Developing a Safety Scaffold Monitoring System Using Wireless Sensor Network Technology

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***Abstract:** Scaffold is the most commonly used equipment in various types of construction works. Since various types of construction works use the same scaffold equipment, it becomes more difficult to be controlled and managed, thus resulting hazard frequently. According to the information announced in July 2012 by Council of Labor Affairs Executive Yan, the site collapse or incomplete anti-falling protection has led the site to accident frequently, and this is the main reason that causes construction industry occupational disasters. The labor death occupational hazard ratio rises up to 13% in scaffold activity, and the Council of Labor Affairs Executive Yan has showed that the death ratio is higher when using the scaffold in construction site, the total number of death has reached to 139 from 2005 to 2010. In order to ensure the safety of scaffold user, this study tends to build a wireless sensor monitoring system to detect the reliability and safety of the scaffold. The wireless sensor technique applies in this study is different with the traditional monitoring technique which is limited with wired monitoring. Wireless sensor technique does not need wire, it just needs to consider the power supply for establishing the network and receiving stable information, and it can become a monitoring system. In addition, this study also integrates strain gauge technique in this scaffold monitoring system, to develop a real-time monitoring data transfer mechanism and replace the traditional wired single project monitoring equipment. This study hopes to build a scaffold collapse monitoring system to effectively monitor the safety of the scaffold as well as provide the time-saving installation, low-cost and portable features.*

***Keywords:** Wireless Sensor Network (WSN), Strain gauge, Scaffold*

Ⅰ. Introduction

1.1 Taiwan's construction industry Site Security Overview

In recent years, building-site accidents in con construction industry come one afer another. According to the Ministry of Labor of the Republic of China, from 2000 to 2011, the figure of construction industry's work-related deaths accounted for half of that of high-risk occupations. In 2011, it also reached 127 people, which accounts for 45% of those of the overall high-risk occupations.

According to The Ministry of Labor's statistics released on 30 May 2012, the career disaster deaths of construction industry in this year increased by 16 people, compared with last year's 26 people, by an percentage of 61.5%. Besides, in the falling of opening has the highest percentage of vehicles for falling deaths of construction industry ; next is dropping from scaffold and roof.

This project will build a Scaffold Monitoring using wireless sensor network technology to monitor the reliability and safety of scaffold. It deploys wireless transmission to achieve real-time monitoring, so as to ensure the safety of labors, and to reduce the probability of disasters brought by the fall of scaffold.

II. Wireless Sensor Network Framework Overview

WSN is composed of many nodes, it could be divided into three parts, Coordinator, Router, and End Device.

a. Coordinator: It is the center of the wireless network, corresponding to the role of a host server, and is in charge of setting up the network and the maintenance of the entire system. Compared with sensing nodes, it requires more memory to calculate which node has positive stronger signal and shortest route. Usually, a coordinator will be connected to a personal computer to receive and process data.

b. Router: It functions like a brouter. When transport distance is long and sensing nodes could not directly transfer packets to the coordinator, router act as booster stations to increase the limit of transport distance. A network may consists of multiple routers, and this many booster station structure is called a multi-hop.

c. End Device: Its main task is to receive data and to transmit, and appropriate sensors should be utilized to suit the purpose. Commonly, nodes will convert analog signal to digital signal, and use packet type wireless network transmission. The ultimate goal is to deliver packets to the coordinator.

Each sensing node is a separate device; its basic structure must be at least composed of a power supply unit, a processing unit, a transceiver unit and a sensing unit, as in Figure 1 (I.F. Akyildiz, 2002).

