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Wireless Sensor Networks Data Processing Summary Based on Compressive Sensing

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Abstract: As a newly proposed theory, compressive sensing (CS) is commonly used in signal processing area. This paper investigates the applications of compressed sensing (CS) in wireless sensor networks (WSNs). First, the development and research status of compressed sensing technology and wireless sensor networks are described, then a detailed investigation of WSNs research based on CS are conducted from aspects of data fusion, signal acquisition, signal routing transmission, and signal reconstruction. At the end of the paper, we conclude our survey and point out the possible future research directions.

Keywords: Compressed sensing, Wireless sensor, Networks, Sparse signal, Data processing.

1. Introduction

In recent years, wireless sensor networks [1, 2] (Wireless Sensor Networks, WSNs) communications and protocol design has been extensively studied, and WSNs often is used in national defense, environmental monitoring, traffic management and many other areas, it is prepared by the international attention, and it is the focus of the research field. However, in a wireless sensor network, there is a resource-constrained feature with node storage capacity and node energy try, such as how to reduce the amount of data which is collected, thus the energy consumption of each node is reduced, and the communication capacity of the network is increased, the survival lifetime of the network is improved, this is a research hotspot.

Compressed sensing theory is the study of signal sparsity or compressibility, and it is the new theory of the signal sampling and the appropriate data compression, and there are distinct advantages and broad application prospects in the signal processing field. In the data acquisition and signal processing, compressed sensing theory breaks through the limitations of traditional Shannon theorem. The data acquisition mode is by changed to achieve further development and innovation of the traditional theory, and the correlation between the data is used, and the transmission and the storage are greatly reduced in the network data. Compressed sensing technology is combined with the appropriate routing protocols to improve the communication capacity of the entire network, latency and network survivability life and other issues.

Structure arrangement of this paper is as follows: The second part introduces the research status of the compressed sensing technologies and wireless sensor networks, third part is the classify summary of the wireless sensor network technology based on the compressed sensing, thesis final part are conclusions and outlook.

2. Compressed Sensing, Wireless Sensor Network Research Status

2.1. Compressed Sensing Theory

Compressive Sensing (Compressive Sensing or Compressed Sensing, CS, also known as compressed sensing or compressive sampling) technology has developed a new field of signal processing techniques [3-6] in recent years. Since 2006, after formal papers are published, Compressive Sensing is quickly attracted attention from researchers in related fields. Pioneers in the field are Terence Tao et al [3-6]. The theoretical studies mainly focus on the sensor matrix selection and reconstruction algorithms. Just in a few years time, compressed sensing has been rapid development their own from theory to applications , and it becomes a hot research direction, and it is widely applied to the areas such as medical image processing, radar, communication, recognition, machine learning, etc.

Compressed sensing process can be described as follows: When a signal meets sparsity, or there is sparse form in a transform domain, the measured signal can accurately reconstructed with less measure signal by compressed sensing theory. Its theoretical framework is shown in Fig. 1.

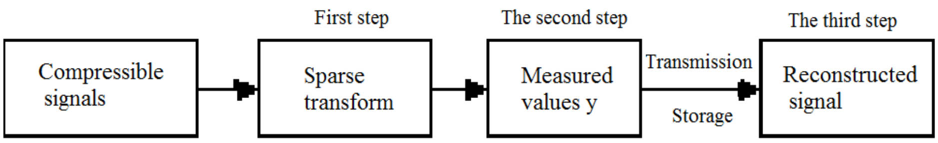

Fig. 1. Compressed sensing theoretical framework.

If a known measured matrix is $\phi \in R^{M\times N}(M << N)$, and a signal is x, the signal measurement process is as follows:

$$y_{m\times 1} = \phi_{m\times n} x_{n\times 1} = \phi_{m\times n} \psi_{n\times n} \theta_{n\times 1} \quad (1)$$

where in the original signal is x , y is the measurement value, ψ is the sparse matrix, ϕ is the measurement matrix, transmission sparse matrix θ's sparsity is K, and it is signal x sparse represents in the transform domain ψ , $\phi\psi$ can be represented from the sensor (projection) matrix A . From the above equation (1), we can see that the amount of the measured value y information is much smaller than the amount of the original signal information, thus the signal transmission process is it greatly improved.

