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A cloud computing-based damage prevention system for marine structures during berthing

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ABSTRACT

In this paper, a cloud computing-based damage prevention system for marine structures during berthing, consisting of a speed camera module and a cloud-computing based web server, is presented. The speed camera module consists of a laser distance sensor, a camera unit, and an LTE modem. These were installed on the marine structure to monitor the speed of ships during berthing. When the ship exceeds the berthing speed limit enacted by the Ministry of Oceans and Fisheries, an image of the ship and its speed data are transmitted to the web server via the LTE modem. This system was successfully tested at Maryang Harbor in Korea to confirm its feasibility. The web server activates an alert system when the image file is received, and the manager or other appropriate personnel can prevent or minimize damage from the berthing by responding immediately. All data were visualized and the berthing energy was calculated through the web server. Approved personnel can monitor the structure via the web server at any time and from anywhere. The system is effective in preventing and inspecting damages by berthing that can be used as an application of structural health monitoring for marine structures.

1. Introduction

Marine structures have different structural design requirements than buildings because loads from berthing, operational loadings, and other loadings must be considered. During berthing, a large force is applied to the entire marine structure, and protective fenders are installed to absorb the bulk of the energy. The remainder is absorbed by the resistance of the seawater, deformation of the ship, and the edge structure (Cha, 2012; Liu and Amdahl, 2010).

Although the fenders are installed to protect both ship and marine structure during berthing, sometimes the impact can be larger than the fenders can absorb, resulting in damage to the fender or the structure (Neser and Ünsalan, 2006; Sakakibara and Kubo, 2007). Furthermore, berthing with too much force can cause the dock to separate from the land. When the marine structure is damaged, serious problems can arise that compromise the safety of those who work on the structure and on the ship. Thus, a monitoring system for berthing is essential to prevent or minimize damage (Huang and Chen, 2003; Versteegt, 2013).

According to Komatsu and Salman (1972), personnel in the marine structure are often unable to observe when damage occurs from berthing since the damaged portion of the structure may be immersed in the ocean. If the damage is not repaired, it may escalate and cause eventual collapse of the structure (Ueda et al., 2002). Data-driven monitoring of berthing, as suggested in this paper, can prevent this type of damage from going undetected.

The speed of the ship is the most important factor determining berthing energy, although there are other factors at play. These factors include: berthing method, berth speed, marine structure type, and environmental influences (such as waves, wind, and tide) (Kong et al., 2004; Metzger et al., 2014). In this research, a cloud computing-based damage prevention system for marine structures during berthing was developed to avoid and minimize damage. We combined cloud computing and an on-site monitoring system equipped with a speed camera module. This system detects the speed of the ship during berthing and, with certain variables manually entered, calculates the berthing energy. The web server receives input from the speed camera module and automatically alerts the manager via a smartphone when the ship exceeds the berthing speed limit. By monitoring the situation and employing a rapid-alert system such as the one proposed in this study, it is possible to minimize casualties and economic damage related to berthing.

2. Materials

In this study, speed camera module was developed for detecting the ships during berthing to transmit the data to cloud computing-based web server. Furthermore, Amazon Web Services was used as the web

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Fig. 1. Primitive concept design of the speed camera module.

server of the system to analyze, visualize, save, and execute the data collected from the speed camera module.

2.1. Speed camera module

The speed camera module is shown in Fig. 1. It was developed to detect the speed of ships, capture images of ships, and to transmit data (including image files) to the web server. The module consists of a microcontroller, a laser distance sensor, a camera unit, and a LTE modem. The module measures the speed of a ship when it is berthing using a laser distance sensor, and if the ship is moving above the speed limit, it sends an image file of a ship to the web server using the LTE modem.

