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Slope Movement Detection using Ubiquitous Sensor Network

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Abstract – About 70% of Korea consists of mountainous areas, and during the construction of many roads and railroads, cut slopes are inevitably formed. The rainy season, frost heaving in winter, and thawing in spring can all cause rockfalls and landslides. The failure of these slopes is increasing every year, causing damage to vehicles, personal injury and even death. To protect people and property from such damage, a real-time monitoring system is needed to detect the early stages of slope failures. The GMG placed TRS sensor units in the slopes to monitor them in real-time. But due to its reliance on data lines and power lines, the system is vulnerable to lightning damage. The whole system can be damaged by a single lighting strike. Consequently, for the purposes of this paper we propose the use of the Ubiquitous Sensor Network (USN) which follows the IEEE 802.1.4. By using the USN system we can minimize lightning damage and can monitor the movement of the slopes consistently.

Keywords: cut slope, GMG, TRS, USN, IEEE 802.15.4

1. Introduction

In Korea, 70% of the country is made up of mountainous regions with many roads, highways and railroads. Cut slopes are inevitably formed during construction or when widening roads. Most of the yearly mean precipitation happens from June to August, in addition to frost heaving in winter and thaw in spring. Because of these climatic and geological features in Korea, there is a very high possibility for rockfalls and landslides to occur on or near roads. According to statistics from the Ministry of Construction & Transportation, there have been 326 failure sites with rockfalls or landslides over a 7-year period. These failure sites are increasing every year, reportedly causing damage to 45 cars, injury to 9 persons, and 4 deaths [1].

To protect people and property from such disasters, it is necessary to use real-time monitoring systems to detect the early stages of slope failure. The GMG have developed a Slope Maintenance System which is able to monitor the slope behavior in real-time. With their accumulated data and long-term know-how, they developed a model to predict the failure of slopes.

To measure the movement of the slope, they install the Slope Maintenance System comprising the TRS sensor units and the data logger. The TRS sensors can measure the tension, rotation and settlement of the slope. The system in the slope consists of the TRS sensor units and the data logger. The data logger parts collect and save the data from the sensors and sends the data regularly to the monitoring server by using CDMA communication modems [2], [3].

As the sensors are connected to the data logger with the data lines, it is vulnerable to lightning. The induced current caused by the lightning follows the power line or the data line and breaks the circuits inside the sensors and data logger. A single lightning strike can damage the whole system. As the slopes are mostly found in the mountain regions, during the rainy season many sensors and data loggers are damaged by lightning strikes.

To minimize lightning damage, we propose the wireless USN system be adopted between the sensors and the data logger. The adopted USN mote is based on the IEEE 802.15.4 data transfer mechanism. As we are using the wireless ad hoc network system, the lightning's effective range will diminish [4]-[7]. And without the data lines and power lines, the induced current has no power of influence in the wireless USN system. So the adoption of the USN mote system can protect the remainder of the system and the system will constantly monitor the integrity of slopes.

2. TRS Sensor System in Cut Slopes

Predicting the cut slope's failure is not easy to estimate. We need long-term accumulated data about the cut slopes, in particular for those cut slopes which are failing. GMG has been monitoring hundreds of cut slopes and has accumulated a lot of data. To properly evaluate the cut slopes, they should be analyzed with many important