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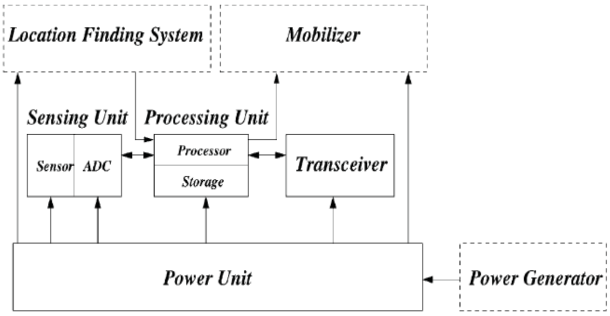

Figure 1: sense node framework chart
(I.F. Akyildiz, 2002)

Ⅲ. Development of WSN modulus

3.1 Hardware System Development

The circuit of the sensor circuit board has two main functions. The first is power supply, where voltage was transformed, reduced and regulated, so adequate power can be supplied to other components on the circuit. Since the voltage requirement for each component is different, the voltage control process is very important. The second function is to convert analog signals obtained from the sensors into digital signals, so they could be sent to the Super Node and processed into packets and transmitted.

3.2 Super Node

The Super Node used here is the Wireless Sensing Transceiver Module developed by Department of engineering Science and Ocean Engineering, NTU (Figure 2). The module utilizes the radio frequency (RF) chip UZ2400, developed by (Da-San co.). The CPU of the module is the MSP430F1611 of the MSP430 series, and it has 48KB of flash memory (ROM) and 10KB of random access memory (RAM). It features IEEE802.15.4 protocol, and is suitable for applications on large scale sensor networks. The module is a full-function device (FFD), and can serve as every type of node.

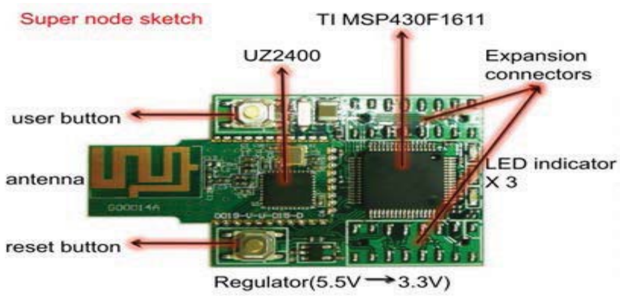

Figure 2: PCB & super node after soldering

3.3 Sensor selection

In this research, the displacement sensor - strain gauge setup was employed. By measuring the degree of strain, we can calculate the force on the frame construction, and determine whether the axial force applied to frame construction exceed the standard or not. In combination with the wireless transmission module and the back-end receiving interface, a construction shelf monitoring system is formed.

The strain gauge measures the strain by relating the electrical resistance of the metal conductor wire and its length. The change in length will result in a proportional change in resistance, which is measured with an unbalance Wheatstone bridge and a sequential voltage amplifier. After data processing, we can translate the electric reading to its corresponding to axis force. In this way, we can determine the status of the security level, and then display the current actual situation by the monitoring system.

The strain gauge used in this research is produced by Mantracourt company, England, model FLA-6-120-11. Its resistance value is 120 Ohm, its gauge size are, L=6mm, W=2.6mm, and its backing are L=12.5mm, W=4.5mm. The signal amplifier used was model ICA2, developed by the same company, with output voltage range between 0.1-5.1 volts. Combined with interface board developed by our group and the Super Node transfer module, we can achieve the goal of using WSN Wireless transmission module to send data, as illustrated in Figure 3 to 5.

Figure 3: Strain gauge

Figure 4: Amplifier

Figure 5: Strain gauge fixed test Copper and transfer module

Ⅳ. Wireless sensor network (WSN) monitoring system for outdoor installation with measured

The site study for this research was conducted in Sanchong, New Taipei City. The construction had lot size of 1980m^2, 24 floors above ground, and 4 floors below ground, and it was a steel reinforcement concrete structure. The monitoring equipment was placed at the scaffold located at the outer north side of the building. Because the equipment was placed outdoors, AA battery boxes are used as power supply for the convenience of changing batteries (Figure 6 to 8).

