# Development of An Internet of Things Based Oil Spill Incident Early Warning System

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**Abstract.** The risk of oil spills are very real, these incident could cause environmental damages and socio-economic losses. These incidents need to be known or realized as early as possible (real-time), to prevent and minimize their environmental and socio-economic impacts. An oil spill early warning system (EWS) based on the Internet of Things (IoT) could be a solution to solve this problem. This research succeeded in developing an EWS called the OSII (Oil Spill Incident Information) System, which allows users to get incident notifications or access the information and response status in real-time wherever they are. The development of this system uses the waterfall method with the stages: requirement analysis, design, implementation, testing and maintenance of the system. Each stage of development is analyzed and discussed in this study. System testing to the OSII System showed quite good results with several suggestions for further development and research.

## 1 Introduction

It is undeniable that the current need for crude oil and its refinery products is still very high. Fuel oil is still the main choice of energy source for the transportation, manufacturing and various other industries. Indonesia is a country that produces and consumers of petroleum. There are quite a lot of industries related to oil production or oil transportation (upstream to downstream) in Indonesia. The busyness of industries related to oil production or oil transportation (upstream to downstream) causes an increase in the risk of accidents and oil spill incidents. Several large-scale oil spill incidents have occurred several times.

Industry players are increasingly trying to minimize this risk. Statistical data on oil spill incidents compiled by the International Tanker Owner Pollution Federation (ITOPF) shows that there has been a decrease in the number of incidents from 1970 to 2022 (see Figure 1). Even though the incidence rate has decreased, this risk cannot be eliminated 100%. Oil spills can still occur, even though various prevention technologies and strict standards have been implemented. The risk of oil spills also exists in Indonesian territory. The major oil spill that has ever occurred is the oil spill in Balikpapan on March 31 2018 in Balikpapan Bay Waters due to a leak in an underwater pipeline owned by PT. Pertamina (Persero) Refinery Unit (RU) V Balikpapan from Lawe-lawe terminal, Penajam, Paser Utara to RU V in Balikpapan. There was also another incident, namely the YYA-1 Platform Oil spill belonging to PT. Pertamina

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Hulu Energi Offshore North East Java (PHE ONWJ) which occurred on July 12 2019 [1]. Number of large oil spills can be seen in Fig.1

