IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 2 Ser. II (Mar. - Apr. 2019), PP 48-56
www.iosrjournals.org

Development of Internet of Thing based Gravity Type Harbor Structure Health Monitoring Platform Using FBG Sensors

ByungWan Jo[1], JunHo Jo[1*], JungHoon Kim[1], SungJun Kim[1], SooMin Cho[1]
[1]*(Civil and Environmental Engineering, HanYang University, Republic of Korea)*
**Corresponding Author: JunHo Jo*

Abstract: *In Korea, as most of harbor structures were developed from the 1960s to 1970s, deteriorating of the port facilities has been progressing rapidly. Although pier-type harbor structure is the most popular type that majority of structure health monitoring for the harbor structures are focused on pier type, there are many gravity type harbor structure in Asia continent like Japan and Korea. Therefore, gravity type harbor structure health monitoring platform is developed and presented in this paper. The platform is composed of three main parts converged with new technologies to monitor the structure efficiently and effectively in real-time at anywhere. Three types of fiber bragg gratings sensors were used to detect the necessary data precisely for condition of the harbor structure: FBG strain sensor, FBG displacement sensor and FBG angle sensor. Then, IoT gateway is used as connection between FBG sensors and web server. By converging IoT technologies into the gateway, the data is transmitted to the web server wirelessly via LTE modem. The web server is converged with cloud computing platform that analyzes and visualizes the data. Therefore, the platform provides the efficient monitoring that the monitoring can be performed anytime and anywhere through the web server. Furthermore, the platform was successfully tested at real gravity type harbor in Korea to examine its durability.*
Keywords: *Harbor Structure, Structure Health Monitoring, Fiber Bragg Grating Sensor, Internet of Things, Cloud Computing*

Date of Submission: 04-03-2019 Date of acceptance: 20-03-2019

I. Introduction

In Korea, more than 90% of import and export cargo is transported through harbor structures. The (average annual?) cost of port logistics is about 20 trillion KRW which is 27% of the total logistics costs. Since more than 25% of the port facilities were developed in the 1960s ~ 1970s, the deteriorating of the port facilities has been progressing very rapidly[1,2]. It has been gradually increasing the importance of diagnosis and maintenance of existing port facilities. In advanced countries, especially in Italy, the maintenance investment account for over 30% of the national civil engineering investment. The maintenance cost is Korea accounts for less than 10% of the total port budget. However, the maintenance costs are expected to increase as the port facility aging increases[3,4,5]. At the same time, it is very crucial to develop the inspection technology to maintain the safe condition of harbor structures.

Currently, the harbor structure management system enforces the safety evaluation of the structure by inspection and diagnosis under the 'Safety Inspection and Precision Safety Diagnosis Detailed Instructions Explanation (Port)' issued by the Ministry of Land, Transport and Maritime Affairs, but most of them are conducted through visual inspection[5,6,7]. Since each structure is evaluated by different supervisors, the grades and comments are subjective to each evaluator's perspective and opinion. It is required to develop a new evaluation method to examine the harbor structure objectively and consistently.

It is challenging to investigate the structure considering its large size under the ocean. If an inspection can be carried out on land, it is easy to use inspection equipment and surveying equipment even with the naked eyes. However, in the case of the underwater diagnosis, divers should participate in the inspection. The underwater diagnosis has less and inconsistent effects because it is difficult to secure a clear view and find precise position with turbidity of the ocean[8,9,10]. Since the investigation is not preceded by a diver who is not a supervisor or a professional, the detection of deterioration can be missed or misdiagnosed.

Recently, the new inspection technology has been developed using waterborne inspection equipment and sound wave. However, it has limitations and requires improvements because the marine life such as seaweed, shellfish and barnacle is attached to the surface of the port facility which makes impossible to detect any deterioration[11,12]. Therefore, it is important to implement the structural health monitoring system that ensures the safety and efficiency of diagnosis of the condition of the harbor facilities.

Due to rapid growth of new technologies such as Internet of Things (IoT), Fiber Bragg Grating (FBG) sensors and wireless sensor network, the technologies has revealed the new capabilities to the field of structural health monitoring[12,13]. Although structure health monitoring is especially difficult for harbor structure because of the environmental characteristics and circumstances, the monitoring is able to investigate the structure efficiently and effectively for harbor structures by converging these technologies into structural health monitoring.

