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An Open Source Data Visualization System for Wireless Sensor Network

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Abstract

This paper presents a data visualization scheme for wireless sensor network which plays an important role in the structure of Internet of Things (IoT). In the infrastructure of IoT, data collected by its end nodes with different sensors can be used to monitor the energy consumption and the salubrity of the environment in public buildings in order to further improve the level of comfort and productivity of the people in these environments. However, the data collected by the wireless sensors at the end nodes of IoT cannot always be directly connected to Internet and provide web-based service to users for some special situations, e.g. electric transport towers installed at remote mountains. In this paper, we propose a framework that uses both open source hardware and software to collect the data at the end nodes from a wireless sensor network while visualizing the data without network gateway and/or web-based cloud server. A Zig Bee based wireless sensor network was applied to achieve an efficient and economical solution to monitor the device in real time and transmit these data to IoT. Experiment results demonstrated that the proposed framework is feasible for achieving an efficient and low-cost visualization system in the wireless sensor network.

Keywords: wireless sensor network, IoT, ZigBee, data visualization

1. Introduction

Wireless sensor network plays a very important role in the infrastructure of Internet of Things (IoT) (Minoli et al., 2017; Zanella et al., 2014; Quinionesetal, 2012; Mitton et al., 2012). In smart cities, it can be utilized to improve the efficiency of public transportation systems and the quality of life of the inhabitants (Kouche, 2012); while in smart agriculture, it can be used to improve the quality of the product and reduce the total amount of water usage (Tooker et al., 2012; Keshtgari and Deljoo, 2012). The data collected by end nodes of IoT with different sensors such as light sensors, temperature sensors, humidity sensors, and carbon monoxide gas sensors can be used to monitor the energy consumption and detect forest fires. It can also help to maintain the salubrity of the environment in public building, e.g. schools, museums, subway stations and tunnels. As a result, we shall improve the level of comfort and productivity of the people in their modern life (Wei et al., 2012; Ghayvat et al., 2015; Kelesetal, 2015; Bellagente et al., 2015; Tao et al., 2016; Sun et al., 2015; Wang et al., 2016; Magno et al., 2015). Traditionally, the above urban IoT infrastructure is capable of integrating different technologies within the current Internet infrastructure to transmit the IoT data (Corna et al., 2015; Kausar et al., 2012; Kim et al., 2010; Yang et al., 2010; Li and Yu, 2011; Xu et al., 2016). However, for certain special scenarios, the data collected by the wireless sensors at the end nodes of IoT cannot always be directly connected to the Internet and provide web-based service to the users. For example, if we want to monitor the temperature and humidity for electric transport towers installed in remote mountains, windmills in sea coast, oil tanks at harbors, greenhouses spread out at farms, it would be very costly for us to make wire connections to transmit these data immediately to the Internet. Figure 1 shows typical IoT infrastructures without directly connected web-based internet services.

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Figure 1. Typical IoT infrastructures without directly connected web-based internet services: electric transport towers (top left), windmills (Top right), greenhouse farm (bottom left), and oil tanks (bottom right).

In those situations, the ZigBee based wireless sensor network would be the most efficient and economical option to monitor the device and transmit data to IoT cloud storage in real-time. ZigBee protocol was primarily designed for data transmission at low speed and low power consumption devices. This paper presents an efficient and low-cost wireless sensor network which plays a key role in the infrastructure of IoT. It uses both open source hardware and software to collect the data at the end nodes from a wireless sensor network and further visualize the data without network gateway or web-based cloud servers. The remainder of this paper is presented as follows. Section 2 introduces the ZigBee based wireless sensor network and the open source data visualization scheme. Section 3 presents the experimental results. Finally, section 4 draws conclusions of this study and also discusses future research directions.

2. Methods

In this section, we will introduce the proposed open source data visualization scheme for the ZigBee based wireless sensor network.

2.1 The ZigBee protocol

The ZigBee protocol is a wireless communication protocol based on the IEEE 802.15.4 standard (http://www.ZigBee.org). It primarily focuses on data transmission for low speed and low power consumption devices. The corresponding data transmission speed can be up to 250 KB/s. In general, the ZigBee protocol supports network topologies including star, mesh, and cluster tree topologies as shown in Figure 2. In ZigBee networks, there exists at least one coordinator which is responsible for managing and connecting other devices to make a star or mesh network connection. Correspondingly, all other devices are called the end-point devices. A bigger ZigBee wireless mesh network can be achieved by expanding the network connection using more coordinators in the network.