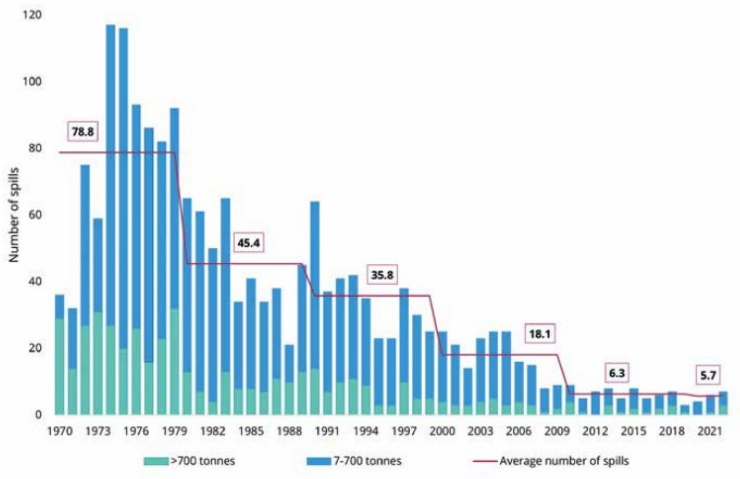


**Fig. 1.** Number of large oil spills (ITOPF, 2023)

Oil spills have an impact on environmental damage, especially the aquatic and coastal environment, which in turn causes socio-economic losses for coastal communities as well as a fall in the reputation of polluting organizations [2]. The impact of oil spills can be prevented or minimized in several ways, including: preventive efforts, preparedness of infrastructure, improving the quality of efforts to deal with oil spills, and information about incidents that can be known as soon as possible. In line with the statement of the former Head of the Disaster Management Section, Directorate General of Sea Transportation, Anung Trijoko Wahono, that the most important thing if an oil or B3 chemical spill occurs, is the speed of reporting so that mitigation efforts can be carried out as soon as possible, so that the area where the oil spill spreads can be minimized [3]. One of the major oil spill incidents, Deep Water Horizon in 2010, greatly impacted the socio-economic and health aspects of the people, especially those living on the coast of the Gulf of Mexico [4]. Long-term ecological impacts of oil spills always occur, especially large-scale ones. This can be seen from three major oil spill incidents, namely: the Exxon Valdez incident in 1989, the Hebei Spirit incident in 2007, and the Deep Water Horizon in 2010 [5]. The impact of an oil spill is influenced by the ecological system affected, the dynamics of the incident, and the countermeasures implemented. As for case studies in Indonesia, the impact of the oil spill in Balikpapan Bay in 2019 shows that the estimated economic loss for only one sub-district, namely Jenebora sub-district, can reach Rp. 41,082,027,068/year, provided that this value is not the total value of the loss of the entire polluted coastal area of Balikpapan Bay [6].

Oil spills in waters can experience weathering processes (Fig. 2) and movement (Fig. 3) because they are affected by currents and wind. This weathering and movement, as well as the physical chemical components contained in oil, cause ecological pollution of the environment, and of course have an impact on socio-economic aspects in coastal areas. The toxic and heavy metal content of petroleum (and their derivatives) can kill microorganisms or larger organisms in the water column, this can reduce productivity and biodiversity in marine and coastal ecosystems. This is an explanation of how oil spills impact the marine and coastal environment ecologically [7]. Aquaculture businesses are also affected when water quality decreases, thus having a negative impact on pond production. Another example is that tourist beaches which are affected by pollution will also reduce visitors, thus having a negative impact on the economy of the tourism sector. This is an explanation of how oil spills impact the socio-economic environment [7]. The facts above show that the risk of oil spills does really exist, and could happen at any time. So, preparedness is an absolute necessity for industry players.

One element of preparedness is Early Warning System (EWS), to prevent greater impacts resulting from an oil spill incident. The impact of oil spills can be prevented or minimized if oil spills are known as early as possible in real time. So that mitigation efforts can be carried out before the oil spill spreads too far. At the same time preventing ecological or socio-economic impacts in water and coastal areas. This also supports the industry to avoid violating laws related to environmental pollution. Appropriate action is also needed, good information can support the selection of decisions to be taken in handling technical or non-technical incidents. The selection of appropriate strategies and actions is an example of a technical matter, while the distribution of information in reports to other parties such as the government, media or other stakeholders is an example of a non-technical matter [2].