Among different types of harbor structure, many countries including the United States adopted pier-type harbor structure. Relatively, less data and studies are discovered on structural health monitoring or maintenance of gravity type. In addition, gravity type wall cannot be examined for deteriorations or defects by structural members which makes it difficult to monitor and evaluate the condition of the harbor structures. Thus, gravity type harbor structure health monitoring platform was developed for efficiency and effectiveness by converging new technologies such as FBG sensors, IoT technologies and cloud computing platform. FBG sensors is design to measure the data precisely even underwater to determine the condition of the structure. Then, IoT technology is used to efficiently transmit the data wirelessly to the cloud computing web server. The web server is designed to analyze the data and visualize the condition of the harbor structure. The platform provides real-time monitoring of the structure which allows supervisor or related personnel can immediately take an action about the condition when deterioration or accidents happen. Therefore, the deterioration or damages can be minimized or prevented in advance.

II. Materials

In this research, FBG sensors, IoT gateway and web server were installed for gravity type harbor structure health monitoring platform.Three types of FBG sensors were selected to monitor gravity type harbor structure; FBG strain sensor, FBG displacement sensor and FBG angle sensor.IoT gateway is installed to gather and transmit the data to web server from the sensors. Furthermore, the web server is installed for the platform to visualize, analyze and save the data.

2.1 FBG Sensors

Fiber Bragg Gratings, the most widely used and deployed optical sensors, were installed on the gravity type harbor structure to investigate structural defects such as strain, settlement and slope changes. FBG reflects the wavelength of light that changes in response to temperature and / or strain changes. It is constructed by exposing a short length of photosensitive fiber to a periodic distribution of light intensity using a holographic interference or phase mask. The refractive index of the fiber changes permanently depending on the intensity with which the light is exposed. The periodic variation in the refractive index is called fiber Bragg grating. FBG sensor is ideal for applications where conventional electrical sensors such as foil strain gages, thermocouples, and vibrating wires are inefficient or difficult to use due to difficult environmental conditions and /or long distances. Therefore, in this case, FBG strain sensors, FBG displacement sensor and FBG speedometer were selected in this system among many other options[9,14].

2.1.1 FBG Strain Sensor

Most of the existing FBG strain sensors are integral moldings which lead to less accurate measurement due to simultaneous deformation of the FBG and packaging. Therefore, this system minimizes temperature-induced deformation by making the sensor and protective package selectively detachable. The measurement range of the sensor is ±2000 με which has greater or equal to 1pm/με sensitivity. This sensor can be installed inside and outside of the structure and has a wide operating temperature range which can be effective in various environments. Table 1 summarizes the detail specification of the FBG strain sensor[9].

Table no 1: Specification of the FBG Strain Sensor

Specifications	Values
Measurement Range	±2,000με
Strain Sensitivity	≥ 1pm/με
Operating Temperature Range	-20 ~ 80°C
Wavelength Range	1,511 ~ 1,584 nm
Sensitivity	≧1,000 με @ 120g tension
Resolution	± 0.05 % F.S
Accuracy	± 0.25 % F.S
Peak Reflectivity	>70%
Center Wave Length Range	1,511nm ~ 1,589nm

2.1.2FBG Displacement Sensor

The maximum measurement range of the FBG displacement sensor is 30mm, where it has greater or equal to 100pm/mm sensitivity. Similar to FBG strain sensor, FBG displacement sensor was also developed to detach the protective package selectively that is demonstrated in Table 2[9].

Table no 2: Specification of the FBG Displacement Sensor

Specifications	Values
Measurement Range	≤30 mm
Operating Temperature Range	-20 ~ 80°C
Wavelength Range	1,511 ~ 1,584 nm
Sensitivity	60, 30pm/mm
Resolution	± 0.05 % F.S
Accuracy	± 0.3 % F.S
Peak Reflectivity	>70%
Center Wave Length Range	1,511nm ~ 1,589nm

2.1.3 FBG Angle Sensor

The FBG angle meter measures the angle change of the structure based on the wavelength change due to the movement of the weight directly connected to the fiber optic sensor. In addition, by using an O ring and waterproof epoxy between the connection of the angle sensor and the package, it allowed durable in the water that is shown in Table 3[9].

