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Design and Implementation of System for Structural Health Monitoring in Horticultures

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Abstract

The extent of damage caused by heavy snowfall and strong winds in extreme weather conditions has recently been increasing. Accordingly, a great number of plastic greenhouses have been damaged by typhoons in summer and heavy snowfall in winter each year. In this study, a system that monitors the structural health of horticultural facilities using acceleration data is proposed. This system analyzes data obtained by structural health monitoring sensors and informs users of problems that have occurred in horticultural facilities through a client. In addition, the system proposed in this study has been designed, implemented, and tested to ensure it can detect a change in the location of an object that has been moved.

Keywords: *controlled horticulture, structural health, monitoring, acceleration sensor, safety*

1. Introduction

Scientific technologies have been constantly converging since the beginning of the transition to the modern era. In the late 20th century, the concept of interdisciplinary integration was actively implemented and new terms such as convergence science or convergence technology were coined. Electronic communication technology, which has made remarkable progress, is an integrated product of various fields, and the field of construction technology is no exception to this trend of convergence. The importance of food security has increased due to a decrease in grain stocks, population growth, and enhanced living conditions since the 2000s. The volatility in the crop conditions of vegetables has led to social issues in Korea, while a need for cultivation under structures and in proposed plant factories, which facilitate stable, year-round cultivation and efficient crop condition management, is increasing in Japan because of the Fukushima Daiichi nuclear disaster. For this reason, ICT (Information and Communications Technologies) convergence technology is now being applied to agricultural food to solve the problems of food shortages and safety [1].

Moreover, extreme climate change is occurring because of global warming. Climate change causes more frequent abnormal climate conditions such as cold snaps, heavy snowfall, localized heavy rain, drought, and strong winds, thus leading to significant socio-economic damage. The scale of controlled horticulture in Korea increased from 762 ha in the 1920s to 52,393 ha in 2011, and horticultural facilities are now being modernized and enlarged [2].

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However, the extent of damage caused by heavy snowfall and strong winds in extreme weather conditions is also increasing. Each year, many plastic greenhouses are damaged by typhoons in summer, heavy snowfall in winter, and year-round gales. Damage to plastic greenhouses was estimated to be KRW 340 billion in 2001 and KRW 180 billion in 2012. Typhoons and strong winds caused 49. 8% of the damage to these facilities, 47.2% was caused by snow, and 3.9% was caused by heavy rain. The average amount of annual damage was calculated to be approximately KRW 80 billion, and the damaged area was 1,411 ha [3].

In this study, a system for evaluating the safety of the structure of horticultural facilities is designed and implemented. GIS (Geographic Information System) technology is used to integrate computer hardware and software, which are designed to effectively collect, save, renew, adjust, analyze, and represent all types of measurable geographical-spatial information, geographical data, and human resources. The sensors attached to the structural supports are designed to notify users of a state of structural instability or danger through a GIS-based client by analyzing the received acceleration data. They also provide information on crop conditions in greenhouses through a management client using the input data. The system developed in this study will facilitate more convenient facility management and increase agricultural production for controlled horticulture farmers.

2. Relevant Research

2.1. Research on Structural Safety Evaluation

Hong *et. al.*, developed a technology that monitors the structural health of full-scale concrete girder bridges using acceleration data. Hong *et. al.*, proposed a two-stage system for structural health monitoring, which can warn engineers of the abnormal state of a bridge in real time and identify its location swiftly and accurately using acceleration response signs, which can be effectively used to detect the overall abnormal behavior of a structural system [4].

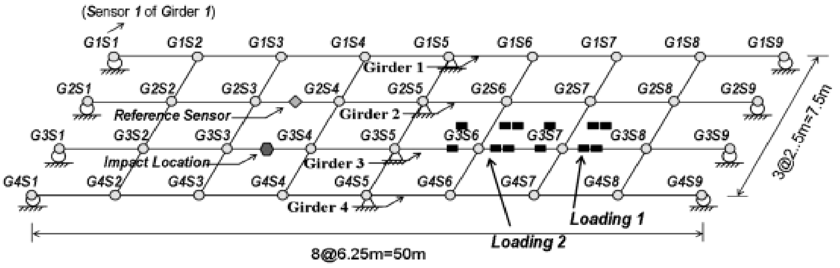


Figure 1. Test Setup for Extracting Dynamic Response Features

Choi *et al.* stated that a more complex system should be developed and analyzed to monitor the overall behavior of bridges because existing sensors accurately observe only the momentary, short-term state of a bridge. The monitoring system proposed by Choi can perform a three-dimensional behavior analysis of bridges using multiple GPS (Global Positioning System) sensors and facilitate bridge safety management by transmitting horizontal and vertical displacement data and warning signals in real time. Furthermore, this system can be connected to other sensors such as optical fiber sensors, strain gauges, and inclinometers to increase its reliability. Figure 2 shows a diagram of the real-time bridge monitoring system using GPS [5, 6].

