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Study of Real-Time Slope Stability Monitoring System Using Wireless Sensor Network

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Abstract

Traditional monitoring instruments have been found difficult to meet the requirement for real-time monitoring. This study applied Wireless Sensor Network (WSN) to slope stability monitoring, In recent years, the slopes in Taiwan have frequently caused disasters after heavy rains, and traand understand the process of slope instability from the characterization variation of new concepts. In the first stage, the Mems Sensors were selected and calibrated, and the accuracy was selected as 0.1 and 0.5° . The self-made tilt calibration apparatus was used to calibrate the accuracy of 33 Mems Sensors respectively placed on the side slope. The stability and repeatability were validated multiple times. The field monitoring was carried out at the second stage. National Highway No. 3 3K+100 and TW PHW62 were selected at test locations, and 23 and 10 sensors were placed at these locations respectively. The data were collected in the in-situ industrial computer, and were transmitted via 3G wireless network card to the remote management unit as the basis of monitoring side slope. This study is now at the overall distribution stage, hoping to use the wireless sensor technology to develop an effective, real-time and energy-saving environmental monitoring system and management platform, so as to construct an intelligent WSN early warning and reporting system, which can be applied to the slope disaster prevention engineering.

Keywords*: Wireless Sensor Network, Node, Slope Stability*

1. Introduction

The monitoring data could be a basis for understand the situation and warning in slopes. Because of the monitoring methods are regular admissions for measuring reading. It could not monitoring real-time if it is caught in a severe weather such as typhoon, heavy rain or earthquake, etc. Many disasters were occurring because of people unable to grasp the immediate situation and evacuated real-time at the bad weather or the typhoon period. The commonly used slope monitoring instruments are included: incline meter, settlement gauge, tilt meter, groundwater table gauge, landslide gauge, rainfall mater and crack gauge, etc. On the consideration of the early warning functions, automation is necessary but the cost is high. Therefore, how to enhance the real-time monitoring technology, and make system cost down are become the important research orientations.

For this part of study, it should be consider as the overall monitoring in the stability of ground surface movement and should control the timing of approaching prospecting anytime. For the purpose of monitoring the slope ground surface movement, MEMS tilt mete is introduced for the related studies these years. Therefore, the selection of the sensor in Micro-Electro-Mechanical System (MEMS) with Wireless Sensor Network could control the overall data variation on-time. WSN is Wireless Sensor Network constructed by the Miniature sensor which has the sensor capability, computing capability and communication capability.

2. Wireless Sensor Network

The wireless sensor is characterized by low power and long operation. It sends out data via the communication components at the node. The communication among various nodes in the environment forms a small network, and the sensed data can be transferred on the optimum data transmission path in this network environment.

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The network system that is consisted of mobile base station can be used. The basic principle is to use the range covered with the dispersed sensor nodes in the network. The nodes form a network in Ad-Hoc mode, and the data link layer of each node is formed of star topology, as shown in Figure 1- Figure 2 [1]. The monitoring data are transferred to the node of base station through relay. Finally, the long distance or temporary base station transfers the data within the whole region to remote observer for processing. The wireless sensor network structure is shown in Figure 3 [1].

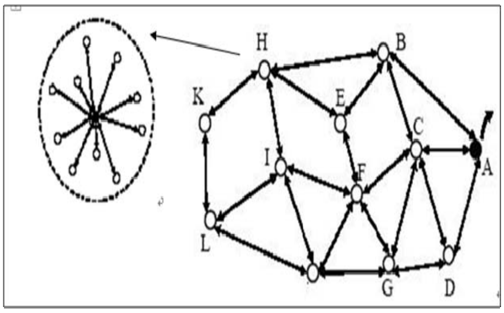

Figure 1. Star topology and Ad-Hoc network layer. [1]

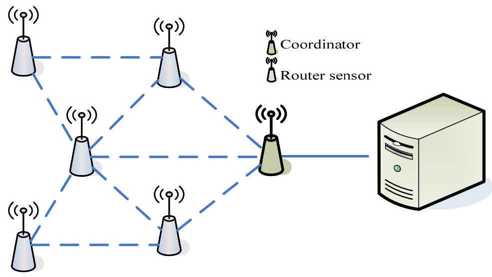

Figure 2. Star topology and Ad-Hoc network layer. [1]