Table no 3: Specification of the FBG Angle Sensor

Specifications	Values
Measurement Range	8 degree (-3 ~5 deg)
Sensitivity	≥ 450pm/deg
Operating Temperature Range	-20 ~ 80°C
Wavelength Range	1,511 ~ 1,584 nm
Resolution	± 0.05 % F.S
Accuracy	± 0.3 % F.S
Peak Reflectivity	>70%
Center Wave Length Range	1,511nm ~ 1,589nm

2.1.4 Cable for FBG Sensors

Figure 1 shows the structure of the ocean type FBG cable. Polyurethane was chosen for the material of the outer cover. Polyurethane is resistant to flames, has excellent durability against external environment such as seawater due to its self-extinguishing power, abrasion and hydrolysis. Aramid Yarn Fiber protects the cable from the tensile strength while the iron core keeps the cable from compressive strength. In addition, 0.9mm of hytrel material is used for the protection tube of the fiber optic sensor[9].

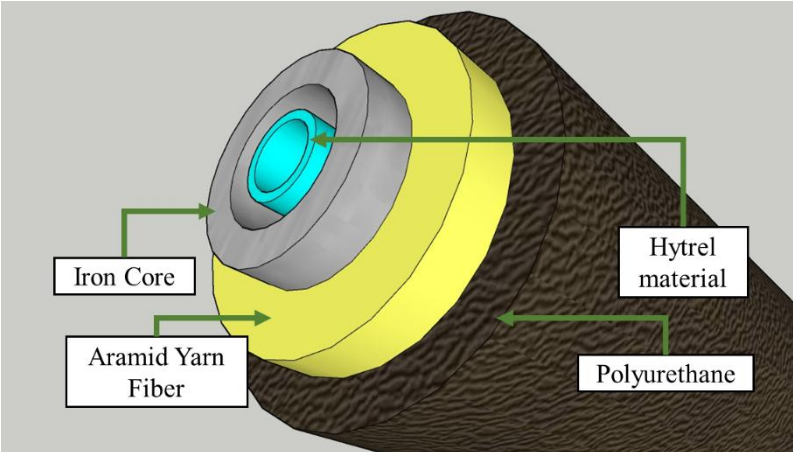

Figure no 1: Designed Cable for FBG sensors

2.1.5 Submergence Test

Since the some of FBG sensors are installed underwater, the FBG sensors in this paper, is the combined form of the cable and the protection for underwater use. In order to confirm its reliability in underwater, three FBG displacement sensors with developed cable above were tested and confirmed that there were no significant differences in wavelength. The table 4 below is the test result of wavelength differences before and after the submergence of the sensor[9].

Table no 4: Results of Submergence Test of the FBG Sensors

	Wavelength before Immersion(nm)	Wavelength after Immersion	Change in Wavelength
FBG Sensor 1	1526.24	1526.22	-0.02
FBG Sensor 2	1550.66	1550.65	-0.01
FBG Sensor 3	1568.41	1568.40	-0.01
Temperature Sensor	1520.47	1520.47	0

2.2 IoT Gateway

The gateway is composed of two main parts. Data logger gathers the data while LTE modem transmits the data from the sensors in the port structures. The platform uses sm 125–500 module of Micron Optics with a four optical channel to display the full spectrum in the wavelength rage from 1510 to 1590 nm. The scan frequency is 2 Hz while a dynamic range of 50dB and FBG sensor capacity from 60 to 120. The data logger collects data using the FBG sensors and sends out wavelength data to the webserver using the LTE modem. An RCU890L LTE modem from Woojin Networks was installed as the LTE module to transfer data to the web servers which would be a source of analysis. The modem is a real-time mobile communication terminal device that control and transmit data to the platform. Thus, the modem is a bridge between the web server and FBG sensors. The details of specifications are presented in Table 5. Furthermore, the platform is capable of receiving the data from multiple data logger that data of each data logger are transmitted wirelessly in the form of TCP/IP packets via a LTE modem from each data logger. Therefore, the data packets are organized and analyzed in the web server[9].

