Wireless Technology for Monitoring Site-specific Landslide in Vietnam

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Article Info

ABSTRACT

Climate change has caused an increasing number of landslides, especially in the mountainous provinces of Vietnam, resulting in the destruction of vital transport and other infrastructure. Current monitoring and forecasting systems of the meteorology department cannot deliver accurate and reliable forecasts for weather events and issue timely warnings. This paper describes the development of a simple, low cost, and efficient system for monitoring and warning landslide in real-time. The authors focus on the use of wireless and related technologies in the implementation of a technical solution and some of the problems of the wireless sensor network (WSN) related to power consumption. Promising compressed sensing (CS) based solution for landslide monitoring is discussed and evaluated in the paper.

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1. INTRODUCTION

Climate change has caused an increasing number of landslides, especially in the mountainous regions of Vietnam. These landslides can cause a disastrous effect on the neighboring communities as well as the local infrastructure and economy [1]. Landslides can be broadly classified into four main types: pre-existing, rainfall-induced, earthquake-induced, and endogenous landslides. In Vietnam, most landslide events are triggered by rainfall and their harm is serious [2], [3].

There are two types of monitoring in Landslide Systems, namely short term and long term [4]-[8]. Long-term monitoring uses a combination of remote sensing data from satellites, global positioning system, geographic information systems, and related mathematical models to predict landslides over large time intervals. Short-term monitoring identifies the early signs of the landslides using a combination of many sensors such as acceleration, soil, rain and temperature.

Wireless communication networks form a critical enabling technology of Landslide Monitoring and Real-time Warning (LMRW) systems. Wireless Sensor Network (WSN) and other wireless technologies are the most appropriate technology for landslide monitoring due to difficult to access terrain, ease of maintenance, cheap and quick installation along with the need to satisfy the important real-time requirement of LMRW system [5], [7], [9], [10]. Most rural communities in Vietnam have at least 2G coverage, which

will be upgraded to 3G and 4G networks in the near future. Furthermore, these systems will provide vital data for national weather monitoring systems.

A number of LMRW have been reported in the literature today. In Idukki, India, a complex and elaborate LMRW deployment of 50 sensors and 20 WSN nodes was described in [5]. Another deployment [9] uses sensor node buried in the slope to detect movement signal and combines with soil parameters for predicting time of landslide. A low-cost solution to detect landslide in [10] utilizes accelerometers to evaluate the landslide risk, but the effect of other parameters such as rainfall has not been considered. Other researchers [11], [12] have used saturated hydraulic conductivity and infiltration of rainwater into slopes along with computer models and simulations to predict landslide risk but their ability for real-time and robust predictions is questionable. Moreover, power consumption for WSN is also an important issue.

This paper describes the use of wireless technology for a simple, low cost, and efficient landslide monitoring and real-time warning system with an integrated rain gauge which provides the rain data. We focused on an innovative development of Compressed Sensing (CS) based algorithm for landslide risk monitoring. The algorithm finds the properties of data acquired in the time domain. Also, the algorithm is specially developed to overcome the problem of power consumption. Wireless data transmission module ZigBee uses the 802.15.4 standard for wireless communication. ZigBee modules also provide the sleep mode to save power consumption. Data is then transmitted to a server using a 3G/2G mobile network. At the server information received from the remote equipment is compared with the predetermined thresholds established by experts in the field to predict likelihood of landslide. The data received from sensor nodes can be monitored on the project website and warning messages are sent to registered users mobile phones.