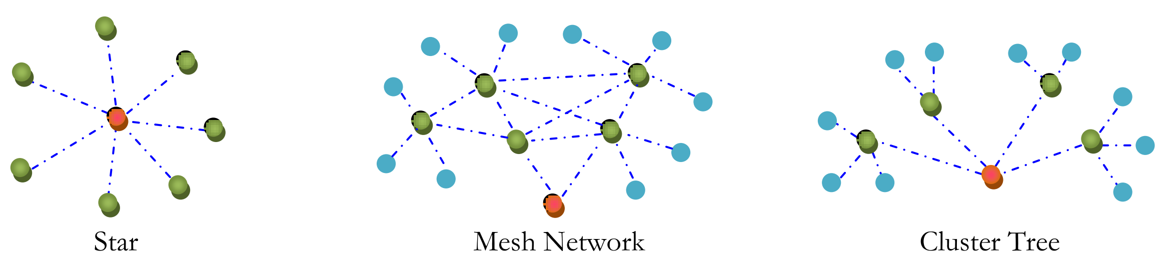


Figure 2. Network topologies: star (left), mesh (middle), and cluster tree topologies (right).

In the infrastructure of IoT, the status of a critical equipment usually need to be monitored by a centralized control system. In such situation, the application of the ZigBee wireless communication system shall significantly reduce cost as well as increase the reliability of the monitoring system as shown in Figure 3.

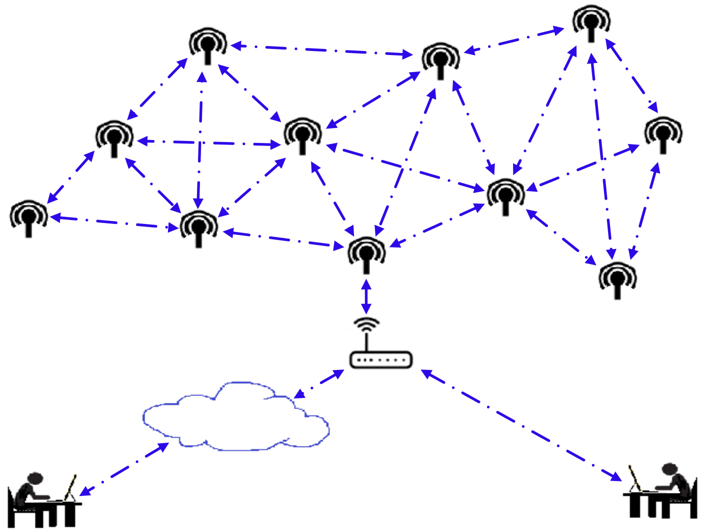


Figure 3. The ZigBee wireless communication system.

2.2. The XBee modules

XBee modules are series wireless data transmission modules manufactured by Digi International Inc (http://www.digi.com). According to Digi, XBee modules are embedded solutions providing fast wireless point-to-multipoint or peer-to-peer networking based on the IEEE 802.15.4 ZigBee networking protocol. The main characteristics of XBee modules are low latency and predictable communication timing. As a result, these modules have been widely used in high-throughput applications. In wireless sensor network, XBee modules are powered by batteries instead of AC power. Due to the limitation of battery life, we usually configure the modules into sleep state for most of the time and wake them up periodically in order to send out data as shown in the experiment results below.

2.3. Configuration of the XBee wireless sensor nodes

In wireless communication system, an XBee wireless sensor node is defined as an XBee module connected with one, two, or a couple of different sensors and powered by a battery. Figure 4 demonstrates a typical XBee node in a wireless sensor network.