2.3 Web Server

The IoT based gravity type harbor structure health monitoring platform requires a server to analyze and visualize the data transmitted from the FBG sensors for the platform. A commercial cloud computing platform, Amazon Web Services (AWS), was adopted as the server for its wide usage in many applications. The server was developed using a web programming language called hypertext preprocessor. While making a unique platform would require resources and time to get certified and minimize the errors, AWS is a certified platform with open source libraries that offers many useful services for structural health monitoring. Also, AWS can manage and support computation server to help monitoring the structure effectively. Without additional installation of data base, AWS offers a database to store the data and analyze the platform.

III. Gravity Type Harbor Structure Health Monitoring Platform

A system diagram of IoT based gravity type harbor structure health monitoring platform is demonstrated in Figure 2. The FBG sensors were installed at the critical location where is defined by pre-analysis of the structure. These collected FBG data are gathered by data logger and sent to the web server for analysis and visualization using IoT gateway.

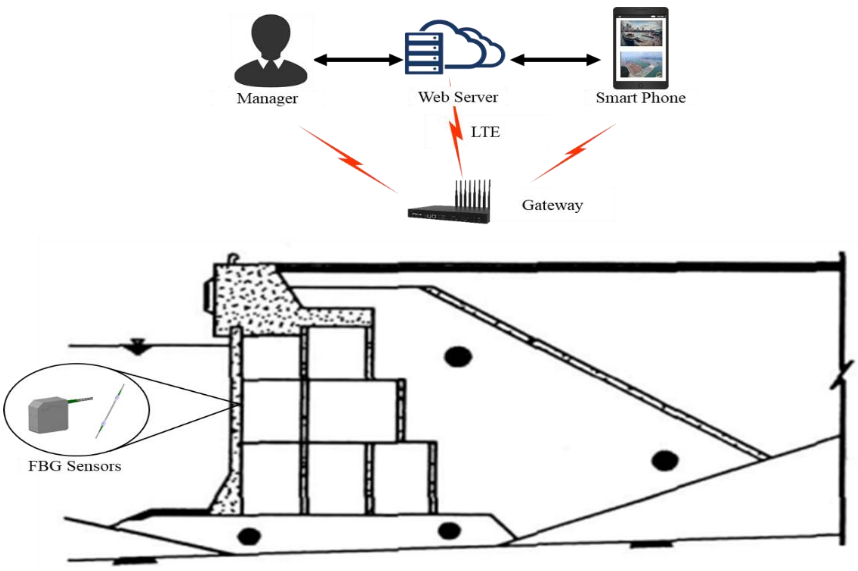

Figure no 2: Configuration Diagram of the IoT based Gravity Type Harbor Structure Health Monitoring Platform

The IoT based gravity type harbor structure health monitoring platform is primarily divided in to FBG Sensors, IoT gateway and web server that is shown in Figure 3. The FBG sensors detect data to evaluate condition of gravity type harbor structure. Then, the data is gathered by IoT gateway and the gateway transmit the data to the web server via LTE. When the data is received, it analyzes the data to determine condition of the structure by safety evaluation index (SEI) and visualize the condition. Thus, supervisor or related personnel of the structure can take an action regarding the condition. Also, the server automatically sends the alert through smartphone when the condition is decreased from the normal.