2. SYSTEM IMPLEMENTATION

Figure 1 shows the implementation of LMRW where the terrain is divided into two areas: safe areas (for rain gauge) and potential slide areas where sensing and transmitting nodes are placed.
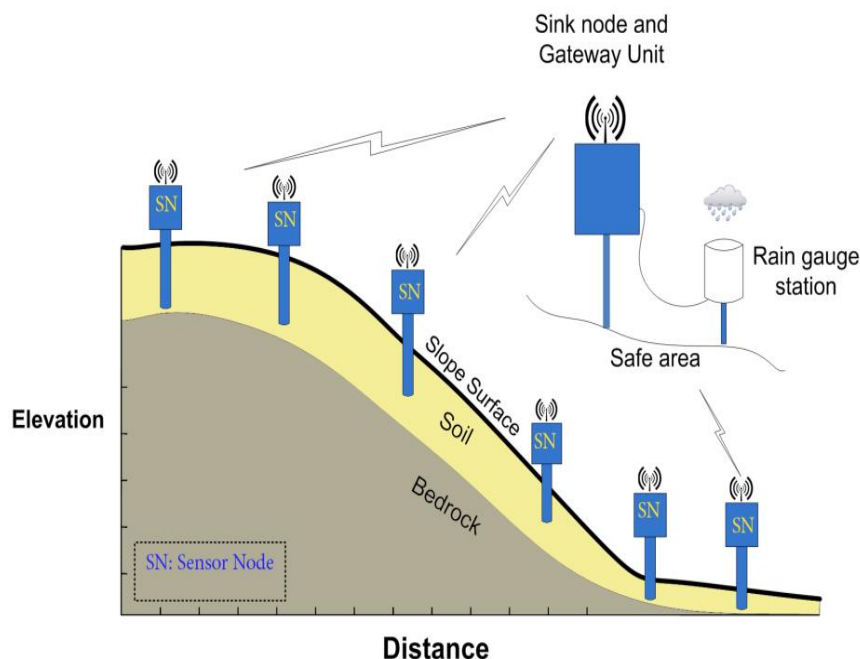

Figure 1. Landslide monitoring system

2.1. System Topology

Figure 2 shows the topology of the system. This network has several sensor nodes that communicate using a Zigbee protocol with a sink node that is part of the data logger. The rain gauge is connected to the data logger through a wired communication link. The logger transmits data to a database through the Internet. The information in the database is used to update the website and send SMS alerts to the community.
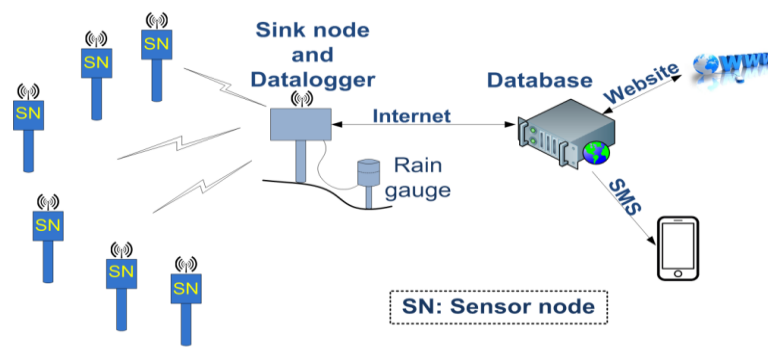
Figure 2. System topology

2.2. Sensor Implementation

The sensor column consists of major components: sensors, microprocessors, transmitter and rechargeable battery (see Figure 3(a,b)). Three types of sensors are used in this implementation, namely soil moisture, temperature and accelerometer (tilt meter and geophone) sensors. The microprocessor receives sensor data as input and executes a number of processes, for example, filtering noise, calibrating sensors, etc. Thereafter, the wireless module, XBeePRO [13] based on 802.15.4, transmits the processed data to a central computer at speeds 250 kbps on the 2.4 GHz band with 50mW transmitted power. The power supply is provided through a battery with sufficient capacity to operate for one rainy season. Figure 3(b) shows the photo of a sensor column.
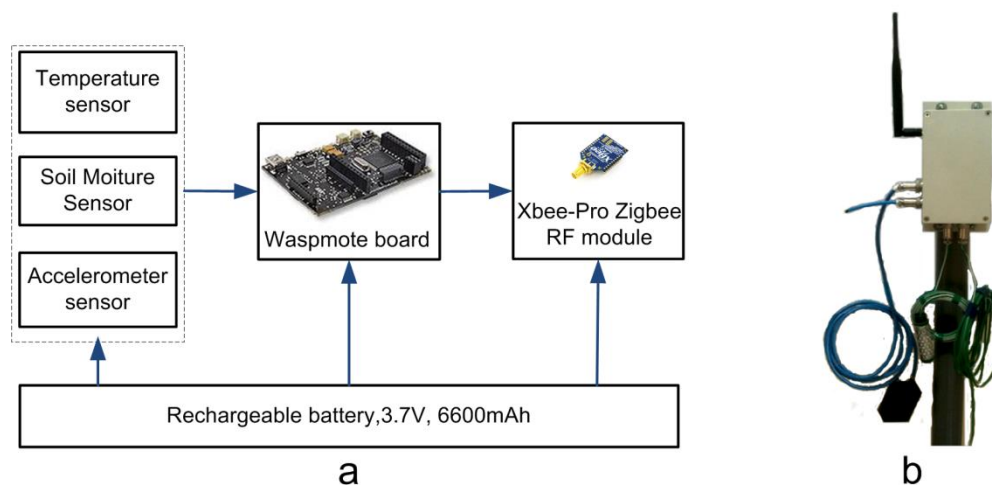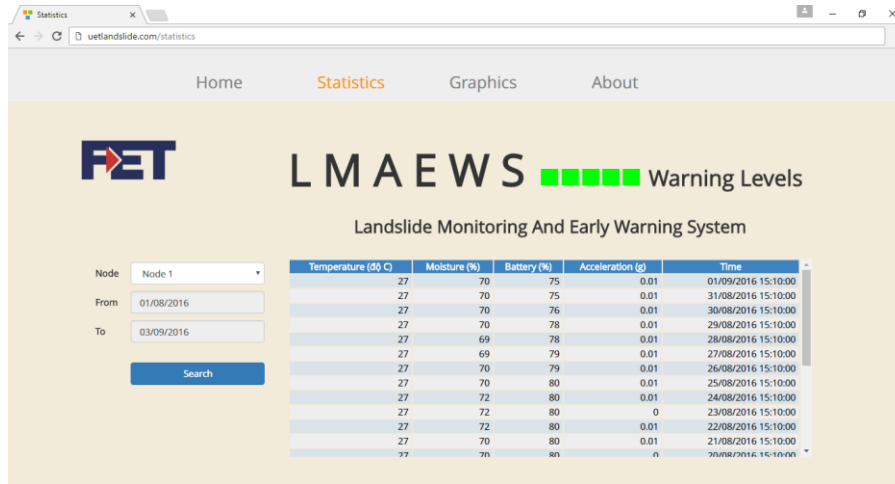