2.1.1. Microcontroller

The microcontroller can be defined as a single-board computer that can receive input from multiple sensors. For this study, the Raspberry Pi 3 Model B was chosen for monitoring berthing speed. This controller has a very large working RAM memory that operates at 900 MHz. More detailed specifications are shown in Table 1 (Raspberry Pi, n.d.). Also, various sensors can be installed and used with the controller including a network module, making it capable of wireless sensor communication between the camera module and the web server using the LTE module (Maksimović et al., 2015). Also, the Raspberry Pi has an expandable interface that multiple sensors can be easily added or removed according to monitoring conditions and requirements.

2.1.2. Camera unit

The camera unit, an IMX219 PQ CMOS image sensor from Sony, was installed to capture an image of a ship if it exceeds the berthing speed limit. The sensor has a resolution of 8-megapixels and has the infrared cut-off filter removed to increase IR light sensitivity. The module is capable of outstandingly high data rates and provides high definition, high sensitivity, low cross talk, and low noise image capture. General specifications of the camera module are listed in Table 2 (Pi NoIR camera module, n.d.).

2.1.3. Laser distance sensor

A laser distance sensor, OSLRF-01 from LightWare, is mounted in the speed camera module to detect ship speed during berthing. The sensor contains a laser, a detector, optics, and sequential-equivalent-time-sampling circuits that permit direct interfacing with the microcontroller. The sensor amplifies and slows down the data into a manageable time base. The sensor is recommended for applications in which high performance and a narrow beam are required. Specifications for the sensor are shown in Table 3.

Table 1
Specifications of the Raspberry Pi 2 model B.

Specifications	Values
Instruction set	ARMv7-A (32-bit)
CPU	4 × Cortex-A7
RAM Speed	900 MHz
Memory	1 GB
SoC	Broadcom BCM 2836
Maximum Power ratings	820 mA
Weight	45 g
Size	85.6 mm × 56.5 mm

Table 2
Specifications of the camera unit.

Specifications	Values
Measurement Range	6° (−3 to +3)
Resolution	8 megapixels
Still picture resolution	3280 × 2464
Max image transfer rate	1080 p: 30 fps 720 p: 60 fps
Temperature range	−20 to +60°
Image control functions	Automatic exposure control Automatic white balance Automatic band filter

Table 3
Specifications of the laser distance sensor.

Specifications	Values
Laser wavelength	850 nm
Pulse width	< 30ns
Pulse frequency	< 16 kHz
Range	0.5–9 m
Resolution	Adjustable
Power supply voltage	12 V (10–16 V)
Peak Power	< 10 W/15.96 W
Average power	< 0.6 mW/0.78 mW
Average energy per pulse	< 0.15 nJ/200 nJ
Dimension	27 × 56 × 65 mm^3
Weight	57 g
Operating temperature	−20 to +60°

The laser distance sensor installed in the camera module measures speed by sending out a narrow radio signal, then receiving the signal that is bounced off the selected target. Because of the Doppler Effect, the frequency of the reflected radio waves is different from the frequency of the originally emitted waves when the target is moving towards or away from the camera module. The laser distance sensor calculates the speed of the ships (v) based on the frequency difference between the initial and returned radio waves, according to Equation (1):

$$v = \frac{\Delta f}{f} \times \frac{S_l}{2} \tag{1}$$

where Δf is the difference in frequency between the initial and returned radio waves, f is the initial frequency, and S_l is the speed of light (LightWare Optoelectronics, 2014).

2.1.4. LTE modem

An RCU890L LTE modem from Woojin Networks was installed in the speed camera module to transfer data to the web servers for alerts and analysis. This modem is a mobile communication terminal device that can control and transfer data in real time. It works as a link between the speed camera module and the web server. The specifications of the LTE modem are shown in Table 4.

2.2. Web server

The cloud computing-based damage prevention system for marine structures during berthing needs a web server to alert the manager of the structure and to display an image of the ship that may potentially cause damage. The server is provided by Amazon Web Services (AWS), a widely used commercial cloud computing platform. AWS was selected as the server due to its proven effectiveness. This open platform is

Table 4
Specifications of the LTE mode.