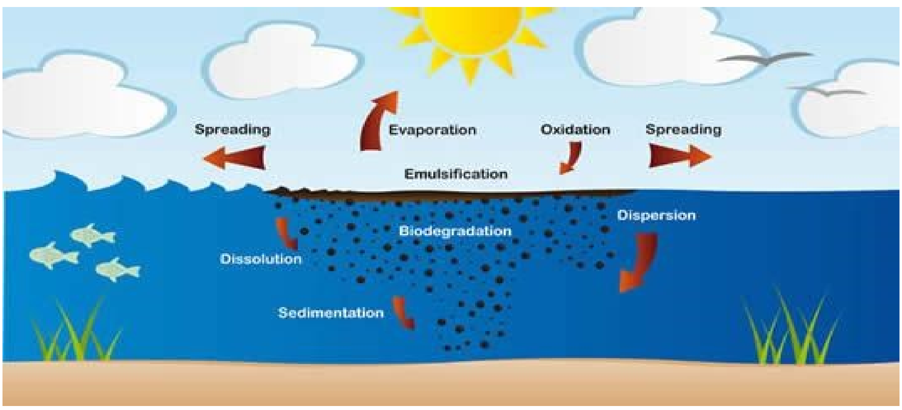


**Fig. 2.** Oil spill weathering process (ITOPF, 2011).

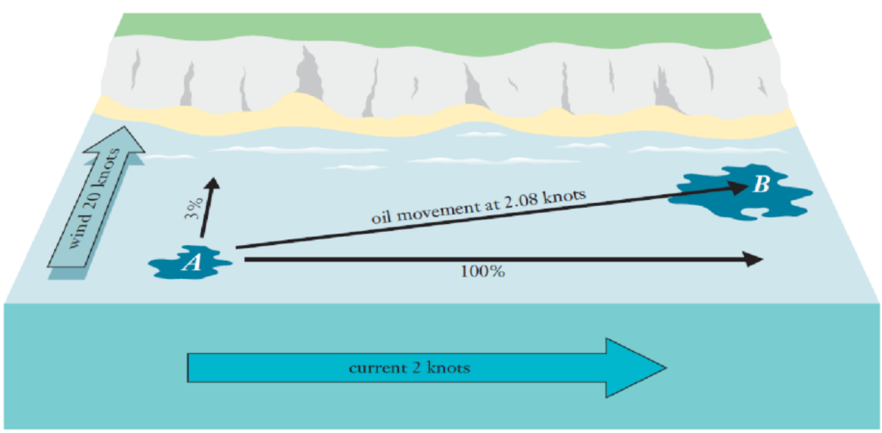


**Fig. 3.** Oil spill movement (ITOPF, 2011).

An instant and real time distribution of information can be done with an Information System, especially an EWS which is supported by Internet of Things (IoT) technology. An Information System based on IoT Technology is a key point for building an efficient remote (real time) early warning system [8]. IoT technology can provide greater speed, making it possible to connect multiple sensors in a single framework to analyze and assess a problem synthetically. An EWS that utilizes IoT technology is an integrated architecture of monitoring, forecasting and hazard prediction, disaster risk assessment, communication and preparedness activities, systems and processes that enable individuals, communities, governments, businesses, and others to take timely action to reduce disaster risks before dangerous events occur [9]. The Illustration of the use of IoT in various fields can be seen Fig.4.