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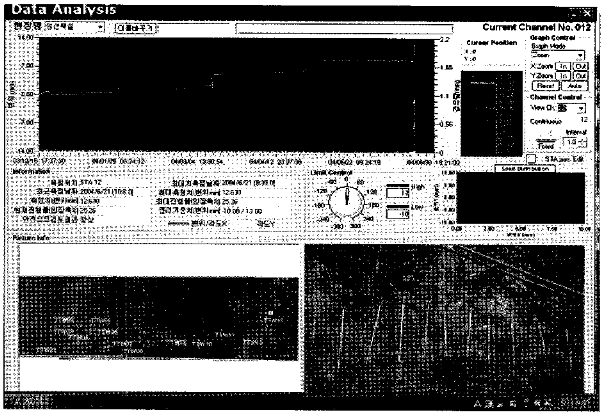
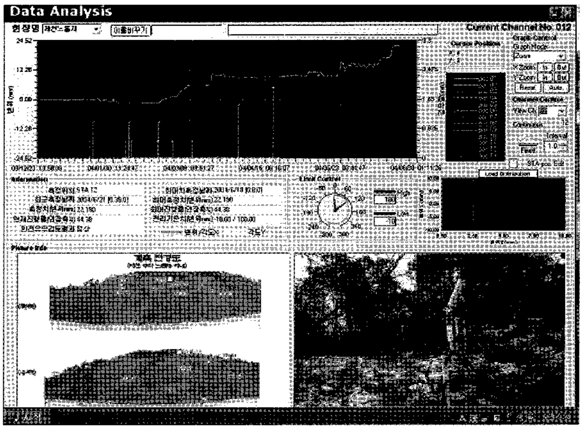




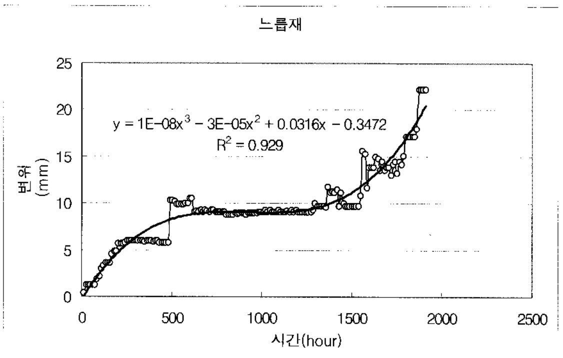


Fig. 1. Measured data and analyzed model of Nerupjae

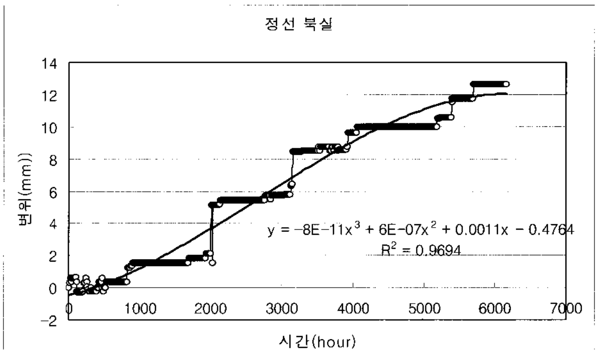


Fig. 2. Measured data and analyzed model of Buksil

factors from the real-time measured time series. And we need to choose a reasonable mathematic model to predict future cut slope failure. GMG analyzed the failing slopes and made the General failure model. General failure models are divided into two main models.

One is the polynomial model (Straightforward accelerated failure), and the other the growth model (Failure with inherent). Fig. 1 shows the trend of the polynomial model and Fig. 2 shows the trend of the growth model. To watch these trends of the slope, there should be a system that does not fail in long- term monitoring. This shows that durability is essential in cut slope monitoring systems.

These two cut slopes are measured by the TRS sensor units developed by the GMG. Fig.3 shows the TRS (Tension Rotation Settlement) sensor units and their placements in the cut slopes. There are four sensors on the TRS sensor unit: two clinometers, one inclinometer and one tension wire. The two clinometers measure the X, Y axis movement, the inclinometer measures the Z axis movement, and the tension wire measures the movement of the sensor unit from the initial position of the sensor.

With this data, we can analyze the movement of the slope by putting it into the two general models and estimating the state of the cut slope. The TRS sensor units are connected to the data logger in data lines and power lines. Because of these lines they are vulnerable to lightning damage.