Properties	RCU890L LTE module
Communication Method	LG U + LTE B5/B7 FDD Cat.4
Interface	DB9 RS-232, RJ-45 Ethernet, GPIO
Band	LTE FDD 850 MHz (B5)/2.6 GHz (B7)
Data Speed	150 Mbps DL/50 Mbps UL
Input Voltage	4.5 V–5.5 V
Operating temperature	−20 to 60°

certified and it provides access to open source libraries. Based on its well-organized computation server management, AWS offers efficient monitoring for the protection of the marine structure and does not require installation of another database to restore and evaluate the platform (Jackson et al., 2010; Lee et al., 2010).

Amazon's EC2 (Elastic Compute Cloud) provides support for the dynamic instantiation and configuration of the virtual machine instance, which is suitable for our system. Thus, EC2 was preferred for our system (among Amazon-supported application programming interfaces) for the hypertext pre-processor. The system uses a T2 medium as an extensible instance. The specifications of the instance are shown in Table 5 (Jo et al., 2018).

3. Damage prevention system for marine structures during berthing

As shown in Fig. 2, the cloud computing-based damage prevention system for marine structures during berthing can be divided into two parts: the speed camera module and the cloud computing-based web server. PHP was used as a web programming language for the web server, while MySQL was used as the database for the system.

A system diagram of the damage prevention system is shown in Fig. 3. The camera module is to be installed on the marine structure surface, at a location where ships can be detected during berthing. The camera module detects the speed of the ship, and if the ship exceeds the berthing speed limit, the module sends an image of the ship via the LTE modem. When the image file is received, the web server sends an alarm alert to managers and assigned personnel via smartphone-based SMS and popup alarms.

3.1. Cloud computing-based web server

The web server is used to alert managers of the marine structure and other appropriate personnel of the need to prevent or minimize damages due to ships berthing at dangerous speeds. With the web server and smart devices, berthing ships can be monitored “anytime anywhere.”

Furthermore, the web server provides an application that allows the manager to calculate the berthing energy of the detected ship by inserting specific information about the ship manually. When the calculated berthing energy exceeds the allowable berthing energy of the fenders or the structure, the manager or related personnel can be aware

Table 5
Specifications of the instance for AWS.

Properties	t2.medium
vCPUs	2
Memory (GiB)	4
Storage (GB)	EBS Only
CPU Credits/hr	24
Clock Speed (GHz)	Maximum 3.3
Networking Performance	Low to Medium

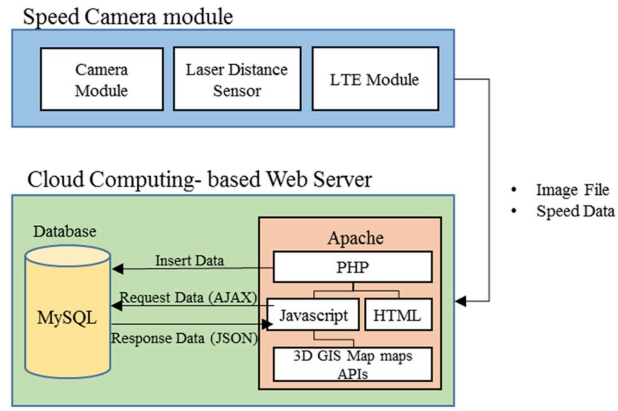


Fig. 2. Configuration diagram of the damage prevention system.

of the location of potential damage, and can use the data for inspection, maintenance, and repair.