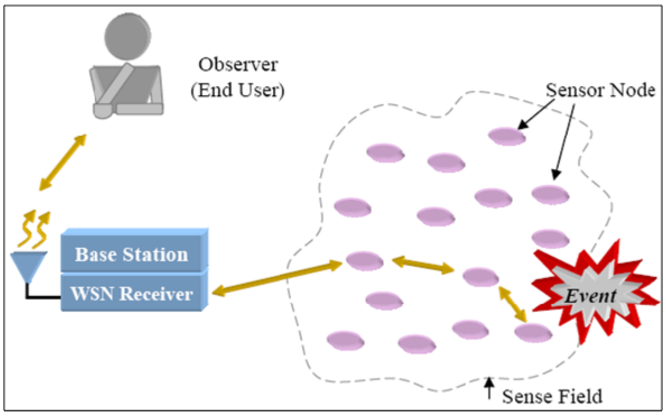

Figure 3.WSN Structure diagram. [1]

The short distance, low power and low bandwidth wireless transmission protocol of Zigbee (IEEE 802.15.4) was used. The transmission distance of Zigbee is over 10m, and the operating frequency band is ISM frequency band of 868MHz, 915MHz and 2.45GHz respectively [2, 3]. The 2.45GHz is universal industrial and medical standard frequency band in the world, providing 16 channels and transmission speed of 250kbps. The Zigbee has high network extensibility, and there can be 65000 nodes in the network. In terms of Zigbee network architecture, Zigbee stack is similar to OSI network seven-layer architecture. The layers from the bottom layer to the user include PHY, MAC, NWK and APS. Each layer implements a part of network function, and the bottom layer constructs the network function of upper layer [2, 3].

3. Research Program

3.1. Research Method and Selection of Demonstration Site

The slope disaster does not occur suddenly without any early warning. The early instability process is accompanied with warning signs of gradual change in earth surface, as shown in Figure 4 and Figure 5. [4]. When the sloping field begins to slide slowly, the slope surface may be protrude or settled down. The variation of side slope surface (earth surface inclination is observed object) is observed by real-time monitoring of characterization variation, so as to grasp the "instability" process before the slope disaster (process of gradual decrease in stability).

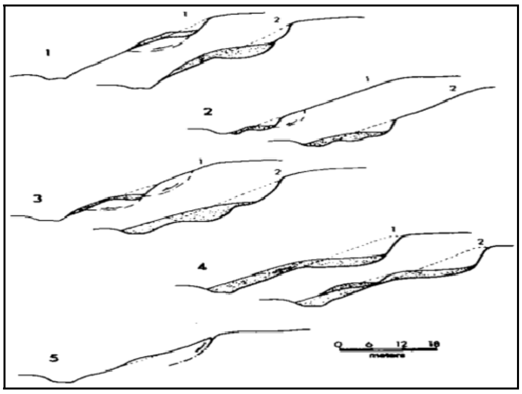

Figure 4. Different regional instability process of slope (obvious surface variation) [4]

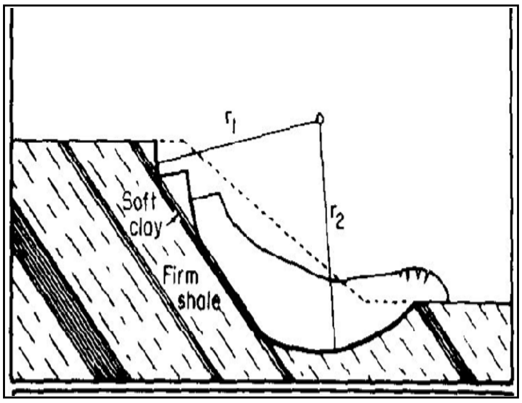

Figure 5. Brittle slope site causes surface subsidence [4]