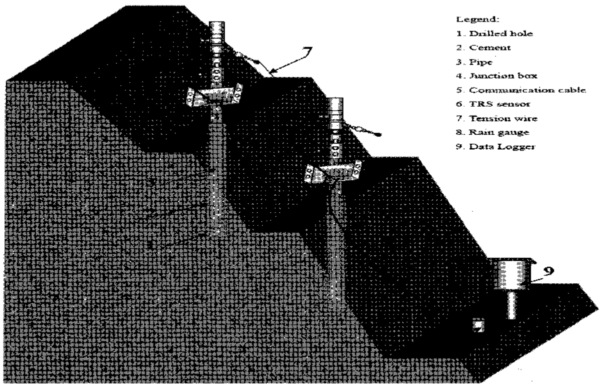


Fig. 3. TRS sensor placement it cut-slope

3. System Configuration

Fig. 4 shows the configuration of the entire real-time monitoring system. This system has the server computer,

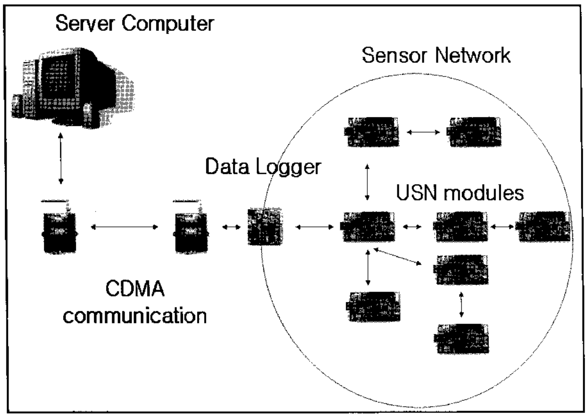


Fig. 4. Entire System Configuration

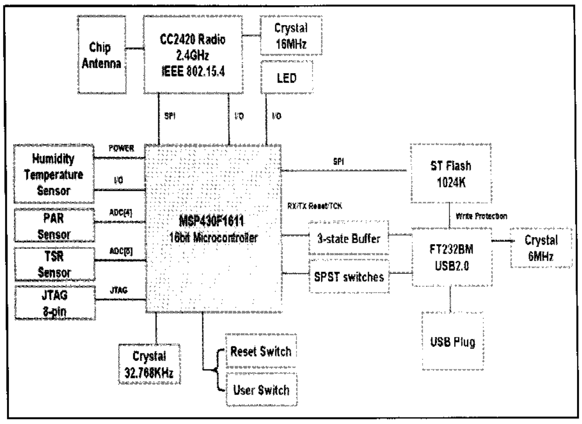
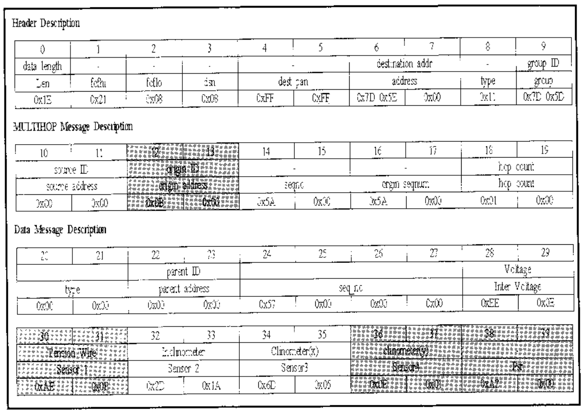


Fig. 5. Block diagram of the TIP810CM

CDMA communication modems, the data logger, and sensor networks. The sensor network consisted of USN modules and TRS sensors. The USN module receives the data from the TRS sensors and makes the ad hoc or mesh network by itself. The USN module converts analog data to digital data with their inherent A/D converter.

They send and receive the data from USN module to USN module. The ID zero USN module receives the other USN modules' data and saves it on the data logger. An entire sensor network's data is saved every minute. And the data logger uses the CDMA communication to send the saved data to the server computer. The sever computer separates the data by the slope's name, analyzes it then places the results on the slope's website. It will then enable the checking of the slopes' behavior in real-time. Wherever the Internet is available we can monitor the slope online.