3.2. Berthing speed limit

The most important goal of the system is to prevent or minimize damage to fenders or marine structures by detecting berthing speed and providing an early warning system. According to the Port and Fishing Port Design Standards provided by the Ministry of Oceans and Fisheries (2014), the berthing speed limit is determined by the allowable berthing impact of the fenders and marine structures. The berthing speed limit is calculated based on observation data of berthing which varies depending on Deadweight Tonnage (DWT) of the ship. The DWT is the maximum weight of cargo that can be carried on board the vessel during sea transport. In most cases, the standards state that the berthing speed limit is 15 cm/s for ships with DWT below 10,000, and 10 cm/s for ships with DWT above 10,000 (Ministry of Land, Transport and Maritime Affairs, 2011).

However, the limit can be changed due to many aspects, including the type of marine structures, the type of fenders, and the condition of the marine environment (Roubos et al., 2018). Therefore, it is important to check with the regulating authority before setting the berthing speed limit.

3.2.1. Sending alerts

As mentioned earlier, the web server is designed to alert the manager and other assigned personnel when an image file of the ship is received from the speed camera module via SMS alert through a smart phone and a pop-up message through a web page. AWS provides the SMS and pop-up message services from its open library.

3.2.2. Berthing energy

When the ship exceeds the speed limit, damage can result for the ship, or the structure, or both. Therefore, the calculated berthing energy of the ship is useful to the manager or related personnel since such data can be used as a reference for inspection or restoration (Chegenizadeh et al., 2015; Mostofi and Bargi, 2012). Calculating the berthing energy can help the manager to compare the impact of actual berthing energy to allowable berthing energies. When the value of calculated berthing energy exceeds that of the allowable energy, the manger can inspect the structure and ship right after berthing.

According to the Ministry of Oceans and Fisheries (2014), there are many methods of calculating berthing energy, such as statistical methods, hydraulic model tests, and the use of hydrodynamic models. However, the kinematic method is widely used because the data required to calculate the energy via other methods are often insufficient

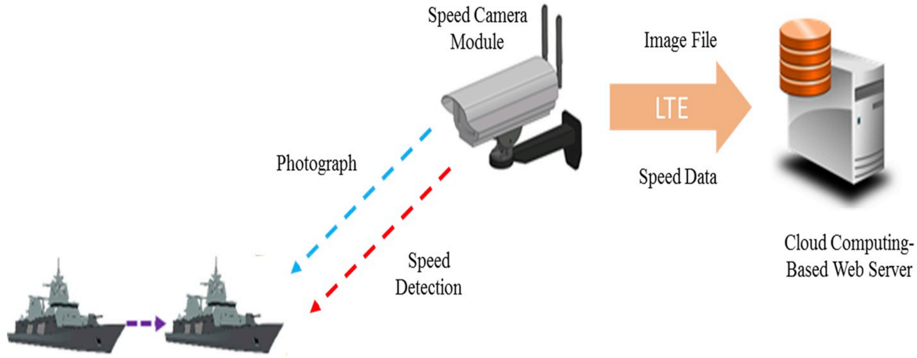


Fig. 3. A system diagram of the damage prevention system.

or because various constants required for calculation are not sufficiently provided. Thus, the berthing energy (E_b) is calculated by the following Equation (2):

$$E_b = \left(\frac{M_s V_b^2}{2}\right) C_e C_m C_p C_s \tag{2}$$

where M_s is the mass of the ship, V_b is the berthing speed of the ship, C_e is the coefficient of an eccentricity, C_m is the coefficient of virtual mass, C_p is the coefficient of pliability, and C_s is the coefficient of shape. A standard for the coefficient of pliability and shape is 1.0. The coefficients of eccentricity and virtual mass are calculated by Equation (3) and Equation (4), respectively:

$$C_e = \frac{1}{1 + \left(\frac{d_c}{r}\right)^2} \tag{3}$$

where d_c is the distance from the contact surface of the ship to the center of the vessel measured parallel to the baseline of the mooring facility and r is the radius of rotation around the vertical axis through the center of the ship; and

$$C_m = 1 + \left(\frac{f_d}{m} \times \frac{\pi}{2C_b}\right) \tag{4}$$

where f_d is the full draft, m is the molded breadth, and C_b is the block coefficient. The coefficient of the block can be calculated by the following:

$$C_b = \frac{v_d}{L_p f_d m} \tag{5}$$

where v_d is the drainage volume of the ship and L_p is the length between perpendiculars, which can be found in the ship registers (Ministry of Oceans and Fisheries, 2014).