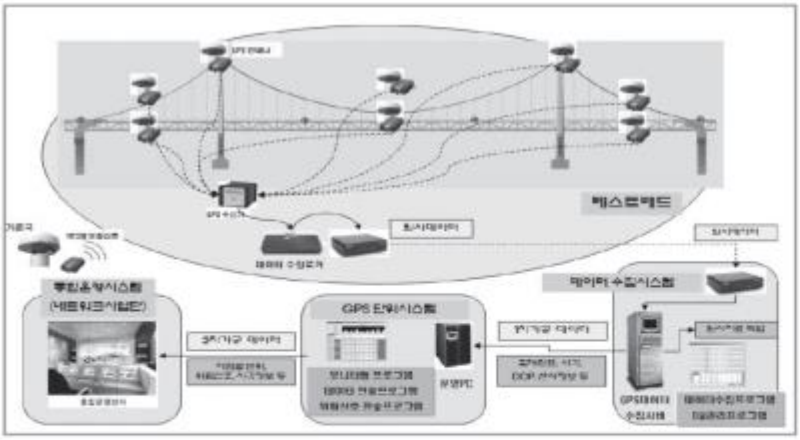


Figure 2. Configuration of Bridge Monitoring System using GPS Information

2.2. Data Application of a Nine-axis Sensor

In this study, MPU-9250, a 9-axis sensor produced by Invensense, was used. The nine axes consist of three acceleration axes, three gyro axes, and three magneto axes. The three acceleration axes were used in this project. An acceleration sensor identifies the movement of an object and measures its slope in a stationary state. When the acceleration sensor assumes that an object is inclined, an inclination angle based on the ground can be measured by using the tangents of the Z and Y axes, as shown figure 3. As the acceleration sensor uses three axes, it can measure an inclination angle based on the three x, y, and z planes [7].

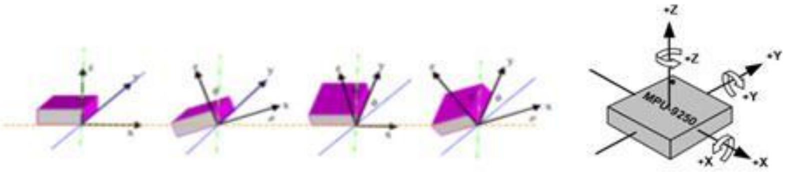


Figure 3. Displacement Changes the Direction Illustrated and MPU-9250 Axial

3. System for Structural Health Monitoring of Horticultural Facilities

3.1. System Design

3.1.1. Schematic Diagram and Structure of the System: Previous diagnostic techniques used various sensors to measure and identify the state of a structure after it has been damaged. In contrast, current diagnostic techniques identify risk factors that could not be accurately estimated in advance to minimize disasters. Structural health monitoring (SHM) is a diagnostic technique that can detect potential accidents, abnormal behavior, damage, and degradation from the construction to maintenance phases.

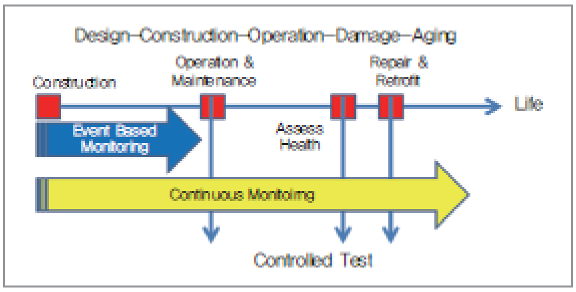


Figure 4. Basic SHM Concept

The structure of system proposed in this study is illustrated in Figure 5.