TIP810CM is the USN module from Maxfor. It is a platform that can utilize various sensors and realize sensor network applications as a devic e node to compose sensor networks to IEEE 802.15.4 based on TinyOS. TIP810CM offers a number of integrated use frequency of 2.4GHz band. It supports ultra low power, and Multi-hop network with IEEE 802.15.4 based on TinyOS [8].



Header Description

0	1	2	3	4	5	6	7	8	9
data length	-	-	-	-		destination addr		-	group ID
Len	fcfhi	fcflo	dsn	dest pan		address		type	group
0x1E	0x21	0x08	0x08	0xFF	0xFF	0x7D 0x5E	0x00	0x11	0x7D 0x5D

MULTIHOP Message Description

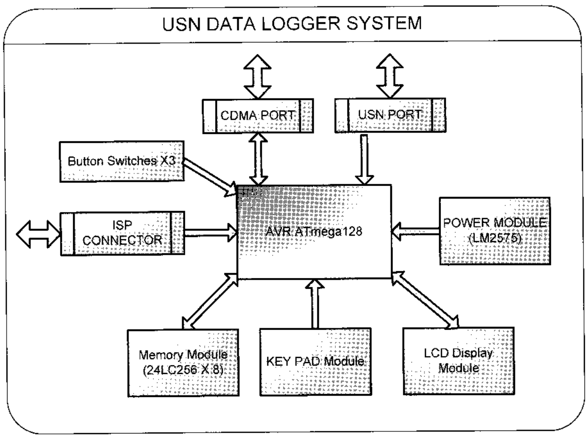
10	11	12	13	14	15	16	17	18	19
source ID		origin ID		-		-		hop count	
source address		origin address		seqno		origin seqnum		hop count	
0x00	0x00	0x08	0x00	0x5A	0x00	0x5A	0x00	0x01	0x00

Data Message Description

20	21	22	23	24	25	26	27	28	29
		parent ID						Voltage	
type		parent address		seq_no				Inter Voltage	
0x00	0x00	0x00	0x00	0x57	0x00	0x00	0x00	0xEE	0x0E

30	31	32	33	34	35	36	37	38	39
Tension Wire		Inclinometer		Clinometer(x)		clinometer(y)			
Sensor 1		Sensor 2		Sensor3		Sensor4		Psr	
0xAE	0x0E	0x2D	0x1A	0x6D	0x05	0x0E	0x01	0xA2	0x00

Fig. 6. Data packet format (USN to USN).



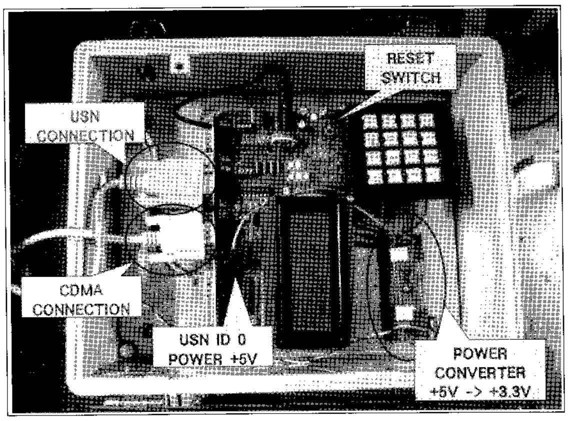
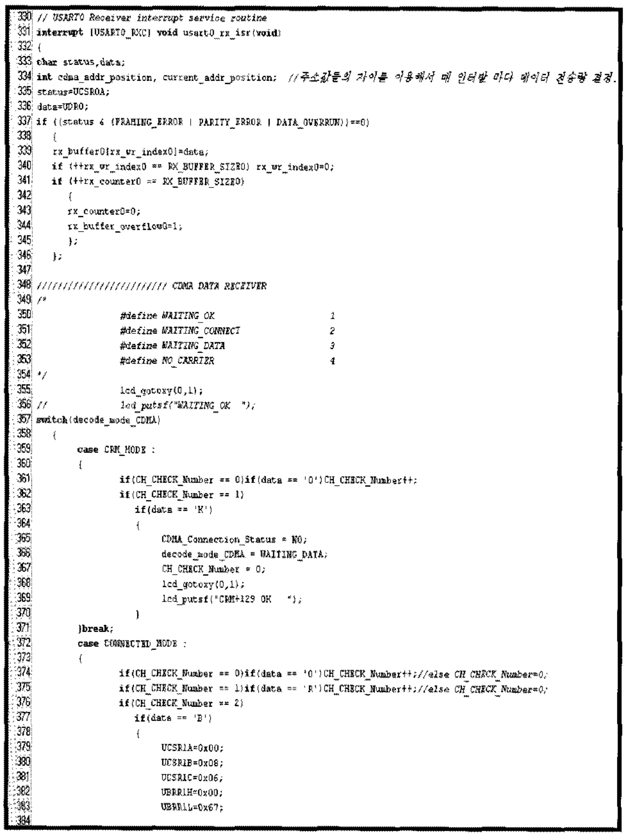