Figure 3. (a)Block diagram of sensor system; (b)Sensor implementation

The Weather Station WS-3000 was used in the project to collect weather data such as wind direction, wind speed, and rainfall. The accuracy of the WS-3000 was tested against other weather stations and the results show the device to be accurate and reliable, but inexpensive.

2.3. Embedded Computing Module

In this paper, the Waspmote using ATmega1281 microcontroller was chosen to connect and process information received from sensors. The Atmega1281 are suitable for engineering a sensor node, which has battery constraint, due to advantageous characteristics such as high performance, low power, etc. The data which sensor nodes gathered on the slope is transmitted wirelessly to the sink node, and subsequently delivered to the central computer where the data is transferred to a MySQL database installed on the web server. The users monitor remotely information through the web application as shown in Figure 4.

Figure 4. Web interface for LMRW

2.4. Warning SMS to any Phone

To broadcasting an alert message to any phone, the central computer is connected to a GSM/GPRS module. In the warning state, an alert message is issued and automatically sent to the responsible people as shown in Figure 5.
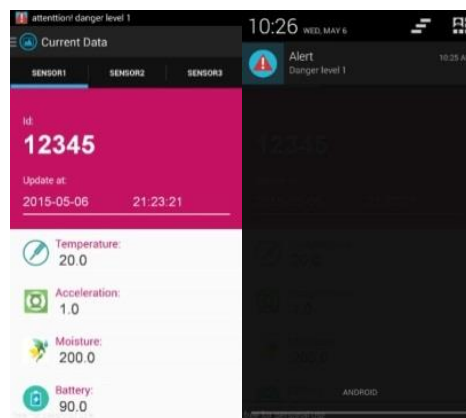

Figure 5. Phone alerts

3.   SYSTEM DESIGN

In the early work [14], the environmental measurements were sent in the discrete-time without any compression. Data recorded from sensors in LMRW is primarily low frequency data. In the current system, the authors redesigned the system to reduce the amount of transmitted data and save power. In this paper, compressed sensing (CS) technique was used to reduce the data transmission [15] by using the Fourier Transform to convert data to the frequency domain from the time domain and sending it along with the corresponding Fourier coefficients. By receiving the transmitted data, a nonlinear algorithm would be applied to reconstruct the original data.

CS is an efficient technique that employs a compact number of samples to reconstruct a sparse signal through using of nonlinear algorithms, such as Orthogonal Matching Pursuit or l_1 norm [16], [17]. Some published works applied this technique: information systems [15], biomedical systems [18-20], networked systems [21], communication systems [22]-[24], robotic systems [25]. This technique consists of two main processes: 1) random or chaotic undersampling and 2) nonlinear reconstruction. In many applications, undersampling will help to reduce a large number of measurements, and thus, reduce the power consumption. Nonlinear reconstruction often consumes more times compared to the reconstruction without CS. However, it is not such a disadvantage in many applications.