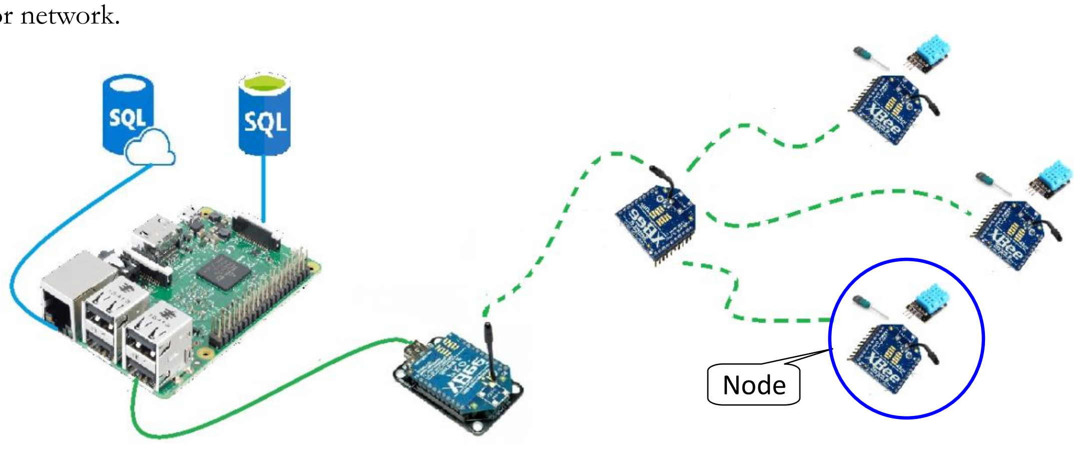
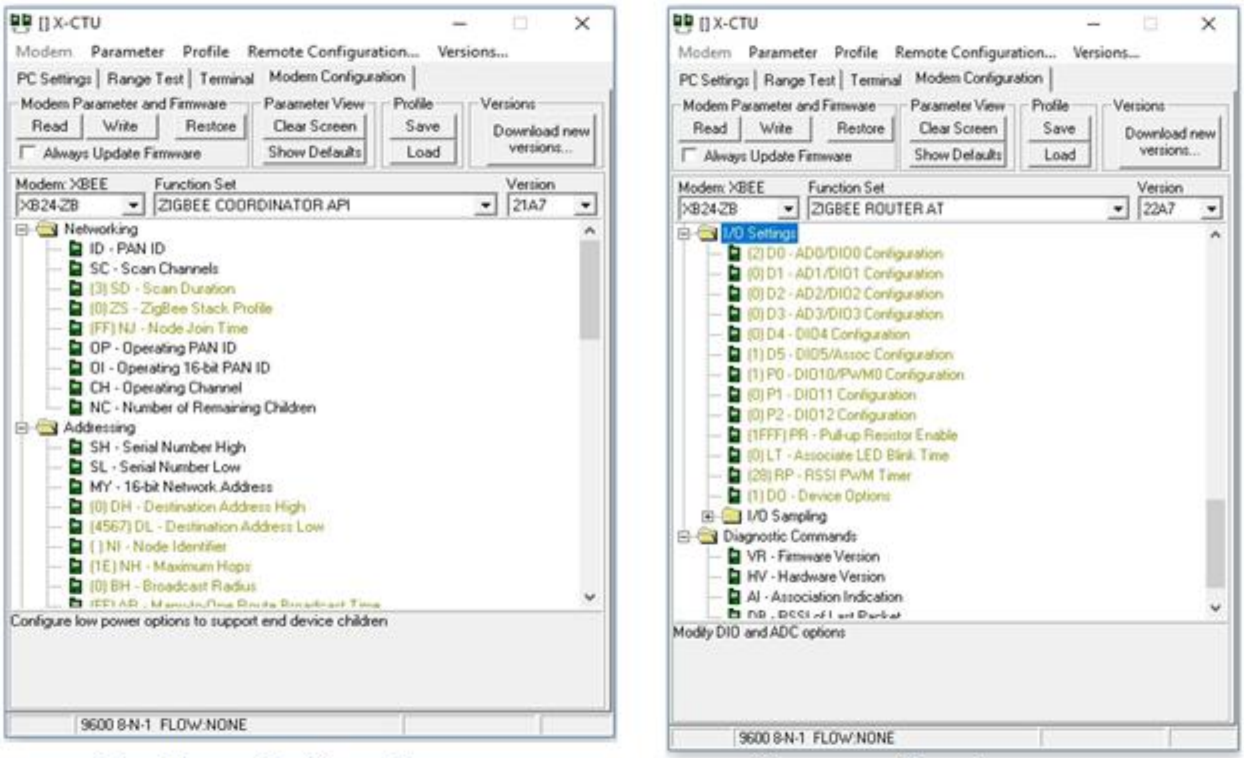


Figure 4. A typical XBee node in a wireless sensor network.