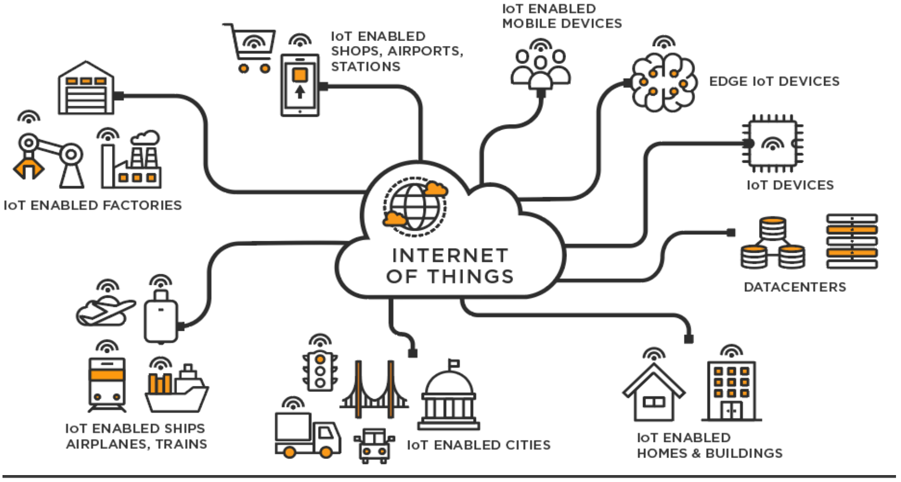


**Fig. 4.** Illustration of the use of IoT in various fields [12]

The pattern or formulation found in IoT-based EWS in general is that the sensors will be equipped with a microcontroller which will be connected to an internet gateway. The data will be sent to the server (cloud or physical), for data processing. This allows the resulting information to be accessed or sent to users in real-time wherever they are. This allows emergencies or disasters to be avoided as early as possible. By adopting this concept, EWS can also be applied to oil spill incidents [2]. This system requires a sensor that is capable of detecting oil spills, in other words capable of distinguishing between unpolluted water and water containing oil. Fluorescence-based in-situ sensors and systems can be used for real-time oil spill monitoring. Fluorometric detection is basically measuring fluorescence at a predetermined wavelength [10]. The results of research that analyzed fluorometric laboratory tests to detect the presence of oil in seawater, showed that statistically significant differences were found between the fluorometric index values for uncontaminated seawater and seawater exposed to various types of oil (i.e. crude oil, lubricating oil, and fuel) [11]. An illustration of how the fluorometric sensor works can be seen in Fig 5. In the existing system, when an oil spill is detected by the sensor, it will turn on the warning light and emergency buzzer. The user will manually hear this buzzer and will take action to deal with the oil spill. This system has a limited distance, only users who are close to the buzzer will hear or know about an oil spill [2]. In the IoT-based EWS, when an oil spill is detected by the sensor, the microcontroller will automatically turn on the warning light and buzzer. The microcontroller will also send data from this detection to the software system. Communication between hardware and software uses the IoT concept which utilizes the internet network. The software system will distribute notifications of this oil spill incident to all system users in real time via a messaging application. Likewise, if there is an oil spill that is seen directly by one of the users. Users can report incident notifications manually with the system application. The system will also distribute incident notifications to all system users in real time. Sensor devices need to be placed in certain places in industrial areas that can detect oil spills carried by flowing water (eg: in canals, canals, near jetties or jetties where oil is loaded and unloaded). When the sensor device detects an oil spill, the system will send this information via the internet to the smartphones of all system users wherever they are in real-time, so that the oil spill can be responded to immediately according to their respective roles.

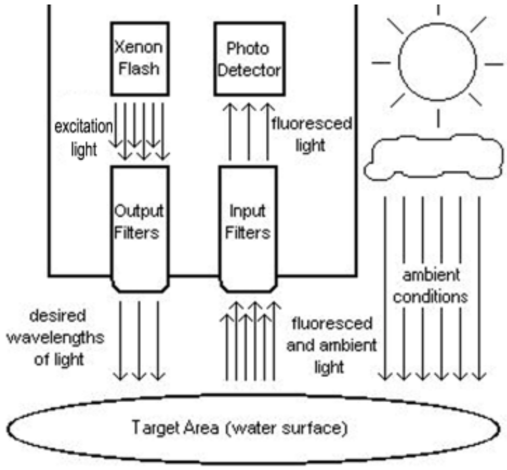


**Fig. 5.** Basic Operation of Fluorometric Sensors [13]

Based on the description above, an IoT-based oil spill incident early warning system is the solution needed so that oil spills can be detected as early as possible (real time). Currently, there is not much research on information systems related to oil spill early warning systems. EWS related to oil spill incidents is currently still conventional, sensors that detect oil spills only activate a buzzer or emergency alarm and are not yet integrated with the information system. To address this research gap and underscore the significance of mitigating the impact of oil spill incidents, this study prioritizes the creation of an IoT-based early warning system. To fill this research gap and because of the importance of efforts to prevent the impact of oil spill incidents, the development of an IoT-based oil spill incident early warning system was appointed as a central theme in this research. This system is named Oil Spill Incident Information (OSII) System. This research also involved PT. XYZ as a provider of oil spill sensors and a test location for system design and development results.

## 2 Material and Methods

System Development Stages, adapting the System Development Life Cycle (SDLC), with one method, namely Waterfall. The Waterfall method proposes an approach to the development or development of software that is systematic and sequential. This method was chosen because it is suitable for developing a relatively new system [14]. This model can be used when the requirements for a problem are well understood, and work can flow linearly. In this model, a new phase can be started after completing the previous phase [15]. This means that the output of one phase will become the input of the next phase. Thus the development process can be considered as a sequential flow like a waterfall. Thus, this method is considered more suitable for projects creating new systems [16]. The stages of the Waterfall model consist of: System Requirements Analysis, System Design, System Implementation, System Testing, and System Maintenance.

## 2.1 Requirement Analysis

At this stage, an analysis of the need for long-distance connections between hardware and software that utilizes Internet of Things technology is carried out, the function and process of the web application being created, identifying obstacles in creating the system, analyzing reliability, weaknesses and the technology used. In this research, a requirements analysis was carried out which was generally grouped into non-functional and functional system requirements.