4. Experimental testing

Maryang Harbor in Korea was chosen for the initial testing of the cloud computing-based damage prevention system for marine structures during berthing. The harbor has a pier-type structure that was constructed in 1999. The installation was comprised of the speed camera module and the cloud computing-based web server.

4.1. Installation

The watershed area and land area for Maryang Harbor are 105,000 square meters and 20,733 square meters, respectively. This is a relatively small harbor with a limited number of ships to berth. Two speed camera modules were installed for monitoring, one on the berthing area, and another where the ship is entering for berthing, as shown in Fig. 4. Also, the web server for Maryang Harbor was enabled after connecting the speed camera module with the LTE modem and the web address is http://4dcon.kr/portmgt/cctv1.html.

4.2. Berthing speed limit

According to the regulations of Maryang Harbor and the Port and Fishing Port Design Standards, the design berthing speed for the fenders in the structure is 15 cm/s and the regulated berthing speed limit is 10 cm/s. Therefore, the speed camera module was designed to take a photograph and send an image file when the ship exceeds 10 cm/s.

4.3. Method

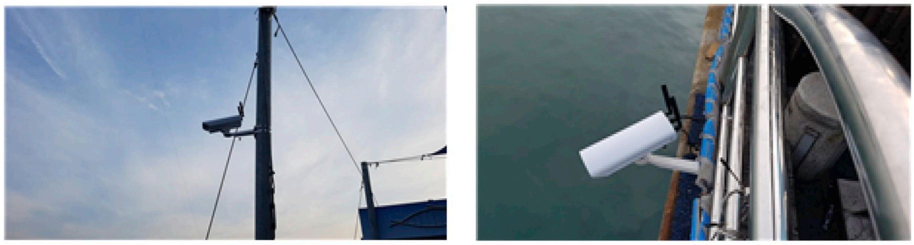
After installing the system in the harbor, an experiment was performed on the data detection and transmission. Thus, the experiment was designed to have a ship to exceed the berthing speed limit. However, the ministry only approved to use a rubber dinghy to test the system because of accidents and damages that can occur during the experiments and it is easy to control the speed. Furthermore, a setting for the berthing speed limit was altered to 9.0 cm/s to minimize the risk of the accidents by exceeding actual berthing speed limit because the experiment was focused on the data detection and visualization. Therefore, the experiment was performed with the ship berthing with the speed between 9.0 cm/s and 10 cm/s.

5. Results

The goal of the experiment was to perform an initial implementation of the proposed system in a real pier-type harbor structure. Since the limit was set to 9.0 cm/s, the speed camera module successfully detected a ship with berthing speed of 9.7 cm/s and sent an image file to the web server via LTE modem, along with the ship's speed data as shown in Fig. 5. After the data were received from the camera module, the alert application was executed to notify the manager, and the web server displayed the data properly.

In addition, berthing energy was calculated by clicking the section for berthing energy, as shown in Fig. 6 below. Although the system requires the remaining variables to be entered manually from the registry to calculate the berthing energy, the web server automatically inputs the berthing speed of the ship. In the case of an unknown ship or foreign ship with no registration in the local registry, person who is using the system can obtain the variables by inquiring the manager of the ship and input them manually. Furthermore, this calculation is used as a reference for comparison with the designed external force for inspecting damage among the structure and ships.

The system successfully detected a ship exceeding the set berthing speed limit and noticed the manager or related personnel of the harbor.



(a) (b)

Fig. 4. The speed camera modules installed (a) on the berthing area and (b) where the ship is entering.