However, the requirement of the signal of interest x is that it must be sparse in the form of a linear representation Φ. After that, the undersampling process is made where the equivalent measurement matrix is denoted by Ψ. Consequently, the measurements are given by $y=\Theta s$, where $\Theta=\Psi\Phi$. The target of this work is clear that it is needed to reconstruct x from y (or s from y).

4. RESULTS AND DISCUSSION

In this work, a deterministic basis created by a sequence of pseudo-random is proposed to substitute for pure random basis. In comparison with CS, the strength of this solution is that this sequence can be easily installed into the microcontrollers before assembling the sensor nodes in the field site. Therefore, the paper considers a dynamic deterministic system whose characteristic is deterministic nonlinear. The deterministic compressed sampling technique is equivalent to the random one on the accuracy of outcome [26]. The authors used a logistic map based dynamic structure which is transformed into a sequence that would have a Gaussian-like behavior:

$$q(n+1) = \rho q(n)(1-q(n)) \tag{1}$$

where ρ is the control parameter [27]; the initial condition q(0) seriously effects the dynamic of Equation 1. q(0) changes a small value will quickly result a big change in the value of q(n). The sparse signal can be reconstructed by using the l_1-regularized least squares method [20]. The solving problem is

$$\arg\min_x \left\{ \left\| F_u x - y \right\|_2^2 + \lambda \left\| \Phi x \right\|_1 \right\}$$
$$subject \quad to \quad \left\| F_u x - y \right\|_2 < \varepsilon \tag{2}$$

where λ is a consistency tuning constant, and $\mathbf{F_u}$ is the under sampled Fourier operator. Data of temperature, acceleration, and moisture are reconstructed at the receiver which are shown in Figures 6-8. The data is reduced by a factor of 25%.

It can be seen from Figure 6 that the temperature increases from 30°C to 33°C and it can be noted that the average difference between the reproduced data and the original one is only 0.58%. In the second scenario as shown in Figure 7, the data of moisture can be reconstructed with an average error of 1.51% in comparison with the original one.
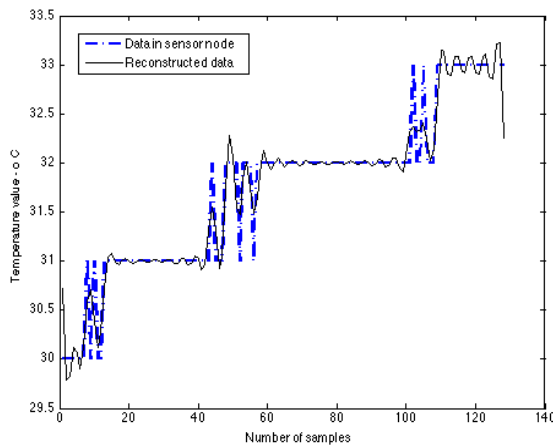

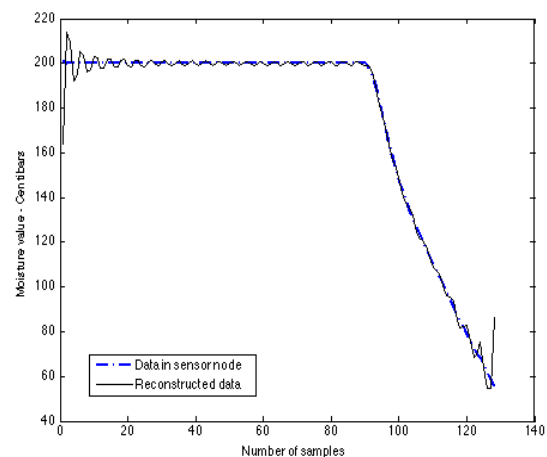Figure 6. Data from temperature sensor, r=0.25   Figure 7. Data from moisture sensor for r=0.25