Figure 6: Monitoring

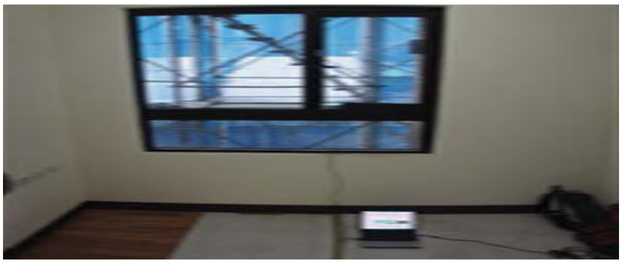

Figure 7: Installation position-scaffold of 4th floor

Figure 8: Strain gauge affixed test device for scaffold

Ⅴ. Measured Data Analysis and Conclusions

5.1 Measured Data Analysis

In site testing, the data measured by wireless strain sensor is very small and didn't meet the standards of warning. Therefore, we set a Destructive tests (Figure 9-11) in order to ensure strain sensor equipment could be reliably measured of the strain and return a warning message to the host server.

There is a scaffold column from research site. Setting strain gauge at upper, middle and lower parts of scaffold column, and connect to wireless sensor technical. Using oil pressure clamps, modules and calipers to measure the relative amount of scaffold deformation. The result shows that invented equipment of this project can measure and record the process of the strain of the scaffold from its secure state to emergent state effectively, and send back the result with the warning.

Figure 5-1 Vernier calipers and hydraulic hand pump

Figure 9: Hydraulic hand pump and mold

Figure 10: Test Equipment full

Figure 11: The actual test situation

5.2 Conclusions

In strain monitoring, we focus on relative deformation. According to statistic and analysis data, we discover no matter wireless or not the value is pretty tiny. There are two reasons may cause this phenomenon. First, in this site, the tie wall bar and cross bracing was setting sturdy, so the chance of buckling would reducing. Besides, the structure was complete, only few labor would worked outside which let live loading is small also make data change not obvious.

Second, according to reference, only grouting would set the carrier pipe on scaffold also let scaffold's loading is small. We suggest that strain monitoring could setting on formwork strut. In 2015, give the testing data from

March 25 and March 30 for example; these two days are no work at outside, and the ratio larger than 1μ strain value which are 0.83% and 2.1% is small, as in Figure 12 and Figure 13.

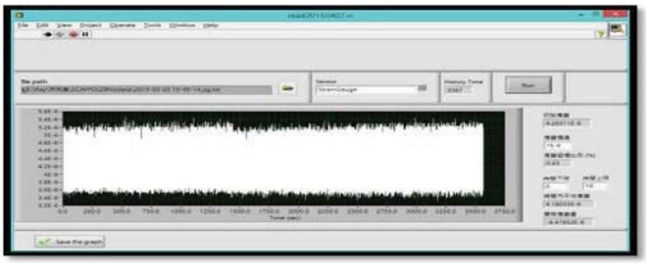

Figure 12: 3/25 Strain Monitoring data in Fig

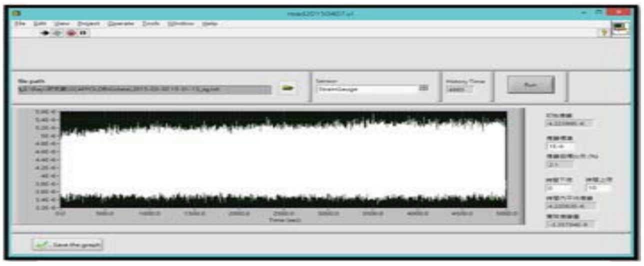

Figure 13: 3/30 Strain Monitoring data in Fig

These results showed the structure of scaffold at outside wall is stable, and difference may be temperature influence. After analysis data the ratio which strain value is larger than 1μ is 4.87%. In the future, choosing more suitable Wheatstone bridge to decrease the influence of environmental disturbance.

According to reference, the allowable loading of scaffold is 1500 kg and young's modules is 2.04×10^6 Comparing scaffold's allowable strain with research results, we suggest that using strain value 0.00115 as the warning value of scaffold.

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