$\hat{\theta}$'s compression reconstruction can be obtained by solving the following equation:

$$min\ ||\theta||_0,\ s.t.\ y = A\theta \quad (2)$$

where y is the known measurements, A is the sensor matrix. But the formula (2) is an NP (Non-deterministic Polynomial) problem, if the projection matrix A satisfies certain conditions [4], the above-described problem $||\theta||_0$ is obtained by solving $||\theta||_1$, namely:

$$min||\theta||_1,\ s.t. y=A\theta \quad (3)$$

As it is shown in [5, 6], if the number of sample values are reduced, $||\theta||_0$ solution can be replaced by solving the problem of non-convex $||\theta||_p, 0 < p < 1$.

$||\theta||_p = \left(\sum_i x_i^p\right)^{1/p}$

$$min||\theta||_p, 0<p<1,\ s.t. y=A\theta \quad (4)$$

In summary, CS reconstruction $\hat{\theta}$ problem can be solved by solving $min\ ||\theta||_p$, $0 < p \le 1,\ s.t.\ y = A\theta$. The linear measurement process is shown in Fig. 2:

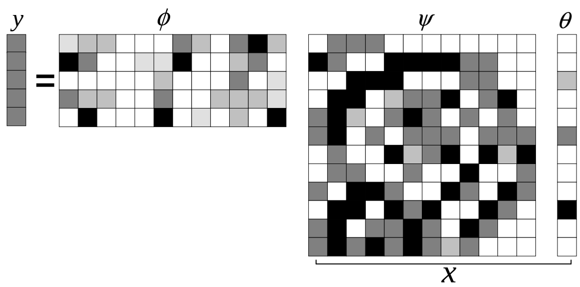

Fig. 2. Compressed sensing linear measurement process.

2.2. Wireless Sensor Networks and its Research Status

WSNs are a large number of tiny sensor nodes which are deployed in the monitor region, and a multi-hop self-organizing network system is formed by the wireless communication way [1]. In 2003, the United States "Technology Review" magazine did recommend that WSNs will be one of the future ten technologies which change people's lives [2]. Currently, IOT (Internet of Things, IOT) is based on sensor network technology, and it gets the attention of the world, and it is developing rapidly. IOT had gone beyond the mere concept of RFID, and it has become a ubiquitous network, its typical wireless sensor network architecture is composed with a large of sensor nodes and data collection center (commonly referred to as a base station) which are located in the detection area. Data path sensor nodes are created by way of the wireless connection and the base station, and the measured data is transmitted.

WSNs are data-centric networks, in many applications, nodes can perceive troops, equipment, supplies, terrain and deployment information, to locate targets, to assess the damage, reconnaissance and detection of nuclear, biological and chemical attacks. Once these highly sensitive data are obtained by an attacker, and it would jeopardize the safety of the entire network, so you must take effective measures to protect the security of confidential information, which is transmitted in WSNs on many occasions [7]. WSNs are task-based networks, three levels of the networks, nodes and data need to be ensured in the operation security, which data security is a top priority, including confidential data (Confidentiality), authenticity (Authentication), integrity (Integrity) and freshness (Freshness) [8]. Data-centric security threats are existed in WSNs, and these threats are largely resolved only through data security technologies, cryptography and digital watermarking technology are the two main methods of data security. Currently WSNs data security solutions are focused on the core technologies of encryption [9, 10].

WSNs studies have modern sense, and it began first in the late 1990s from the United States, and subsequently, the technology is predicted by many important institutions to be the important new technology which will change the world, and its related research work is carried out around the world together [11]. With further research, WSNs have been achieved results in the important areas such as the military defense, industry and agriculture, urban management, biomedical, environmental monitoring, disaster relief, counter-terrorism and counterterrorism, the remote control of hazardous areas [17].