## 2.2 System Design

The system design stage is the stage where complete system specifications are made. In this study, a system design was carried out which included:

a. Process Modeling: a formal way of describing how a business operates. Illustrate the activities that are performed and how data moves between the activities. There are many ways to represent process models. A popular way is to use UML (Unified Modeling Language) such as: activity diagrams, system architecture, and others.
b. Data Modeling: a formal way to describe the data used and created in an information system. This model shows the person, place or object where the data is taken and the relationship between the data. In this research, data modeling is presented with Class Diagrams.
c. Interface Design: The user interface is the display where the user interacts with the system. The purpose of the user interface is to allow the user to carry out each task within the user's requirements (user requirement). So in building a user interface must be based on user needs.

## 2.3 System Implementation

The system design results must be translated into a web-based software program that is integrated with hardware using Internet of Things technology. The result of this stage is an oil spill incident information system (both software and hardware) which is in accordance with the results of the system design that was created at the design stage. At this implementation or coding stage, the author creates a web-based application with the php programming language. The php file that has been created is then uploaded to the specified hosting so that the web application can be accessed. Coding is also needed on the microcontroller, as a component of the Internet of Things, to enter instructions so that the system runs according to the desired rules. After the system is ready, then the complete system operation is carried out according to the type of system user that has been determined. Obstacles and bugs may be found, so it needs corrections to the code that was made before. Operation and repair of the system are carried out continuously until the system can run properly.

## 2.4 System Testing

At this testing stage individual units as well as the entire system are tested as a complete system to ensure whether it meets the functional requirements of the system. Tests carried out on the system are more focused on the performance of the software system that has been built. The types of tests performed are as follows:

a. Validation Test, using the Black Box method.
b. Compatibility Test, with Sortsite software to find out how well this application runs in several popular web browsers (Google Chrome, Safari, Opera, Edge, and Firefox).

c. User Acceptance Test, with a total of at least 10 respondents, representing each type of application user (Admin, Management, Response Team Leader, and Facility Operator).

**Table 1. Aspects of User Acceptance Test.**

| No | User Acceptance Aspects (Score) | (4) | (3) | (2) | (1) |
|---|---|---|---|---|---|
| 1 | Appearance of the application is quite interesting | | | | |
| 2 | This information system is especially useful for dealing with oil spills | | | | |
| 3 | The application is quite easy to use | | | | |
| 4 | The functions available in the application meet your needs | | | | |
| 5 | The information produced by the application is accurate and easy to understand | | | | |
| 6 | The response time or system performance is good | | | | |

Description: 4: Very Good; - 1: Very Not Good

The rating system for testing user acceptance uses a 4-point Likert scale to avoid neutral selection [21]. The classification of the results of the user acceptance assessment was made according to Table 2. The calculation of the index percentage of the total user acceptance score (index %) is carried out by Formula (1) below.

$$Index\ \% = \frac{Total\ score}{Highest\ score}\ x\ 100 \quad (1)$$

**Table 2.** User Acceptance Assessment Classification.

| No | Classification | Index % |
|---|---|---|
| 1 | Very Good | 76 – 100 % |
| 2 | Good | 51 – 75 % |
| 3 | Not Good | 26 – 50 % |
| 4 | Very Not Good | 0 – 25 % |

## 2.5 System Maintenance

The maintenance phase involves correcting errors that were not found in the previous stages, improving the quality of the implementation of the system unit, and continuously improving system services. There are three types of maintenance: Corrective, Perfective, and Adaptive Maintenance [17]. The maintenance phase involves correcting errors that were not found in the previous stages, improving the quality of the implementation of the system unit, and continuously improving system services. There are three types of maintenance, namely Corrective, Perfective, and Adaptive Maintenance. The maintenance phase is usually carried out continuously, with the aim of always meeting dynamic user needs. In this research, system maintenance is limited to corrective maintenance only. So system maintenance is only carried out until all system functional requirements are declared to have passed 100% using the Black Box testing method. Needs for future development are also identified at this stage.