The Figure 8 shows the variation between the reconstructed and original data from the acceleration sensor for a low compression ratio of $r=0.25$. It can be observed that there is considerable error between the actual and sensed data for this value of compression ratio. Next, the authors investigate the best compression ratio.
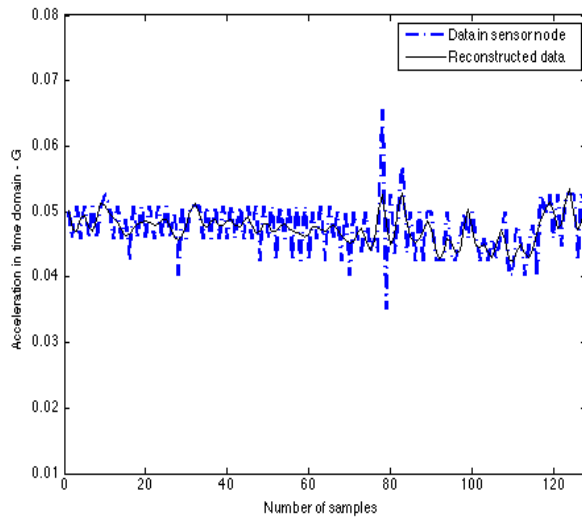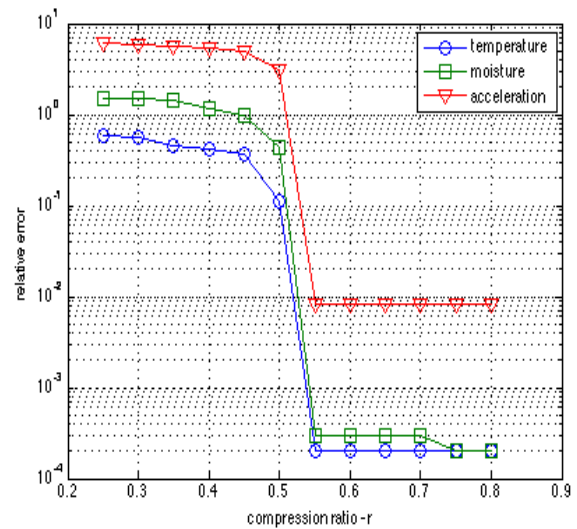
Figure 8. Data from the acceleration sensor for r=0.25

Figure 9. Effect of compression ratio on relative error.

To analyze the performance of the reconstruction system and the effect of compression ratio, a parameter called the relative reconstructed error (e) is proposed:

$$e = 100\% \frac{1}{L} \sum_{i=1}^{L} \frac{|x_i - \hat{x}_i|}{|\hat{x}_i|} \tag{3}$$

where L is the total number of data used for calculation, x denotes the original data and $\hat{x}$ denotes the reconstructed one.

Figure 9 indicates the influence of the compression ratio on the relative error. It is observed that the error is larger for low range compression ratios between 0.25 and 0.5. If the compression ratio is greater than or equal to 0.55, the error is quickly reduced to zero. These results suggest that the k-space data is decent enough for reconstruction of the original data. For the future work, a compression ratio of r=0.55 is selected based on this result.The algorithm finds the properties of data acquired in the time domain. It is specially developed to overcome the problem of power consumption. Wireless data transmission module ZigBee uses the 802.15.4 standard for wireless communication. ZigBee modules also provide the sleep mode to save power consumption.

5.   CONCLUSION

This paper described a successfully implemented LMRW with an operational scheme for transmitting compressed data that were acquired from three different sensors. Properties of data acquired in the time domain are exploited toapply Compressed Sensing technique for power saving. A number of wireless technologies were used in the real-time system design based on system, power and data rate requirements. A finite number of Fourier coefficients of time-domain data were transmitted and the amount of data transmitted was halved thus reducing the power consumption. This prototype can form the basis of solving real world problems related to natural disasters and to assist communities throughout the globe.

REFERENCES
[1]   T. Glade*, et al.*, "Landslide hazard and risk", John Wiley & Sons, 2006.
[2]   D.M. Duc, "Rainfall-triggered large landslides on 15 December 2005 in Van Canh District, Binh Dinh Province, Vietnam", *Landslides*, vol. 10(2), pp. 219-230, 2012.
[3]   D.H. Loi*, et al.*, "The 28 July 2015 rapid landslide at Ha Long City, Quang Ninh, Vietnam", *Landslides*, vol. 14(3), pp. 1207-1215, 2017.
[4]   O. Monserrat*, et al.*, editors. "Long term landslide monitoring with Ground Based SAR", *EGU General Assembly Conference Abstracts*, 2014.

[5]   M.V. Ramesh, "Design, development, and deployment of a wireless sensor network for detection of landslides", *Ad Hoc Networks*, vol. 13, pp. 2-18, 2014.