As for the observation point inclination measurement principle, the COS function is used to back calculate the included angle between the acceleration value measured by Z-axis and the G value (1.0g) normal to the earth's core. It is the included angle to Z-axis, expressed as Z and X directions respectively. As 2-dimension is used in slope stability analysis, the present inclination of slope structure or local variation of earth surface can be known from this angle. The computing mode is shown in Figure 6. [5, 6]

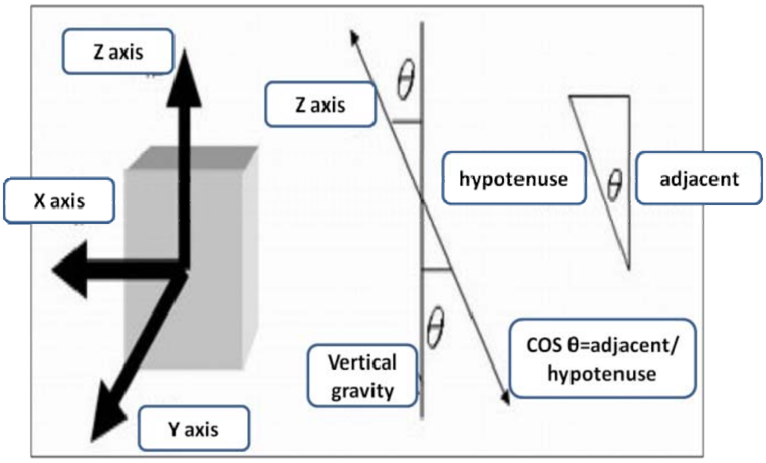

Figure 6. Schematic diagram of angle measurement and calculation. [5,6]

Multiple joint surveys were carried out for selecting the slope demonstration site. National Highway No. 3 3K+100 (former National Highway No. 3 landslide disaster area) and TW PHW62 were selected as the demonstration sites in this study. As the slope field has multiple catch drain systems, when the slope surface begins to change, the catch drain will certainly crack, jostle and deform first. Therefore, the inclinometer was installed on the catch drain in the slope surface to monitor where the characterization variation is most likely to occur, as shown in Figure 7.

3.2. Selection of Mems Sensor

As related products were concerned with highly professional domains, Lu-chang Dai was consulted. Dai provided the following information for this study.

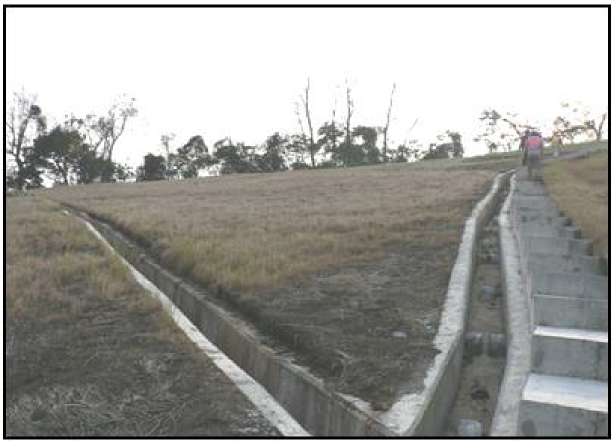

Figure 7. Drain system for National Highway No.3.

Analog Devices, High Accuracy, Dual-Axis Digital Inclinometer and Accelerometer-ADIS16209 0.1°

- Freescale tilt sensor using accelerometer
- Inclinometer Sensor _ Level Single and Dual Axis Inclinometer Sensors.
- MEMS tilt sensor CXTA_Datasheet 0.05°
- MEMSIC digital CXTILT_Datasheet 0.2°

This study selected the sensors of ADIS16209 0.1° and ADXL345 0.5°. The inclination measurement range ±10° of traditional products on the present market is inapplicable to monitoring slope surface variation. The inclination measurement range of the specification selected in this study can be ±90°, and it is of dual-axis measurement.

3.3. WSN Modules Assembly and Layout

This study used two sensors with different accuracies, ADXL345 0.5° and ADIS16209 0.1° sensors to monitor the slope inclination. The microcontroller CC2430 used four-wire SPI (Serial Peripheral Interface Bus) and I2C (Inter-Integrated Circuit) communication interfaces to command sensors ADIS16209 and ADXL345 to feed back sensor values. The values were read every 3 sec, the Router transferred the measured data to the Coordinator, and the Coordinator collected all data. Then the UART (Universal Asynchronous Receiver/Transmitter) transmitted the data to the industrial computer.