Fig. 7. Data logger system

Fig. 5 shows the block diagram of the TIP810CM. It has MSP430 which has very low current consumption and a 7

A/D converter with 12 bit resolution [9]. With that, we can use many sensors with high-resolution ability. As the displacement of the slope can sometimes be very slow, high resolution ability is absolute necessity. With CC2420, TIP810CM uses the 2.4 GHz band and forms the multi-hop or ad hoc network themselves. CC2420 uses a DSSS (Direct Sequence Spread Spectrum) transceiver and O-QPSK modulation. It can transmit 250 kbytes per second at maximum [10]. The data format used is shown in Fig. 6.



```
// USART0 Receiver interrupt service routine
interrupt [USART0_RXC] void usart0_rx_isr(void)
{
char status,data;
int cdma_addr_position, current_addr_position;  //주소값들의 차이를 이용해서 매 인터럽 마다 데이터 전송량 결정.
status=UCSR0A;
data=UDR0;
if ((status & (FRAMING_ERROR | PARITY_ERROR | DATA_OVERRUN))==0)
   {
   rx_buffer0[rx_wr_index0]=data;
   if (++rx_wr_index0 == RX_BUFFER_SIZE0) rx_wr_index0=0;
   if (++rx_counter0 == RX_BUFFER_SIZE0)
      {
      rx_counter0=0;
      rx_buffer_overflow0=1;
      };
   };

//////////////////////////// CDMA DATA RECEIVER
/*
                #define WAITING_OK                  1
                #define WAITING_CONNECT             2
                #define WAITING_DATA                3
                #define NO_CARRIER                  4
*/
                lcd_gotoxy(0,1);
//              lcd_putsf("WAITING_OK  ");
switch(decode_mode_CDMA)
   {
        case CRM_MODE :
        {
                if(CH_CHECK_Number == 0)if(data == '0')CH_CHECK_Number++;
                if(CH_CHECK_Number == 1)
                   if(data == 'K')
                   {
                        CDMA_Connection_Status = NO;
                        decode_mode_CDMA = WAITING_DATA;
                        CH_CHECK_Number = 0;
                        lcd_gotoxy(0,1);
                        lcd_putsf("CRM+129 OK   ");
                   }
        }break;
        case CONNECTED_MODE :
        {
                if(CH_CHECK_Number == 0)if(data == '0')CH_CHECK_Number++;//else CH_CHECK_Number=0;
                if(CH_CHECK_Number == 1)if(data == 'R')CH_CHECK_Number++;//else CH_CHECK_Number=0;
                if(CH_CHECK_Number == 2)
                   if(data == 'B')
                   {
                        UCSR1A=0x00;
                        UCSR1B=0x08;
                        UCSR1C=0x06;
                        UBRR1H=0x00;
                        UBRR1L=0x67;
```

Fig. 8. The algorithm for the data format change

It shows the data structure from the USN mote to the USN mote. The mote uses RF power with 10mW.