[6]   F. Agliardi*, et al.*, "In situ and remote long term real-time monitoring of a large alpine rock slide", Landslide Science and Practice: Springer, 2013. p. 415-421.

[7]   Q.A. Gian*, et al.*, "Design and implementation of site-specific rainfall-induced landslide early warning and monitoring system: a case study at Nam Dan landslide (Vietnam)", *Geomatics, Natural Hazards and Risk*, vol. 8(2), pp. 1978-1996, 2017.

[8]   Q.A. Gian*, et al.*, "Monitoring of Landslides in Mountainous Regions based on FEM Modelling and Rain Gauge Measurements", *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 6(5), pp. 2106-2113, 2016.

[9]   A. Terzis*, et al.*, editors. "Slip surface localization in wireless sensor networks for landslide prediction", *Proceedings of the 5th international conference on Information processing in sensor networks*, 2006: ACM.

[10]   H.Z. Kotta*, et al.*, "Wireless sensor network for landslide monitoring in Nusa Tenggara Timur", *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 9(1), pp. 9-18, 2011.

[11]   A. Ali*, et al.*, "Simplified quantitative risk assessment of rainfall-induced landslides modelled by infinite slopes", *Engineering Geology*, vol. 179, pp. 102-116, 2014.

[12]   B.D. Collins and D. Znidarcic, "Stability analyses of rainfall induced landslides", *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 130(4), pp. 362-372, 2004.

[13]   A.H. Kioumars and L. Tang, editors. "ATmega and XBee-based wireless sensing", *International Conference on Automation, Robotics and Applications (ICARA),* 2011: IEEE.

[14]   D.C. Nguyen*, et al.*, "Multi-sensors integration for landslide monitoring application", *VNU Journal of Science*, vol. 30(6S-B), pp. 202-210, 2014.

[15]   D.L. Donoho, "Compressed sensing", *IEEE Transactions on information theory*, vol. 52(4), pp. 1289-1306, 2006.

[16]   Y. Zhang*, et al.*, "A Study on Image Reconfiguration Algorithm of Compressed Sensing", *TELKOMNIKA*, vol. 15(1), pp. 299, 2017.

[17]   J.A. Tropp and A.C. Gilbert, "Signal recovery from random measurements via orthogonal matching pursuit", *IEEE Transactions on information theory*, vol. 53(12), pp. 4655-4666, 2007.

[18]   S. Yang and M. Gerla, editors. "Energy-efficient accelerometer data transfer for human body movement studies", *International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing*, 2010: IEEE.

[19]   M. Lustig*, et al.*, "Sparse MRI: The application of compressed sensing for rapid MR imaging", *Magnetic resonance in medicine*, vol. 58(6), pp. 1182-1195, 2007.

[20]   Y. Zhang*, et al.*, "Exponential wavelet iterative shrinkage thresholding algorithm with random shift for compressed sensing magnetic resonance imaging", *IEEJ Transactions on Electrical and Electronic Engineering*, vol. 10(1), pp. 116-117, 2015.

[21]   H. Zheng*, et al.*, "Data gathering with compressive sensing in wireless sensor networks: a random walk based approach", *IEEE Transactions on Parallel and Distributed Systems*, vol. 26(1), pp. 35-44, 2015.

[22]   K. Hayashi*, et al.*, "A user's guide to compressed sensing for communications systems", *IEICE transactions on communications*, vol. 96(3), pp. 685-712, 2013.

[23]   C. Caione*, et al.*, editors. "Compressive sensing optimization over ZigBee networks", *Industrial Embedded Systems (SIES), 2010 International Symposium on*, 2010: IEEE.

[24]   S.U. Khan*, et al.*, "Diagnosis of Faulty Sensors in Antenna Array using Hybrid Differential Evolution based Compressed Sensing Technique", *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 7(2), pp. 961-966, 2017.

[25]   S. Qiu*, et al.*, "Brain–Machine Interface and Visual Compressive Sensing-Based Teleoperation Control of an Exoskeleton Robot", *IEEE Transactions on Fuzzy Systems*, vol. 25(1), pp. 58-69, 2017.

[26]   J.A. Tropp*, et al.*, editors. "Random filters for compressive sampling and reconstruction", *Acoustics, Speech and Signal Processing, 2006 ICASSP 2006 Proceedings 2006 IEEE International Conference on*, 2006: IEEE.

[27]   J.C. Sprott and J.C. Sprott, "Chaos and time-series analysis", Oxford University Press Oxford, 2003.

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