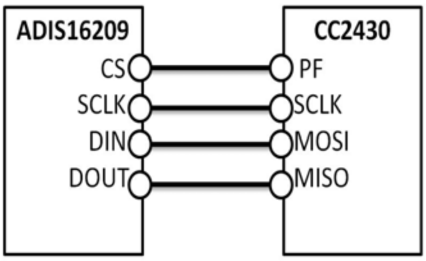

Figure 8. SPI Connect Diagram.

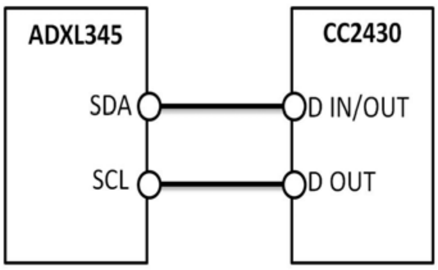

Figure 9. I²C Connect Diagram.

3.4. Calibration and Repeatability Study for WSN System

The self-made adjustable tilt calibration stand was used for test. First, the level meter was used to level the calibration stand. The electronic inclinometer calibrated by the testing agency approved by TAF (Taiwan Accreditation Foundation) was placed on the fixed tilt plate on the stand. The WSN inclinometer was placed on the same plane, as shown in Figure.10. The flat was tilted and the angle of inclined plane was determined simultaneously. The two methods were compared to identify the linear read value of the selected WSN inclinometer and its repeatability. The test procedure is shown below:

1. The tilt calibration stand was leveled, and the electronic inclinometer was placed on the fixed tilt plate on the test stand. The accuracy of the tilt plate was 25 sec (0.007°), which is much higher than the selected MEMS Sensor (0.5° and 0.1°), and serves as the basis of calibration.
2. The WSN inclinometer was placed on the calibration stand to measure the initial values of two instruments respectively.
3. The lifting shaft was turned clockwise to lift the stand. It was turned 5, 10, 15, 20 and 25 revolutions respectively, and the angular variation measured by tilt plate and WSN inclinometer was recorded.
4. The 25th revolution is the initial value, counter clockwise turning to lower the stand, by 20, 15, 10, 5 and 0 revolutions respectively. The angular variation of tilt plate and WSN inclinometer was recorded respectively. The repeatability (stability) of instrument was validated.
5. All the units were divided into 33 groups and tested. The units were expressed as Node.1~ Node.33. Two groups of units with accuracy of 0.5° and 0.1° are shown in Figures.11~14.

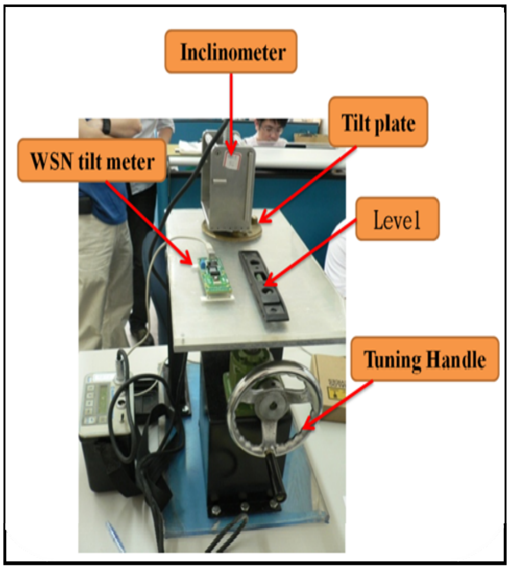

Figure 10(a). WSN tilt meter calibration test.

Figure 10(b). Tilt calibration stand Lateral view

6. Calibration and repeatability evaluation study were conducted. The results are shown in Figures. 10~13. Only the typical results were selected for presentation. As seen, the selected Mems sensors have stable results in the WSN system. Although some results are slightly different (units with accuracy of 0.5°) from the standard (tilt plate), the results are normal values in the accuracy range. The difference in the components with 0.1° accuracy is reduced obviously. In terms of stability, the inclination value of WSN presents linear response, and should be further validated. The trends of read values of lifting and lowering of calibration stand almost overlap each other, which is the result of inclination value repeatability of WSN system.

