concentrated in just a few coefficients of the DCT. Due to this reason, the DCT is often used in image compression applications [3].

The two-dimensional DCT of an M-by-N matrix A is defined as follows.

$$B_{pq} = \alpha_p \alpha_q \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} A_{mn} \cos\frac{\pi(2m+1)p}{2M} \cos\frac{\pi(2n+1)q}{2N}, \quad \begin{matrix} 0 \le p \le M-1 \\ 0 \le q \le N-1 \end{matrix}$$

$$\alpha_p = \begin{cases} 1/\sqrt{M}, & p = 0 \\ \sqrt{2/M}, & 1 \le p \le M-1 \end{cases} \quad \alpha_q = \begin{cases} 1/\sqrt{N}, & q = 0 \\ \sqrt{2/N}, & 1 \le q \le N-1 \end{cases}$$

The values Bpq are known as the DCT coefficients of A.

The invertible transform of DCT is used, and its inverse is given by-

$$A_{mn} = \sum_{p=0}^{M-1} \sum_{q=0}^{N-1} \alpha_p \alpha_q B_{pq} \cos\frac{\pi(2m+1)p}{2M} \cos\frac{\pi(2n+1)q}{2N}, \quad \begin{matrix} 0 \le m \le M-1 \\ 0 \le n \le N-1 \end{matrix}$$

$$\alpha_p = \begin{cases} 1/\sqrt{M}, & p = 0 \\ \sqrt{2/M}, & 1 \le p \le M-1 \end{cases} \quad \alpha_q = \begin{cases} 1/\sqrt{N}, & q = 0 \\ \sqrt{2/N}, & 1 \le q \le N-1 \end{cases}$$

The inverse DCT equation can be represented as any M-by-N matrix A can be written as a sum of MN functions of the form-

$$\alpha_p \alpha_q \cos\frac{\pi(2m+1)p}{2M} \cos\frac{\pi(2n+1)q}{2N}, \quad \begin{matrix} 0 \le p \le M-1 \\ 0 \le q \le N-1 \end{matrix}$$

These functions are known as the basic functions of the DCT. The DCT coefficients Bpq applied to each basis function.

Proposed Algorithm

- The image first is read as arrays of pixels.
- The DCT is applied to each block; it is worked from left to right, top to bottom.
- Each block is compressed using quantization loop based on index value and sorting.
- The array of compressed blocks that comprise the image is stored in a drastically reduced amount of space.
- When desired, the image is reconstructed, known as a process that uses the Inverse Discrete Cosine Transform (IDCT).

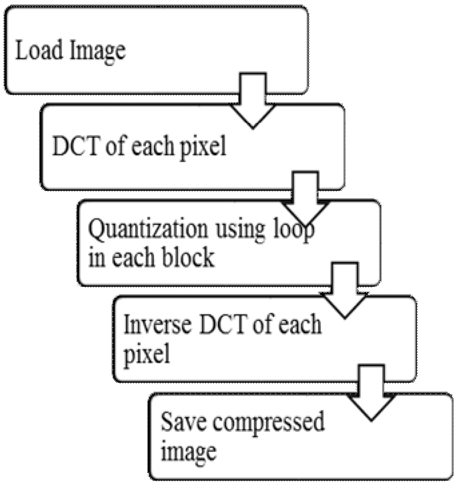

Figure 2: Flow Diagram for DCT Compression

Mean Square Error

In general MSE of an estimator measures the average of the squares of the errors in an image, that is, the difference between the estimator and what is estimated. MSE is a function which is corresponding to the expected value of the squared error. The difference occurs because of compression and because the estimator doesn't account for information that could produce a more accurate estimate.

Given a noise-free m×n image I and its noisy approximation K, MSE is defined as:

$$MSE = \frac{1}{m\,n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2$$

Peak Signal to Noise Ratio

As a measure of the quality of the image, the peak signal to noise ratio (PSNR) is typically used. This PSNR ratio expresses the difference in quality between the original image and the decompressed one, while the higher the PSNR is the better the quality of the decompressed image is. The expression of PSNR in decibels (dB) is given below in (1).

$$PSNR = 10 \log_{10}\left(\frac{255^2}{MSE}\right) \quad (1)$$

$$where: \quad MSE = \frac{1}{m\,n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left\|I_0(i,j) - I_r(i,j)\right\|^2$$

$$m,n = image\ size > 0,$$

$$I_0 = original\ value,$$

$$I_r = compressed\ value$$

STD and Mean

An outlier is defined in terms of standard-deviation and mean values of image data [4]. The standard deviation is a statistical measure of the pixel value for an image. If pixel values of images are similar then deviation tends to zero values else it gives higher values. The algorithm could decrease the communication noise within the sensor nodes by utilizing discrete transformation and reduce the risk of data insufficiency.