The XBee module has 64-bit address printed on its back. There are two parts in this address: the high address and the low address. The high address is located at the top line with a value of 0013A200 which is the common address assigned to Digi International Inc. Meanwhile, the low address which is unique for every XBee module is located at the bottom line of the XBee module.

For the configuration of XBee modules in a wireless sensor network, the XBee modules can be configured into two types: Coordinator and Router.

In this paper, we used the software X-CTU to perform the configuration of XBee modules. The X-CTU software can be downloaded from Digi's website (http://www.digi.com/products/wireless-wired-embedded-solutions/ZigBee-rf-modules/xctu). In order to make an XBee mesh network, we need to configure only one XBee module as a coordinator which acts like the root of the tree. As a result, the coordinator of the XBee module collects all the information from the mesh network. After that, the coordinator will send all the information to the database server or storage on the Internet. On the other hand, the router will only relay the packets for end nodes. Its configuration will be different from that of the coordinator. In addition, all XBee modules in the same wireless sensor network should contain the same PAN ID number. A detailed procedure of XBee coordinator and router configuration is described in Faludi's work (2010). Figure 5 shows the configuration of XBee modules in the wireless sensor network.



Coordinator Configuration **Router configuration**

Figure5. Configuration of XBee modules in the wireless sensor network: Coordinator configuration (left) and Router configuration (right).

2.4. Data visualization system

In this paper, the data we collected from the wireless XBee mesh network was processed and displayed by a software "Processing" (http://www.processing.org). Processing is a flexible software sketchbook. Details of how to use the software can be found at www.processing.org. Figure 6 presents the algorithms for data visualization in our wireless sensor network.

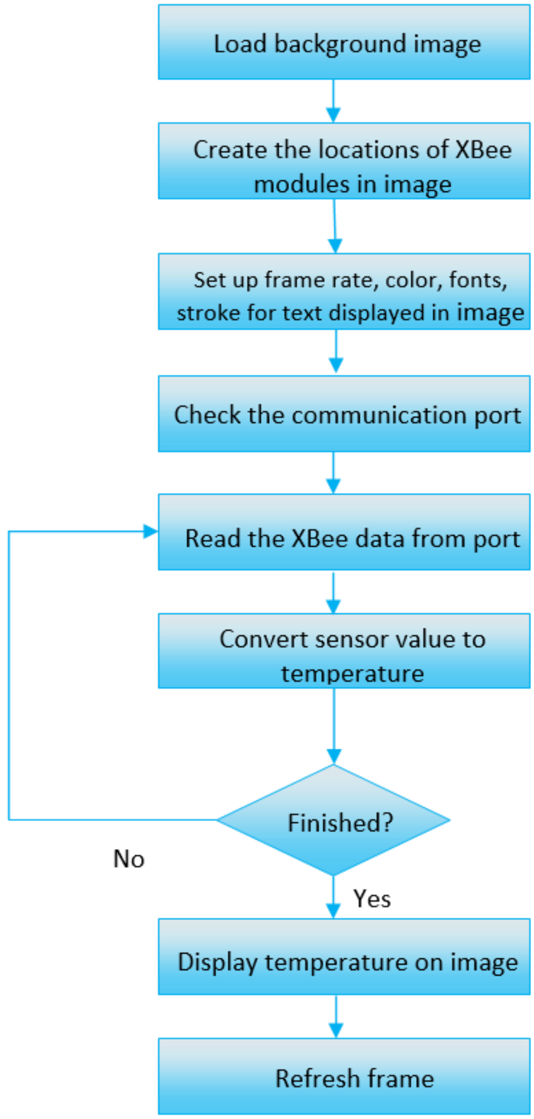


Figure 6. Algorithms for data visualization system in the wireless sensor network.