Thus, they were able to monitor the situation anytime and anywhere to prevent or minimize damages from the berthing. In addition, the file and data were saved in the server for future reference or an inspection.

Considering the nature of the system, it is important to proceed qualitative analysis based on user's experience. We conducted interviews with the facility manager and supervisors who actually used the system to monitor their journey from their experience with the calculation application and alert system to after-alert repair. Interviewees were very pleased especially with real-time alert feature. They were able to take an action right away to minimize the damages and further prevent accidents. They were satisfied with the berthing energy calculation application which helped them to calculate the energy. When the speed exceeded excessively, they were able to inspect the structure immediately and repair or reinforce the damaged part which would prevent a secondary accident. As receiving positive praise from the users, it was proven that the system not only provided accurate data but also a meaningful information in real-time use.

6. Conclusion

In this paper, the development of a cloud computing-based damage prevention system for marine structures during berthing was presented. During the experiments, the system performed in accordance with the berthing speed limit which demonstrated feasibility for preventing damage to the harbor structure. The following conclusions were formed: (1) the cloud computing platform is well suited to efficiently monitor ships during berthing in real-time, (2) damage can be prevented or minimized by monitoring “anytime anywhere” using cloud computing technology, (3) the system can be used for structural health monitoring for marine structures, and (4) as a certified web server platform that is easily extendable, Amazon Web Services is appropriate and useful for this type of damage-prevention system.

Future work will involve further testing and concentrating on accuracy of data. In this paper, the experiment focused on the initial implementation of the system in a real harbor structure, whereas more tests are necessary to ensure the accuracy of speed data. In addition, auto-calculation of the berthing energy can be examined as a convergence of new technologies such as image recognition, artificial intelligence, and big data. This type of converged technology system would be able to automatically calculate berthing energy and predict damages by berthing.