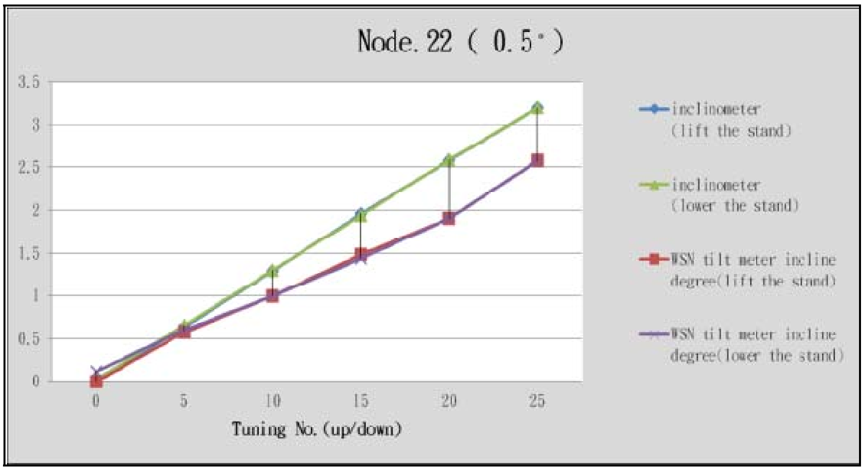

Figure 11. Node 22 (accuracy 0.5°) calibration result.

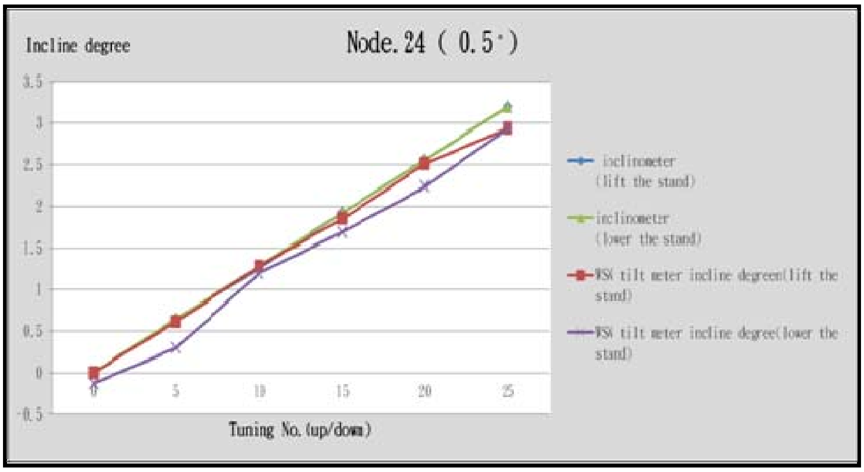

Figure 12. Node 24 (accuracy 0.5°) calibration result.

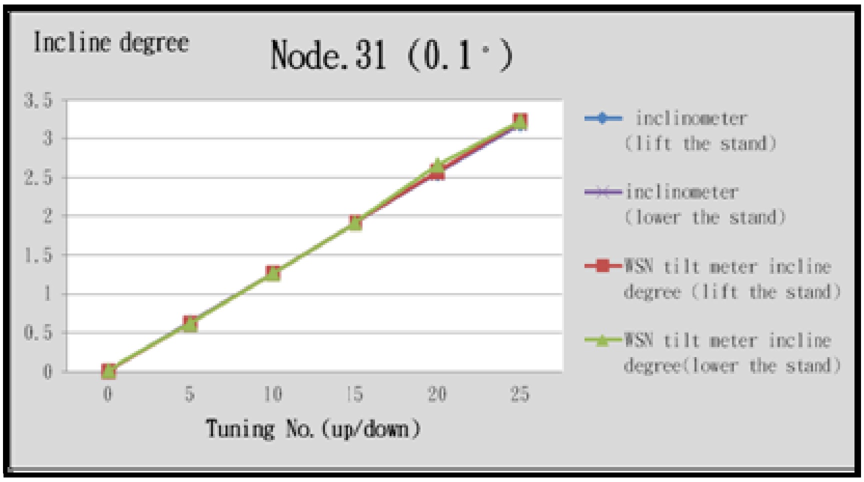

Figure 13. Node 31 (accuracy 0.1°) calibration result.