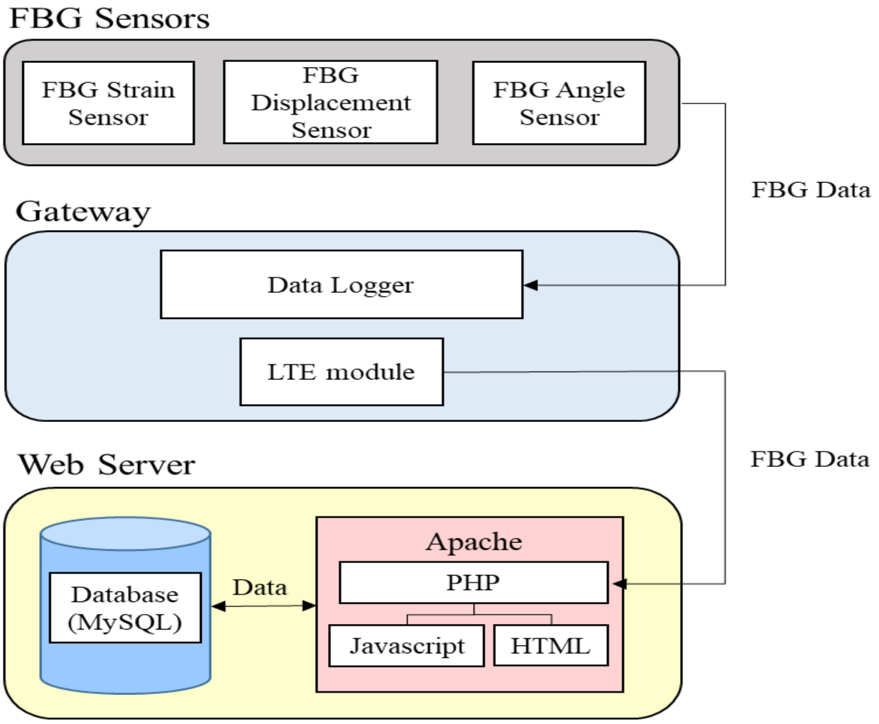

Figure no 3: System Diagram of the IoT based Gravity Type Harbor Structure Health Monitoring Platform

3.1 Safety Evaluation Index

In "The Port and Fishing Port Design Standards," the Ministry of Oceans and Fisheries states that the final condition of a gravity type harbor structure is classified as the lowest index of the SEI obtained by the sensors. Accordingly, the webserver will automatically choose the lowest index among the sensors for the platform to define condition of the structure.

3.1.1. Safety Evaluation Index for FBG Strain Sensors

According to the standards, allowable stress design method is applied to evaluate the external force of the structure as shown in Equation (1).Although allowable stress can be caluclated from the structural calculation, actual stress is calculated using data from FBG strain sensor and the structural calculation[7].

$$\text{Safety Factor (S.F.)} = \frac{\text{Allowable Stress}}{\text{Actual Stress}} \tag{1}$$

From the detected data from the FBG strain sensor, the condition of structure varies from Safety Factor (S.F.) can be defined for SEI that is demonstrated in Table 5.According to the table, SEI of "A" indicates that the condition of the structure is normal or stable when S.F. is above or equal to 1.0. Then,S.F. of less than 1.0, less than 0.9, and less than 0.75 were set as "C", "D", and "E" for SEI,respectively,representing that the the condition is unstable[10].

Table no 5:SEI of the FBG Strain Sensors

Condition	Safety Evaluation Index
SF ≥ 1.0	A
0.9 ≤ SF ≤ 1.0	B
0.75 ≤ SF ≤ 0.9	C

0.6 ≤ SF ≤ 0.75	D
SF ≤ 0.6	E

3.1.2. Safety Evaluation Index for FBG Displacement Sensors

According to "The port and Fishing Port Design Standards, the extent of settlement to determine the condition of the structure that the FBG displacement sensor is used to measure it. When the settlement range is under 5 cm and 2 cm for unprogressive and progressive subsidence, respectively., SEI becomes "A" for normal condition that considered as settlement has not occurred. However, the 1st, 2nd, 3rd, and4th thresholds for progressive subsidence are 2 cm, 5 cm, 8 cm, and 12 cm with safety evaluationindex of "B", "C", "D", and "E", respectively. Furthermore, the thresholds for the1st, 2nd, 3rd, and 4th thresholds for unprogressive subsidence are 5 cm, 8 cm, 12 cm, and 16 cm andthe corresponding SEIs are "B", "C", "D", and "E", respectively, that is shown in Table 6 below[10].