To verify the mote's communication reliability, we tested it with all the motes in the playground. The mote's maximum reliable communication range in LOS (Line-of-Sight) was 70m. So with these result we used these motes to form a mesh or ad hoc network at the test bed.

The data logger has the USN module, Real-time clock (DS12C887), Serial EEPROM (24LC256*8), LCD module, keypad module, and CDMA communication modem with micro-controller (Atmega128). As shown in Fig. 7, the main micro-controller in the data logger is an Atmega128 which is programmed to manage the whole system and to perform the tasks as shown.

The ID zero USN module in the data logger receives data from the other USN modules using the RS-232C interface. The program is designed to receive data every minute. When every USN module's data is received, it is saved in the Serial EEPROM with the date and time as its name (2008_03_10_11_23) in ASCII code. The data format is shown in Fig. 8. The micro-controller changes the data format from Fig.6 to Fig.8.

The status of all data loggers is displayed on the LCD screen simultaneously. The required data from the host server is sent using CDMA communication between the modems in fixed time (every 10 minutes). CRC (Cyclic redundancy checks) Stream Data Error Check Method is used to check for errors in the received data. The algorithm for the data format change and CDMA communication is in Fig. 8.

4. System Evaluation and Test

To confirm the system's ad hoc or mesh network and evaluate the whole system's performance, we installed the whole system in Gumi. The tested system was installed in GMG's testbed. The testbed has about 40 degrees of slope with an area of 30m2. The tested system consisted of a data logger, TRS sensor modules, the CDMA communication modems and server computer. The TRS sensor units were mounted on the piles which were drilled 10m in depth. The piles are 7m away from each other. The TRS sensor modules are completely sealed in an aluminum case and the data logger was also installed in the steel case with the CDMA communication module for protection from the weather. Fig. 9 shows the installed system in the testbed. To analyze the system's reliability,

we gathered more than 10,000 data in the server computer and the data logger.

The data in the data logger showed that the USN motes built up a successful ad hoc or mesh network. They gathered the data from the sensor system almost every minute without any errors or faults. A successful ad hoc wireless communication system is used to monitor the slopes with this communication system.