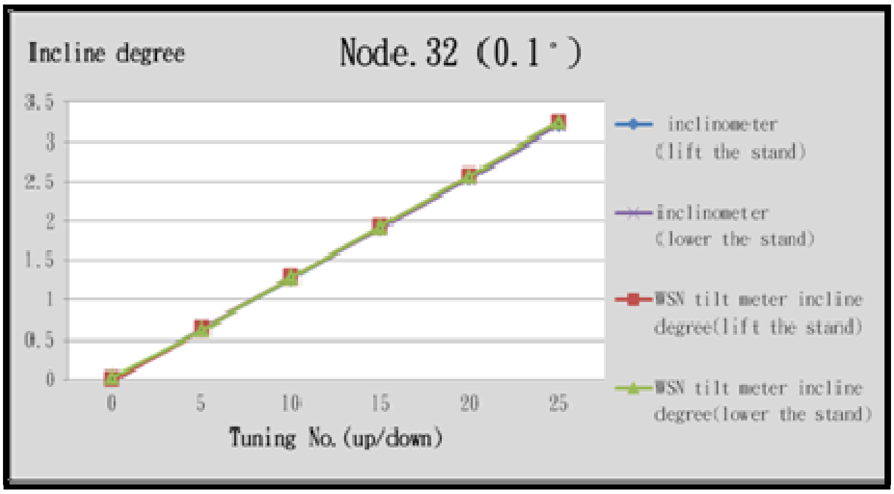

Figure 14. Node 32 (accuracy 0.1°) calibration result.

4. Construction and Planning of WSN Slope Surface Tilt Monitoring System

4.1. In-Situ Units Set Up and Installation

The in-situ instruments included packaging box (industrial computer, Coordinator, 3.5G wireless network card, 3G wireless sharer), 3G network card antenna, 380v-110V transformer and 39 groups of units and aluminum fixing support.

A large-scale slide occurred at National Highway No. 3 3K+100 on April 25, 2010, and caused casualties. Fully automatic 24 hr traditional monitoring system had been installed at present, including in-land inclinometer, electronic hydraulic indicator. There were 8 transverse drains and 2 longitudinal drains in the slope surface. The heavy weed growth on the slope surface, which may influence the WSN transmission effect, was considered in the node setup. Therefore, aluminum fixing support was used to fix the packaged node to the top (about 50cm high). There were 23 groups of nodes after measurement and evaluation, including 8 groups of 0.1。 and 15 groups of 0.5。. The layout is shown in Figure.15.

Figure 15(a). Setup of node for transverse drains.

Figure 15(b). Setup of node for longitudinal drain.

The in-situ packaging boxes were fixed to concrete wall, containing industrial computer, receiver, 3.5G wireless network card, and 3G wireless sharer. The protection of packaging boxes enhances the durability of in-situ equipments, and secures the stability of the overall monitoring system.

In addition, the downslope at TW PHW62 slope site and National Highway No.3 3K+100, considering the deep layer of upslope (National Highway No.3) has begun to slide, which would influence the stability of downslope directly (TW PHW62). The slope surface can be monitored based on the characterization variation in the new concept. It is at the layout stage at present.

Figure 16(a). Schematic of layout at TW PHW62

Figure 16(b). Setup of node for longitudinal drain

5. Back End Data Transmission Mode

The wireless sensor network stack protocol Z stack developed by Texas Instruments Inc. was used as the development tool. It was integrated with acceleration sensor, and Zigbee was used to construct a wireless sensor environment for monitoring the slope inclination value. The measured data from various nodes were collected in local computer, and the data were transferred via Chunghwa Telecom 3.5G mobile network card to the database in the remote server for storage. Webpage was created in the server. The user and monitoring unit can link to the webpage of remote computer via network browser, so as to view the real-time data and duration data of nodes. The system structure is shown in Figure 17.