Table no 6:SEI of the FBG Displacement Sensors

Safety Evaluation Index	Maximum Settlement Range	
	Unprogressive	Progressive
A	Under 5cm	Under 2cm
B	5cm ~ 8cm	2cm ~ 5cm
C	8cm ~ 12cm	5cm ~ 8cm
D	12cm ~ 16cm	8cm ~ 12cm
E	> 16cm	> 12cm

3.1.3. Safety Evaluation Index for FBG Angle Sensors

To monitor the port structure, an angle sensor was placed on the structure for the measurement of the slope. The evaluation standard from the Ministry of Oceans and Fisheries is determined by the maximum angle of the slope at the investigated state. The SEI is described as "A" when the slope has not happened while different index values are set depending on the slope angle, as shown in Table 7. The FBG angle sensor presents the direct measurement of slope angle and the standards for the angle data are the minimum measurements of slope for each index. The 1st, 2nd, 3rd, and 4th standards of unprogressive slope are 1.8°, 2.7°, 3.6°, and 5.4° with safety evaluation indices of "B", "C", "D", and "E", respectively. The 1st, 2nd, 3rd, and 4th standards for progressive slope are 0.9°, 1.8°, 2.7°, and 3.6° with safety evaluation indices of "B", "C", "D", and "E", respectively[10].

Table no 7:SEI of the FBG Angle Sensors

Safety Evaluation Index	**Maximum Slope Range**	
	Unprogressive	**Progressive**
A	Under 1.8˚	Under 0.9˚
B	1.8˚ ~ 2.7˚	0.9˚ ~ 1.8˚
C	2.7˚ ~ 3.6˚	1.8˚ ~ 2.7˚
D	3.6˚ ~ 5.4˚	2.7˚ ~ 3.6˚
E	> 5.4˚	> 3.6˚

3.2 Alert System

IoT based gravity type harbor structure health monitoring platrform is design to send alert when the condition becomes below normal that is SEI of "A". When SEI is below "A", the structure is considered as deteriorated or damaged that manager or related personel of the structure need to know the condition. So, they can take an action immediately regarding the condition to prevent or minimize any damages or accidents. Thus, the web server is designed to alert the related personnel by SMS message. Amazon Web Service provide a service called "Amazon Simple Notification Sevice" that send SMS message to registered smartphones for the set conditions. Therefore, the platform is designed to automatically alertes manager or related personel when the SEI become below "A"[10].

IV. Experimental Testing

Experiments were lead to practical implementation of the subjects. The Maryang harbor was selected as the test venue to evaluate the durability of the gravity type harbor structure health monitoring platform. The harbor has two types of ports that a pier-type port constructed in 1999 and gravity-type port constructed in 2018, located in Maryang-meyon, Korea. The installation of platform was completed in January 2019 to test the safety state of the structure. The entire installation included gateway, FBG sensors, and web server.

4.1 Installation

Pre-analysis on the structure was performed using SAP to define the number and location of FBG sensors for the installation. From the analysis, 18 FBG strain sensors, 2 displacement sensors and 4 angle sensors were installed in the structure for structural health monitoring. Figure 4 (a) and (b) show the installed FBG sensors that were installed below the structure and underwater. After all required FBG sensors were installed in pre-analyzed location of the structure, the test was processed focusing on the web server.

(a) (b)

Figure no 4: The FBG Sensors Installed (a) under the harbor structure and (b) underwater

4.2 Web Server

The web sever for gravity type Maryang harbor was developed for the testing that is demonstrated in Figure 5below. For the main page of the web server, the total safety index of the structure is demonstrated to visualize the condition in the top right corner. However, detailed FBG monitoring data can be shown by selecting options in dashboard located on the left. Also, the manager or related personnel can see inspection status and anouncement of the structure in the main page. Therefore, they can monitor the structure in real time at anywhere by opening the web server using computers or any mobile devices.