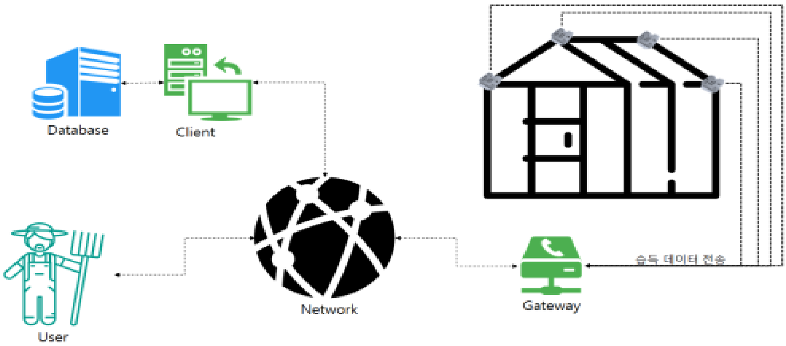


Figure 5. Safety Evaluation System of Configuration

This system consists of sensors that measure a change in the location of structural supports and vibration, a gateway that interfaces with the network, a database (DB) that saves the transmitted data, and a client that analyzes the data and displays it. This system transmits the combined GPS and acceleration data measured by the sensors through the gateway and saves it to the DB. The client analyzes the data in the DB, determines vulnerable points based on the location of the sensors, and provides this information on a map. The user is informed of the vulnerabilities in the horticultural facility based on this information and takes measures to address them.

3.1.2. DB: The DB for safety evaluation was designed using DB Designer 4 and is shown in Figure 6. It was established as an E-R diagram using Mysql 5.1.41-community. The DB was designed to ensure it can be expanded to provide further functions for environmental control and monitoring.

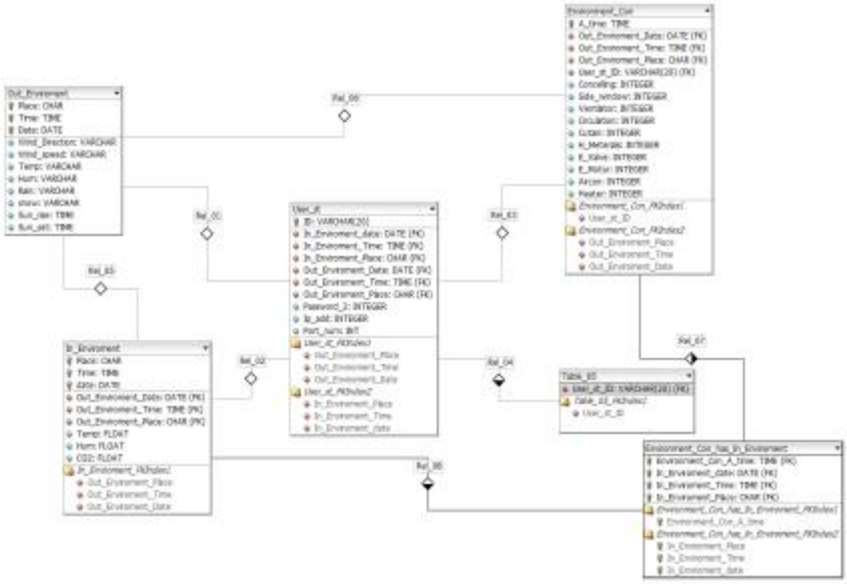


Figure 6. E-R Diagram to Database

Table 1 shows the user information table. The user can access the server via the client by inputting the user ID, password, IP address, and access port number. The client is connected to the server based on the information saved in the DB.

Table. 1 User Information Table

Table title (English)		User_IN	Table title (Korean)		User information		
Table description		Saved program connection settings					
No	Column title (English)	Column title (Korean)	Type	Length	NULL	P.K. (PRIMARY KEY)	F.K. (FOREIGN KEY)
1	ID	User	Vachar	20	N	Y	
2	Password	Password	Integer	10	N		
3	IP_add	IP address	Integer	20	N		
4	Port_num	Port number	Int	8	N		

Table 2 shows the safety evaluation information table. The sensors for structural health monitoring include sensor node IDs and information on adjacent nodes. Moreover, the acceleration and gyro values on the X, Y, and Z axes are measured at the location of each sensor and saved in the DB.