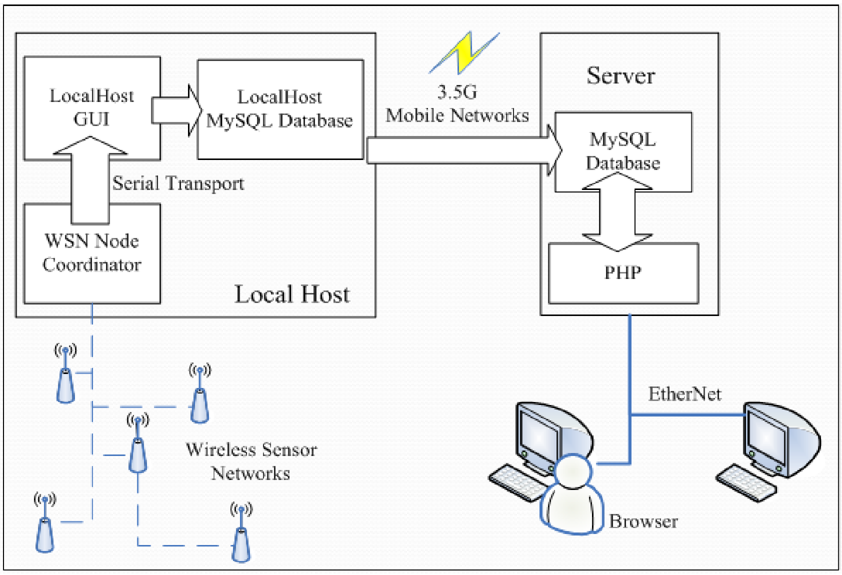

Figure 17. System structure

6. WSN Monitoring System Interface

The operating state of laid nodes can be clearly seen from Google map, where green represents normal state, and red represents abnormal state. On the other hand, the real-time data and duration data of each node can be viewed on the remote management platform.

Figure 18. Industrial computer

Figure 19.Node state interface on Google map.

Figure 20. National Highway No. 3 3K+100 on management platform.

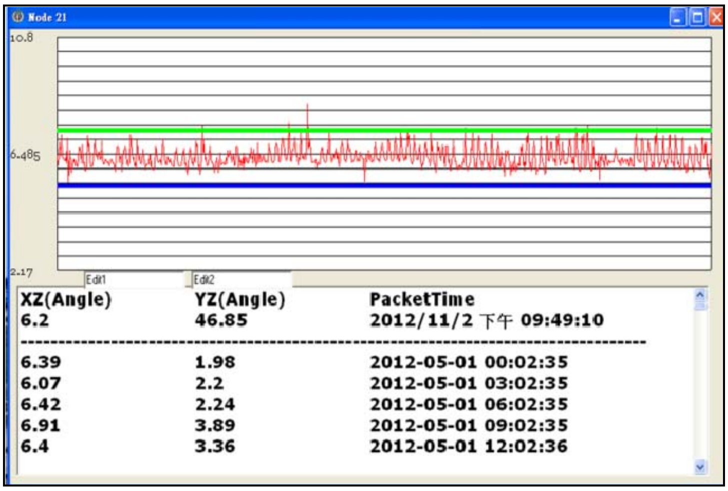

Figure 21. Node state interface on management platform.

7. Conclusion

There were many problems in the construction of the WSN monitoring system. For example, in the course of connecting nodes to power cord on site, short circuit, system off line, data transmission suspension and in-situ industrial computer leakage occurred many times because of carelessness. They are problems in field installation and operation, and they have been solved, allowing the WSN monitoring system to be in normal operation. Since the primary data read by each set of nodes set up in-situ are different, the initial value of each set of nodes has been set according to the data read by WSN monitoring system. Subsequent discussion and research are carried out to find out the substantial meaning of the monitoring data. In addition, for using WSN monitoring system in civil domain, the energy-saving design is an important factor that should be considered for field application. Therefore, wind power-solar generator will be laid at National Highway No. 3 3K+100, with an attempt to use this generator to supply power to all the in-situ instruments and equipments for energy-saving.

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