3. Wireless Sensor Networks Research Based on Compressed Sensing

3.1. Research Purposes and Practical Significance

A large number of sensor nodes are often deployed in general sensor networks. From a cost point of view, the simple embedded system is generally installed in these sensor nodes as operating systems, processing power and battery power is limited, encryption adoption often lead to a sharp decline in the life of the sensor nodes, so the overall survival time is reduced in the entire wireless sensor networks. Therefore, how to design efficient algorithms, the confidentiality is protected, while energy consume is as little as possible in the sensor nodes, and these become an important research direction.

Compared to JPEG and JPEG2000 lossy compression methods, the superiority of CS technology is: (1) to collect fewer samples and to take advantage of its reconstructed signal. (2) If simple coding (linear projection) and the complexity decoding (non-linear projection) are used, and in general practice, the computing power is relatively weak in the encoding side, the decoder (typically a base station or a computer) has a strong computing power [12].

Considering the limited energy and computing power limit in WSNs, the above two advantages make that the CS technology can be better used in WSNs, and it is suitable for WSNs secret transmission of information with security. Data can transmitted in a secure secret, while the lifetime of the sensor network is longer, and there is strong significance in the research and application value.

3.2. Research Summary

It is summarized in this paper that compressed sensing is used in wireless sensor networks, the current study is focused on the following four aspects.

3.2.1. Compressed Sensing Technology Applications in WSNs Data Fusion [13-15]

The authors [13] pointed out that with the expansion of the applied scope in WSNs target sensor, fusion functions become more complex, the energy loss is also growing in the fusion computing. Therefore, the authors propose that compressed sensing technology is used in WSNs data fusion. Adaptive distributed data fusion algorithm is applied, acquisition and integration-related sensor nodes are made in the routing process, so that the transfer energy and integration are reached to a minimum. Experimental results show that the use of adaptive distributed data fusion algorithm can reduce energy consumption.

CS data acquisition applications in WSNs are researched in references [14], the network energy consumption is minimized by joint routing and compressed integration. First, the document [14] describes the optimal solution of the optimization problem, the second, its NP-Completeness is proved. The next mixed integer programming frameworks and greedy heuristics (Greedy Heuristics) are proposed, the optimal solution and the suboptimal solutions can be efficiently obtained in the integration trees. The role of greedy heuristics is confirmed in the results, as well as the energy efficiency is designed by using the proposed routing and integration.

The authors [15] propose an ordinary compressed sensing ((Plain-CS) and mixed compressed sensing (Hybrid-CS) concepts, and the specific data fusion mechanism is used in the network layer of WSNs. In literature [5], the advantages of data collection are researched by using compressed sensing in WSNs. The authors first describe the general CS, and then propose the integration CS framework of traditional data collection and ordinary mixing CS. Three optimization problems are given based on the amount, and CS is not calculated, and ordinary CS and mixed CS throughput are used. Simulation results show that compared with not using the CS, throughput may not be improved by using only ordinary CS technology, while the throughput can be greatly improved by the use of hybrid CS technology.

3.2.2. CS Technology Application in WSNs Data Acquisition and Signal Acquisition [16, 17]

Authors [16] proposed a new method of information based on the CS framework monitoring of 1-D environment in WSNs. The signal compressibility is used in the method, and the fusion center (Fusion Center, FC) is reduced, the sample values are recovered in the sampling signal, thereby the energy consumption is reduced in sensor nodes. Innovation of this method is to construct the random sampling new programs, the sampling causal relationship and hardware limitations are considered, and the randomized design and computational complexity are balanced. Further, the sampling rate indicator (Sampling Rate Indicator, SRI) feedback mechanism is established, so that the energy loss of the sensor can be minimized in the case, the sampling rate is adjusted to a range of the acceptable reconstruction performance. The actual data is obtained by using WSNs deployment, an acceptable reconstruction error is implemented in the case, the number of sample values can be effectively reduced in this method, in order to achieve the energy losses reduction in the data acquisition and transmission.