3. Experiment results

In this work, we built an XBee wireless network with a coordinator, several routers end nodes, and a local computer as a base to save and display data in the network. We tested the wireless network by collecting real-time temperature data in a campus range. As there exists only maximum two hops in this study, the transmission delay between end nodes and coordinator would be very small and can be ignored (Piyare and Lee, 2013; Bilgin and Gungor, 2012). Figure 7 shows the real-time temperature data monitoring results from an open campus at College of Staten Island of the City University of New York. Figure 8 shows the real-time temperature data monitoring results from a city campus located at the New York City College of Technology. The red dots represent the locations of the wireless sensor installed in the network.

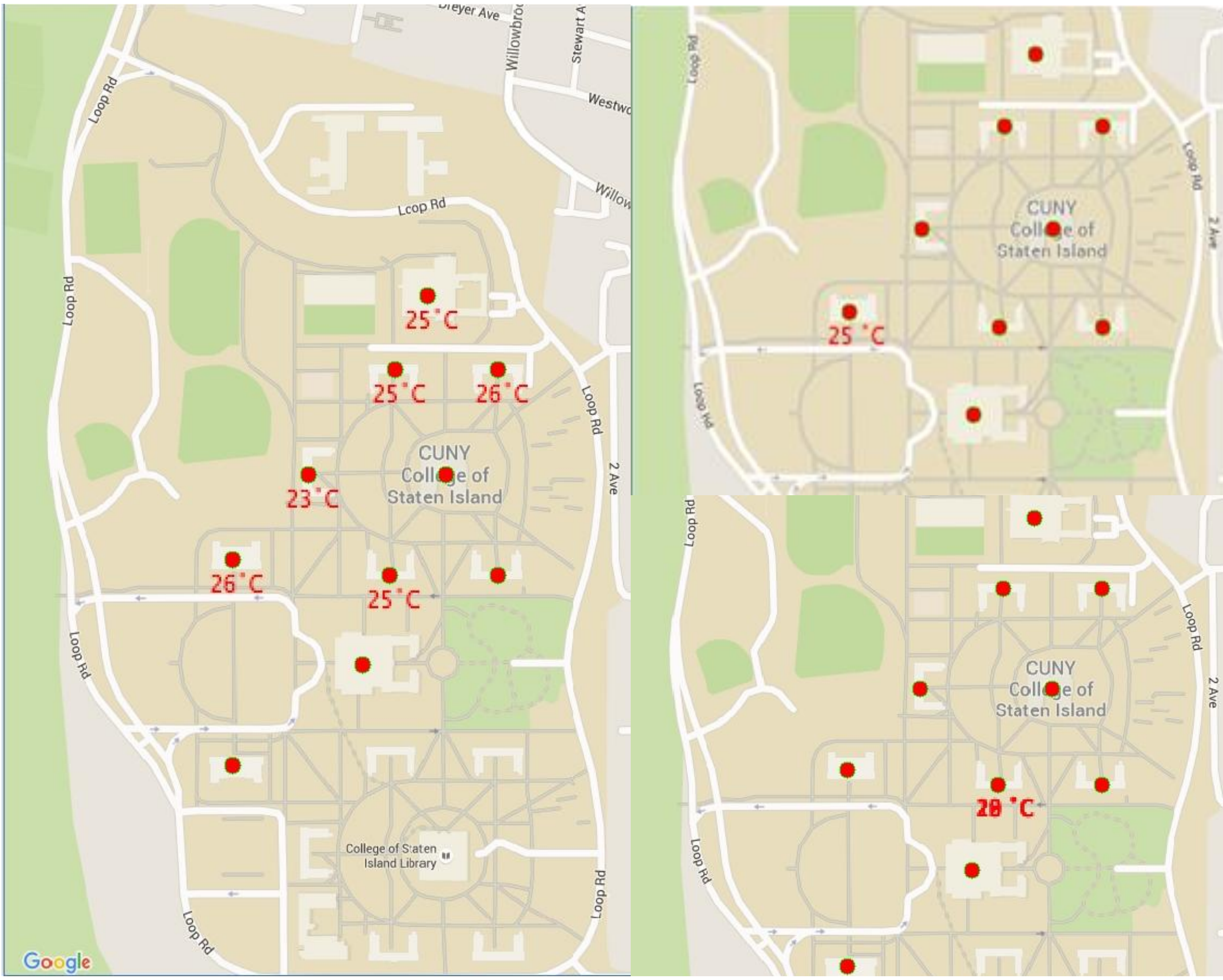


Figure7. Real-time data monitoring results from an open campus. Left: active six nodes were displayed simultaneously, while four other nodes were inactive according to user's configuration. Right (top and bottom): single node was displayed for animation effects.