Fig. 10 shows the results of the system's reliability. It

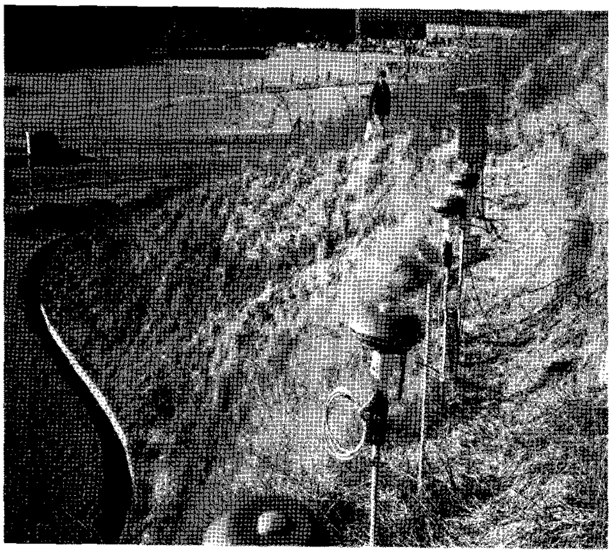


Fig. 9. The system in the testbed

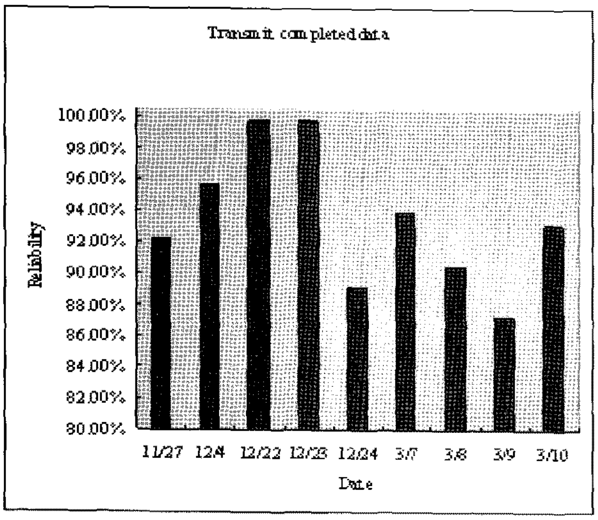
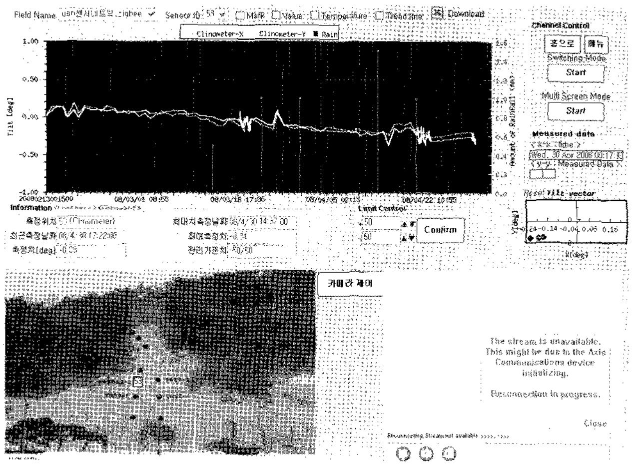


Fig. 10. Reliability result

shows the probability of successful transmission of the data from the server computer to the web server. We chose 9 sample days to analyze the system. The best results on 12/22 and 12/23 show almost 100% successful transmission, while the worst result on 3/9 shows 87% successful transmission. Overall results show an average 93% successful data transmission.

But the data transfer probability between the CDMA communication system and the server computer has some gaps, and there are some gaps between the server computer and the web server.

These gaps are caused by errors in the CDMA communication and errors in data transferring between the web server and the server computer. About 7% of the data was lost in CDMA communications and data transferring between the web server and the server computer. When the web servers are too busy to communicate with other server computers, some of the data was during transmission.



The stream is unavailable.
This might be due to the Axis Communications device initializing.

Reconnection in progress.

Fig. 11. Slope movement displayed by the web server

This data loss should be considered along with the need to update the communication program between the server computer and the web server. Fig 11 shows the movement and trends of the testbed's slope measured with the USN system.

$$y = -8E\text{-}11x^3 + 6E\text{-}07x^2 + 0.0011x - 0.4764, \text{ and } R^2 = 0.9694 \quad (1)$$

$$y = 1E\text{-}08x^3 - 3E\text{-}05x^2 + 0.0316x - 0.3472, \text{ and } R^2 = 0.929 \quad (2)$$

Equation (1) is from the polynomial model in Fig 1, and equation (2) is from the growth model in Fig 2. We compared the testbed's data analysis with these two equations. The result shows that the testbed is neither the polynomial model nor the growth model. The analysis does not follow the trend of a polynomial model or the trend of a growth model. It is in the steady-state. The actual displacement in the testbed measured by the USN system is 0.5mm, which means almost no movement. And that is identical with the analyzed data.

5. Conclusion

In this paper, the real-time slope monitoring system with Ubiquitous Sensor network is tested and the results examined. In the test, the ad hoc or mesh network is well formed between the nodes in the test field. The data has been transferred between the nodes with reliability and accuracy. With these results we can cover the slope with a wireless USN communication system and can monitor the slope in real-time. Overall results were good enough for its use as a real-time slope monitoring system. Despite the little errors and the probability gap, the USN system is able to display and show the movement of the slope with consistency. The proposed system is still monitoring the testbed and has been transferring the data for more than 7 months. From the result of the test and evaluation, the real-time slope monitoring system with the USN system can monitor the slope with minimal lightning damage during rainy seasons.

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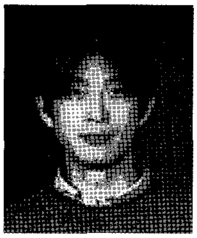

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