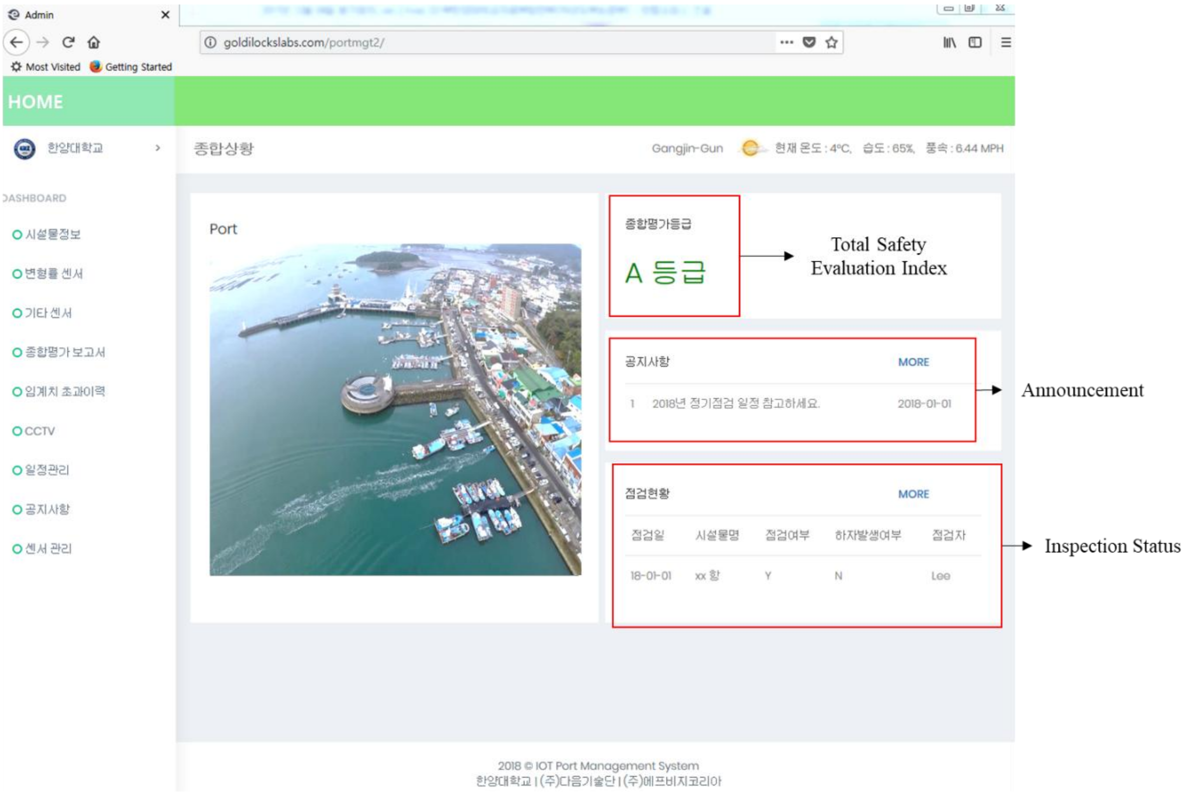

Figure no 5: Main Page of the Web Server for IoT based Gravity Type Harbor Structure Health Monitoring Platform

4.2.1 Data Transmission

After installation of FBG sensors and the gateway, an experiment was conducted to test transmission of the data from the FBG sensors to the web server. The data was transmitted properly to the webserver and used for analysis as demonstrated in Figure 6. The data was displayed with graphs in real-time. In addition, the screen presented useful information when monitoring the structure such as information of the detected sensor, thresholds of the sensor for SEI and current value with SEI. Depending on the location of the FBG sensors, different types of sensors can be selected at the top part of the webserver. All data is saved and automatically analyzed to examine the condition of the structure that is demonstrated in total condition page of the web server.

Figure no 6: Detailed Monitoring Page of the Web Server for IoT based Gravity Type Harbor Structure Health Monitoring Platform

V. Results

The experiments were conducted to demonstrate successful implementation of the platform in a real gravity type harbor structure. As the FBG sensors and cables functioned successfully in the ocean, data was properly transmitted to the data logger. The webserver started to analyze and visualize the data to examine the condition of the structure. The data transferred from the sensors were stored in the server of the platform via the LTE modem for web server analysis.

As important as the function of the system, the qualitative analysis based on user's experience is crucial to examine its practicality. Interviews were conducted with facility managers and supervisors who have experience with using the system to monitor the gravity type harbor structure in Maryang Harbor. The surveys from the users showed satisfaction about the real-time alert feature. They had an opportunity to take an action immediately after monitoring to minimize or prevent damages. They expressed potential for the adaptation of the system in the near future.