Our visualization system can display data from multiple nodes simultaneously as shown on the left of Figure 7 and Figure 8. It also can display the data at one node for one second and then move to next node for animation effects as shown on the right of Figure 7 and Figure 8. All of the nodes are displayed alternately in the monitoring system.

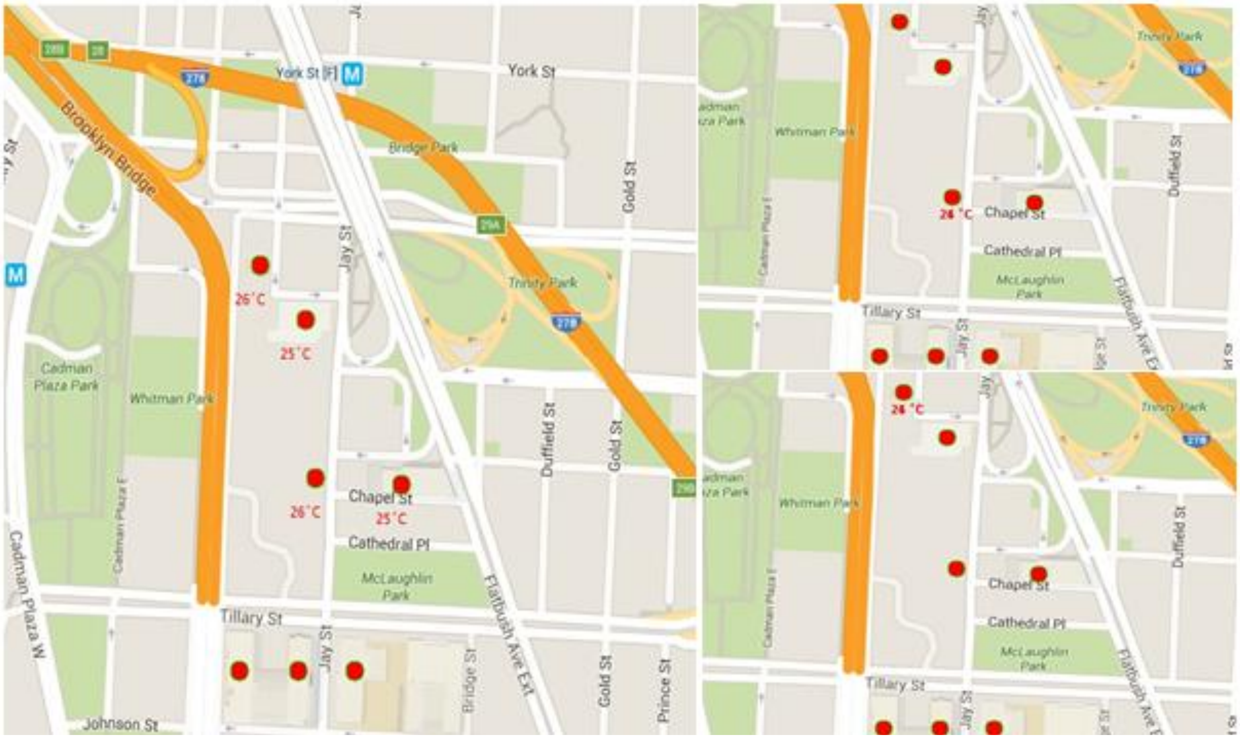


Figure 8. Real-time data monitoring results from a city campus. Left: active four nodes were displayed simultaneously, while three other nodes were inactive according to user's configuration. Right (top and bottom): single node was displayed for animation effects.

4. Conclusions

This paper presented a low-cost wireless monitoring system using open source hardware and software. It provided a practical implementation of wireless sensor network which could be utilized in many remote locations in none internet connection environment for collecting important data for IoT. It also established a practical platform in which the user can add different types of sensors for real-time data monitoring without using cloud storage space such as Azure or iDigi accounts. Experiment results demonstrated that the proposed framework is feasible for achieving an efficient and low-cost visualization system in the wireless sensor network. Further research work on expanding XBee module nodes to achieve a large wireless network is under progress.

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