Results and Tables

The sample database is collected from a wireless sensor network which is interfaced through MATLAB. The results are processed using MATLAB software.

The set of image frames consists of normal images, outlier images and a background image represented in figure (3). All images are compress based on compressive sensing. Then the difference profile of images with the background image is obtained and analyzed as shown in the table (1). The set of image frames are obtained from WSNs and same algorithm is applied to all image databases. The execution time mainly depends on the dimension of images and size of image database, the average time was about 30 seconds for one image base.

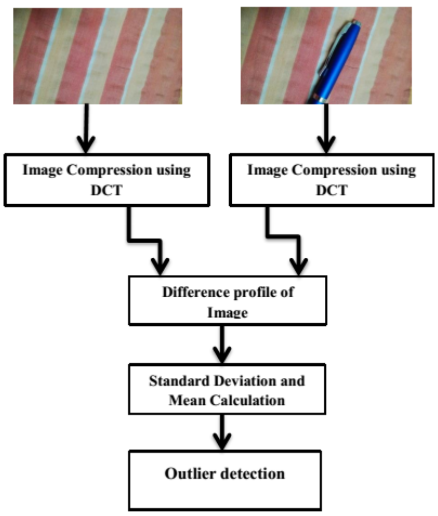

Figure 3: Block Diagram of Proposed method

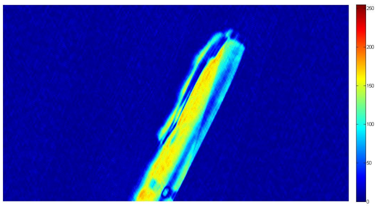

Figure 4: Difference Profile of image

This method can be implemented for different dimensions of images database that is collected through Bluetooth interface with MATLAB.

Table 1: Analyzed Image Values

Image	Dimensions (pixels)	Size of Image (kB)	Compression ratio (%)	Mean square error MSE	Peak Signal to Noise Ratio PSNR (dB)
Background image	1440x2560	1370	78.02	9.6378e+05	53.5457
Test Image	1440x2560	1600	79.62	9.6376e+05	53.9570
Detected Image	1440x2560	94.8	–	–	–

In proposed paper the PSNR obtained between two images is the measure of quality between the compressed image and test image. Higher the PSNR give better quality of compression. As shown in table (1), we obtained a moderate compression of images.

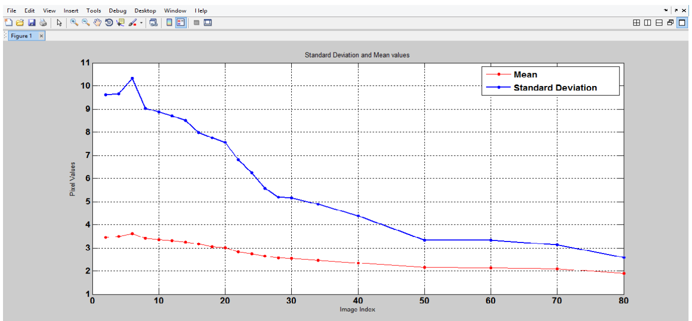

Figure 5: Standard deviation and Mean for images which illustrate places where the pixels' standard deviation has higher value.

The experimental results as shown in figure (5) consist of standard deviation and mean values of difference profile of 80 synthetic image frames are measured. The images are of dimensions 1392x512. The maximum deviation is obtained in images are represented in figure (6). This represents the image frames with outliers of significantly high deviation values.

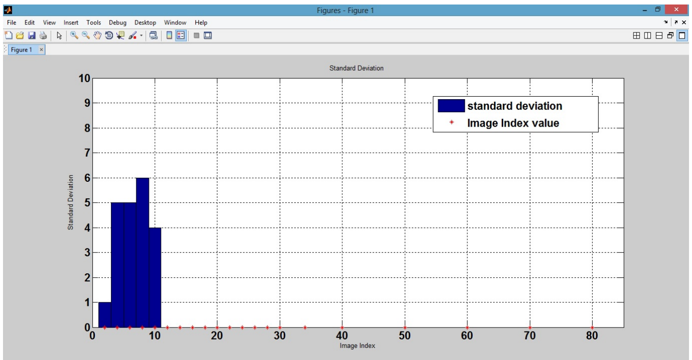

Figure 6: Detected Outlier image based on standard deviation.

Conclusion and Future Work

The degree of outliers can be obtained using the Standard deviation and mean calculations. Higher deviations represent the outliers in the image frames. Also the image quality is reduced after compression and hence can be improved by using different filters. In future we would like to detect outlier types depends upon different features of objects such as shape, orientation or intensity values.

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