VI. Conclusions

In this research, IoT based gravity type harbor structure health monitoring platform using FBG sensors was developed following with a functional testing in real gravity type harbor structure. The FBG sensors used in the experiment were performed well and measured precisely for harbor structure underwater. By converging IoT technologies into structural health monitoring, the FBG data were wirelessly transmitted to the web server for analysis via LTE modem. Then, the server provided analysis of the data and visualized the condition of the structure. This information is accessible in real-time at anywhere by using computers or any smart devices. Also, the web server used certified webserver from Amazon Web Services which provided useful services to monitor the condition using alert system and was easily extendable to add or edit more FBG sensors. Finally, future work will involve further testing of the platform for accuracy of data for a long period of time

References

[1]. Lee S.Y, Kim J.T, Huynh T.C, Structural identification of gravity-type caisson structure via vibration feature analysis.Smart Structures and Systems. 2015;15(2):259-281.

[2]. Lee S.Y, Lee S.R, Kim J.T, Vibration-based structural health monitoring of harbor caisson structure. Sensors and Smart Structures Technologies for Civil. 2011.

[3]. Yoon H.S, Lee S.Y, Kim J.T, Yi J.H, Field Implementation ofWireless Vibration Sensing Systemfor Monitoring of Harbor Caisson Breakwaters. International Journal of Distributed Sensor Networks. 2012;8(12).

[4]. Huynh T.C, Lee S.Y, Nguyen K.D, Kim J.T, Structural Damage Monitoring of Harbor Caissons with Interlocking Condition. Journal of the Korean Society for Nondestructive Testing. 2012;32(6):678-685.

[5]. Jung D.U, Choo Y.Y, Port Structual Health Monitoring System Using Wireless communication. Proceedings of Symposium of the Korean Institute of communications and Information Sciences. 2008:525-528.

[6]. HanT.H, ParkS.H, JangI.S, HanS.H, ParkW.S, Establishment of Seismic Monitoring System in Domestic Major Ports. The Korean Society for Marine Environment & Energy. 2012;5:2061-2064.

[7]. Ministry of Land, Transport and Maritime Affairs. Safety Inspection and Precision Safety Diagnosis Detailed Instructions Explanation (Port) (Rd-11-E6-024). Available online: http://academic.naver.com/article.naver?doc_id=62783480. 2011 (accessed on 11 December 2018).

[8]. Lee S.Y, Huynh T.C, Kim J.T, Vibration characteristics of gravity-type caisson breakwater structure with water-level variation. International Journal of Distributed Sensor Networks. 2013;(9):

[9]. Jo B.W, Jo J.H, Asad K.R.M, Kim J.H, Lee Y.S, Development of a Cloud Computing-Based Pier Type Port Structure Stability Evaluation Platform Using Fiber Bragg Grating Sensors. Sensors. 2018;18(6).

[10]. Ministry of Oceans and Fisheries. Port and Fishing Port Design Standards (11-1192000-000184-14). Available online: http://www.mof.go.kr/article/view .do?articleKey=14360&boardKey=2&currentPageNo=1. 2014 (accessed on 11 December 2018).

[11]. Chau K.W, An expert system for the design of gravity-type vertical seawalls. Engineering Applications of Artificial Intelligence. 1992;5(4):363-367.

[12]. ParkJ.H, KimJ.T, LeeS.Y, Performance Evaluation of Imote2-Platformed Wireless Smart Sensor Node for Health Monitoring of Harbor Structures. Korea Society of Coastal and Ocean Engineers. 2011;23(1):26-33.

[13]. NewhookJ.P,BakhtB, MuftiA.A,TadrosG, Monitoring of Hall's Harbor wharf. Health Monitoring and Management of Civil Infrastructure Systems. 2001;4337:234-244.

[14]. Chana T.H.T, Yu L., Tam H.Y, Ni Y.Q, Liu S.Y, Chung W.H, Cheng L.K, Fiber Bragg grating sensors for structural health monitoring of Tsing Ma bridge: Background and experimental observation. Engineering Structures. 2006;28(5):648-659.

JunHo Jo. "Development of Internet of Thing based Gravity Type Harbor Structure Health Monitoring Platform Using FBG Sensors." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 16, no. 2, 2019, pp. 48-56.