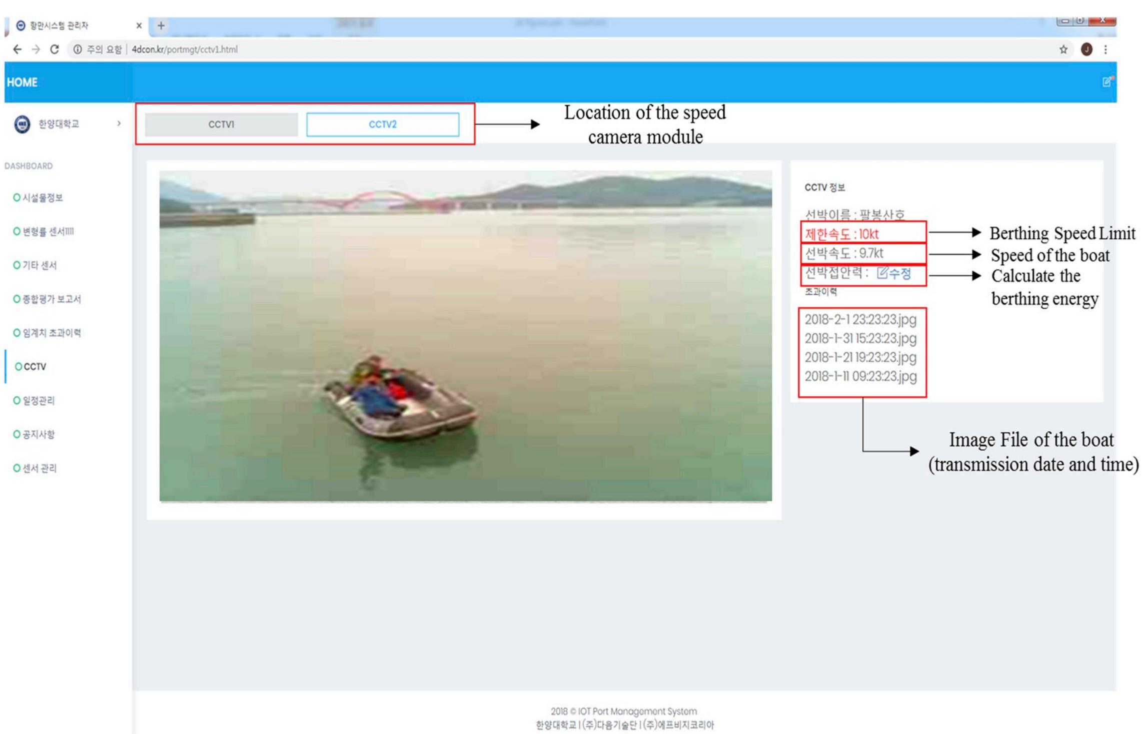


Fig. 5. Page for monitoring the berthing.

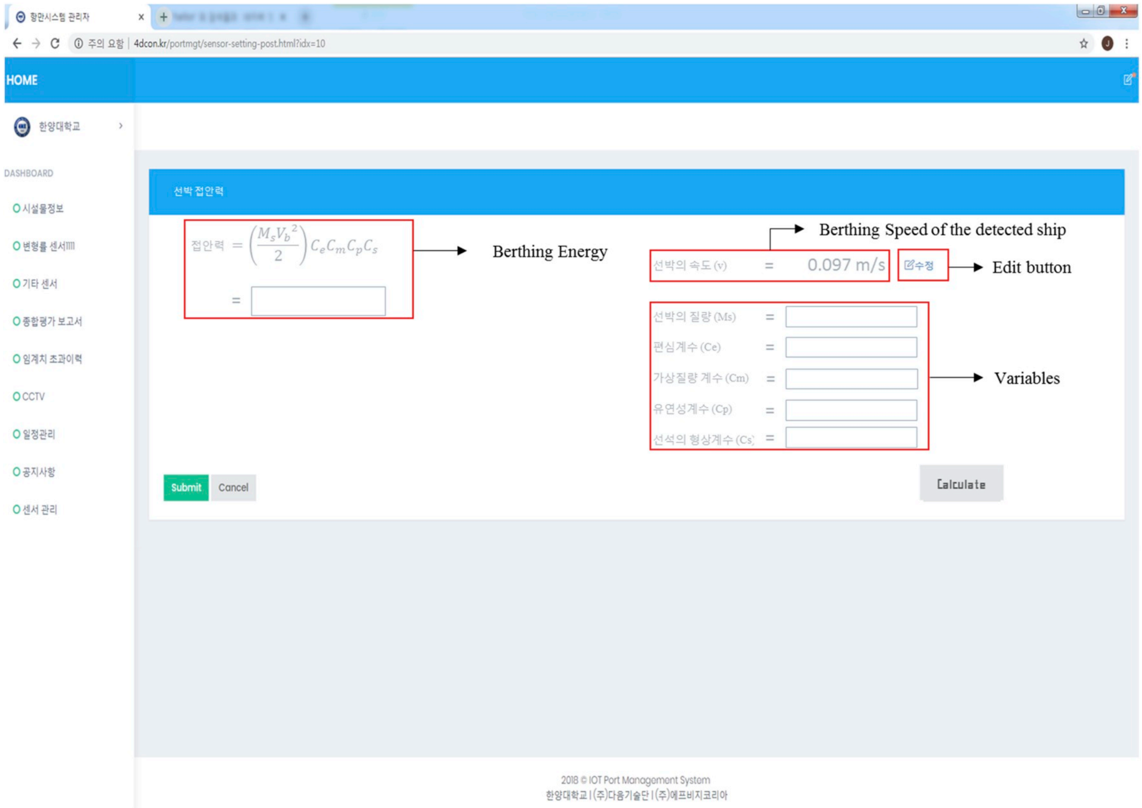


Fig. 6. Page for calculating the berthing energy.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.oceaneng.2019.03.056.

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