Table 2. Safety Evaluation Information Table

Table title (English)		Sensor_DATA		Table title (Korean)		Safety	
Table description		Safety evaluation information					
No	Column title (English)	Column title (Korean)	Type	Length	NULL	PK	FK
1	sensor_node_id	Sensor node ID	Vachar	16	N	Y	
2	parent_node_id	Adjacent node	Vachar	16	N		

3	battery	Battery	Intger	4	N		
4	accel_x	Acceleration on the X axis	Double	24	N		
5	accel_y	Acceleration on the Y axis	Double	24	N		
6	accel_z	Acceleration on the Z axis	Double	24	N		
7	gyro_x	Gyro on the X axis	Double	24	N		
8	gyro_y	Gyro on the Y axis	Double	24	N		
9	gyro_z	Gyro on the Z axis	Double	24	N		
15	date	Time	Time	20	N		Y

3.1.2. IoT(Internet of Things) Management System: An IoT management system monitors risky situations in real time by managing sensor conditions and using the obtained data; all the processes are carried out in a single system. Based on a requirement analysis, this system was designed to include a risk analysis module, data management module, and network management module. The entire monitoring processes are automatically repeated after they are performed by the user (Figure 7). A sensor module automatically cycles between sleep and awake states to maintain an optimal lifespan. When it receives a request from the system, it awakens and reports its state. The data transferred from the sensors consist mainly of data measured by sensors and node condition data saved by the corresponding management tools. Of the data transferred, sensor data are saved by the sensor management tool and used after being decoded and processed by a risk analysis tool. Node condition data are saved by a network management tool and provided to the user through a network analysis tool. To support maintenance and facilitate smooth system management, the network management tool notifies the user when the abnormal state of a node is detected. This tool is able to check and adjust node conditions as well as add and remove nodes. The data management tool has functions related to the analysis of the transferred data and includes an interface that can be connected to an enterprise information system.