In [17], the authors first analyze and elaborate the fusion technology of existing data collection in WSNs, and CS related theories and key technologies are deeply focused, according to WSNs specific characteristics and different application environments, the WSNs data acquisition model is built on a variety of CS. For a variety of data types within the network, the wireless cycle data collection model is established with Initiative launch, passive activation, and abnormal detection mode, to achieve accurate recovery of data within the network anomalies. Bayesian CS is applied for WSNs signal acquisition, and fast vector machine algorithm is used, the sparse coefficient is estimated by the maximum edge likelihood estimate method, to complete the reconstruction of the original measurement signal. With this algorithm, the speed will be significantly improved in the reconstructed signal.

3.2.3. CS Applications in WSNs Data Recovery and Signal Reconstruction [18, 19]

In [18], the authors survey the compressed sensing in the wireless sensor networks, which is combined principal component analysis (Principal Component Analysis, PCA), good results are got in the data recovery. First, the authors construct the signal recovery framework under Bayesian theory, and prove that under certain signal statistical assumptions, CS signal recovery method is ideal. Therefore, the above assumptions are also applied to the actual deployment of WSNs and process the acquired data. The final conclusion is that the use of CS approach, the recovery is reasonable not only in the framework, and there is also good performance in obtaining the data.

The main contribution in [19] is to design the WSNs control architecture, which is the control WSNs connection from an external server to the network. In this architecture, a fusion principal component analysis is designed, and CS compression and recovery technique is used in sensor components, and the signal is reconstructed with a relatively small sample. Experimental results show that to restore the signal is very effective in the use of CS technology, and the automated system can be fully achieved and in non-stationary signal data acquisition and reconstruction for the WSNs.

3.2.4. CS Application in WSNs Data Transmission and Routing [20, 21]

The current focus of most research work lies data efficient collection and transmission.

In [20], the authors pointed out that CS has a very high potential application for the entire distributed WSNs. A solution program of data acquisition is proposed in WSNs, and routing is selected and random projection of cooperative transfer data is found by CS technology. The authors studied the CS and routing framework of the joint recovery, there are two different signals performance, they are the composite signal and the actual sensor data. The results show that for the composite signal, when using CS, the reconstructed enhancement effect is obtained in the central node, however, the actual sensor data is not well reflected in the reconstruction. The prospect is also raised in paper[20], which routing and signal indicates are further researched, and CS can be deployed in real WSNs, these play better performance.

The traditional CS applications often subject to intensive measurements， massive transport costs are generated [21]. To solve the above problem, several methods are proposed based on CS sparse measurements, and random routing is improved, it is applied for efficient data collection and typical WSNs environment, the different network topology structure is consistent, and the existing data collection frameworks are compared, the correlation properties are analyzed. The obtained results show that: in the proposed framework, the energy consumption is very effective for the signal reconstruction and reducing routing.

Research shows that compressed sensing is used in wireless sensor networks, there are been numerous research papers in foreign countries, which is mainly used to reduce the energy consumption of sensor nodes in WSNs, thereby the more long-term life cycle is obtained, involving signals or data acquisition, data transmission and routing, data fusion, signal reconstruction and so on. However, these studies are based on data transmission ideally without outside influence, when there are the malicious attacker, the data loss, interception, tampering and other issues which are pruned, and which has brought great trouble to data security, especially in some transmission of confidential data. Researchers found that: the compressed sensing research of WSNs is less in data secret transmission and reconstruction at home and abroad, therefore, how to reduce energy consumption and how to transmit the secret data are the need urgent research questions.

4. Conclusion and Outlook

The compressed sensing theory is applied in wireless sensor networks, the energy loss can be reduced in signal acquisition, transmission and reconstruction, the lifetime of the sensor nodes are increased at a greater extent. These theoretical research has been relatively mature, but with the development of wireless sensor networks, data security has become increasingly concerned, and the current majority of the compressed sensing applied research focus lies in the effective collection and transmission of WSNs data, and in the environment for wireless sensor networks, the exposition is less on the secretive transmitting of data security and reconstruction, its literature is rarely discussed at domestic and foreign. Therefore, how to give effective compressed sensing, WSNs secure data transmission model is an important research direction in the future. In addition to the compressed sensing domain, the wireless sensor network data fusion processing is another important area of research [22].

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