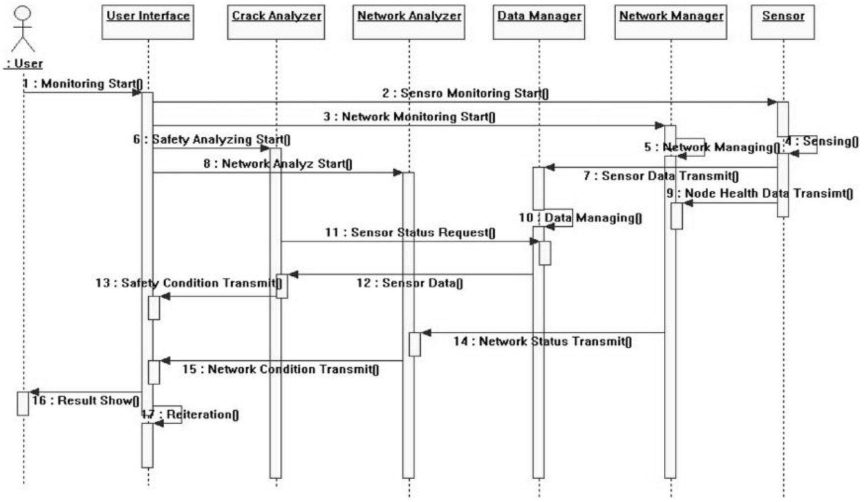


Figure 7. Sequence Diagram for IoT Management System

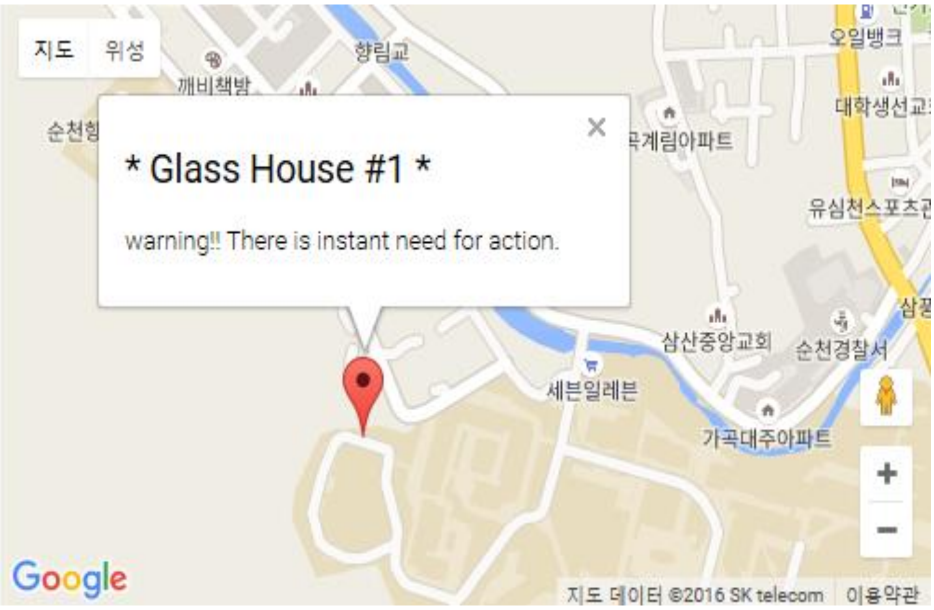
3.2. System Implementation

Figure 8(a) shows an implemented safety evaluation gateway, which transfers the data obtained by the safety evaluation information monitoring sensors to the DB. Figure 8(b) shows an implemented sensor prototype, which is attached to a structural support in a greenhouse, measures the GPS and three-axis acceleration, and transfers the data to the gateway.

(a) (b)

Figure 8. (a) Safety Evaluation Sensor Gateway, (b) Safety Evaluation Information Monitoring Sensor

The Google Map API (Application Programming Interface) was used to overlay the safety evaluation results on a map. In addition, a marker function was used to establish a POI(Point of Interest), which is shown in red in case of danger and green in a safe state. When the marker is clicked, the current GPS and acceleration data obtained by the safety evaluation information monitoring sensors are displayed.



* Glass House #1 *

warning!! There is instant need for action.

Figure 9. Safety Evaluation Information Monitoring Client GUI

4. Conclusions

In this study, the concept of IoT was implemented to efficiently operate a risk factor monitoring system for horticultural facilities. In this process, a system framework and IoT-based monitoring system were designed. A network was created and IoT sensor nodes were built to operate the designed system in horticultural facilities. In addition, a test using this prototype was conducted.

To this end, a system for evaluating the safety of structural supports in horticultural facilities was designed and executed, and a test on this system was carried out by attaching sensors on a stick. When the stick is bent or moved to another location, the sensors show an accuracy of 87%. In addition, 2.4 s are required on average to transfer the obtained data to the client. This result verifies that the system proposed in this study operates properly and enables users to take measures when a change in building safety occurs. In addition, this system allows users to swiftly react to extreme weather such as heavy snowfall, thereby reducing damage to facilities as well as recovery costs.

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References

[1] Y. Gwon, Gyeongnam policy Brief 2012.06(2012-20), Gyeongnam Development Institute, Korea **(2012)**.

[2] J. U. Im, S. W. Yun, H. T. Kim and Y. C. Yoon, “Protected Horticulture and Plant Factory”, The Korean Society For Bio-Environment Control, vol. 22, no. 1, **(2003)**, pp. 73-79.

[3] H. R. Ryu, S. C. Gwak, M. K. Choi, M. W. Cho, I. H. Yu and Y. A. Shin, “Analysis of Climatic Disaster Condition on Plastic Greenhouse”, Proceedings of the 2015 Spring Joint Conference of Korean Society of Agricultural Machinery / Korea Society for Bio - Environment Control; Jeonju, Korea.

[4] H. D. Soo and K. J. Tae, Journal of Diagnostic Structure. Korea Institute for Structural Maintenance and Inspection. vol. 14, no. 1, **(2010)**, pp. 165-174.

[5] C. B. Gil, S. D. Jae and N. Y. Woo, “The Journal of the Korean Society of Surveying, Geodesy, Photogrammetry and Cartography”, Korea Society of Surveying, Geodesy, Photogrammetry, and Cartography. vol. 28, no. 3, **(2010)**, pp. 377-383.

[6] J.-C. Yoon, H.-J. Yoon, H.-W. Cho, H.-S. Na and B.-W. Jo, “Comparison Analysis of Structural Health Monitoring Techniques of Bridge”, Proceedings of 2014 Spring the Korean Society for Railway, Jeju, Korea, **(2014)** October, pp. 615-618.

[7] InvenSense Inc, MPU-9250 Product Specification Revision 1.0, InvenSense Inc, California **(2014)**.

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