Operational system requirements are divided into two parts, Hardware and Software. Hardware operational requirements can be seen in Table 3, while software operational requirements can be seen in Table 4.

**Table 3.** Hardware operational requirements.

| No | Item | Information |
|---|---|---|
| 1 | Non-contact Oil Sensor | Fluorometric, oil spill detection sensor |
| 2 | Microcontroller ESP 32 | a small processor (IoT device) that connects sensors to the internet. |
| 3 | 18650 Battery | Sensor and Microcontroller Device Resources. |
| 4 | Voltmeter | as an indication of the power status of the sensor device system and microcontroller. |
| 5 | Warning Light | which is active when the sensor detects an oil spill. |
| 6 | Alarm Sound | which is active when the sensor detects an oil spill. |
| 7 | PC processor | 1 gigahertz (GHz) or faster processor. |
| 8 | PC RAM | 1 gigabyte (GB) for 32-bit or 2 GB for 64-bit. |

**Table 4.** Software operational requirements.

| No | Item | Information |
|---|---|---|
| 1 | Windows 10 | to operate system support applications |
| 2 | Arduino IDE 2.1.0 | to provide compilation commands to the microcontroller. |
| 3 | Visual Studio Code | php editor to create website files and write the code. |
| 4 | MySQL | as a database. |
| 5 | phpMyAdmin | to handle MySQL administration. |
| 6 | Microsoft Edge | a web browser to display web-based systems. |
| 7 | Telegram Messenger | to distribute notifications in real-time to all system users. |

# 3. Result and Discussion

## 3.1 Requirement Analysis

System requirements (functionally) must be able to accommodate the needs of system users. Users of this system in an oil spill incident can be grouped into: Admin, Management, Operators, Responders, Others, and Sensor Devices. It is expected that this system can be utilized by users from industries that have a risk of oil spills, such as the oil and gas industry in particular, and also other industries that have oil facilities (storage, distribution, loading and unloading of oil, etc.). Stakeholders (local governments and communities) in the surrounding area can also become users who utilize this system.

The first is the Admin User. The admin user oversees managing the system. Admins can also manage user data, including approving new user registrations. Admin also manages sensor device data, including installing new sensor devices. The second is the Management User. Management users are users who have middle and high-level positions in the organization. This management usually plays a role in determining important decisions in emergency situations and coordinating with stakeholders both internal and external to the organization. Therefore, management must have the capability to access comprehensive report information related to an oil spill incident within this system.

The third is the Operator User. Operator user is an abbreviation for Facility Operator. The operator is in charge of closing and shutting down the facility when an oil spill incident occurs. This is done to ensure safe conditions and to stop the release of further oil spills originating from facilities in industrial areas. Operator can do closing status report in this system. The fourth is the Responder User. Responders are a team tasked with dealing with and cleaning up oil spills that have polluted the environment. This is done so that the condition of the polluted environment can return to normal. Responders can report response status in this system. The responder team is led by a Leader who will report the response status.

Next are The Other Users. This other user group was created to accommodate other users who have other roles (finance, logistics, safety, external liaison, and others) and do not include management within the organization. This user can also view complete report information of an oil spill incident in this system. The last one is Sensor Devices. The sensor device is a piece of hardware consisting of an oil spill sensor, a power sensor, and a microcontroller circuit. The oil spill sensor functions to detect if an oil spill occurs. This information is then received and sent by the processor or microcontroller via the internet so that it can be known as soon as possible by all system users.

## 3.2 System Design

The results of the system design in this study are shown in the form of: Activity Diagrams, System Architecture, and Database Models, The following design is an Activity Diagram. This diagram models the processes that occur in the system. Fig. 6 shows an Activity Diagram of the developed system that in general the system consists of hardware, software and users. As a comparison, Fig. 7 shows an Activity Diagram of the current conventional system which only involves hardware and users.

In a conventional system (Fig. 8), when an oil spill is detected by the sensor, it will turn on the warning light and emergency buzzer. The user will manually listen to this buzzer and will take action to prevent oil spills. This has distance limitations, only users who are close to the buzzer will hear or know about the oil spill incident.

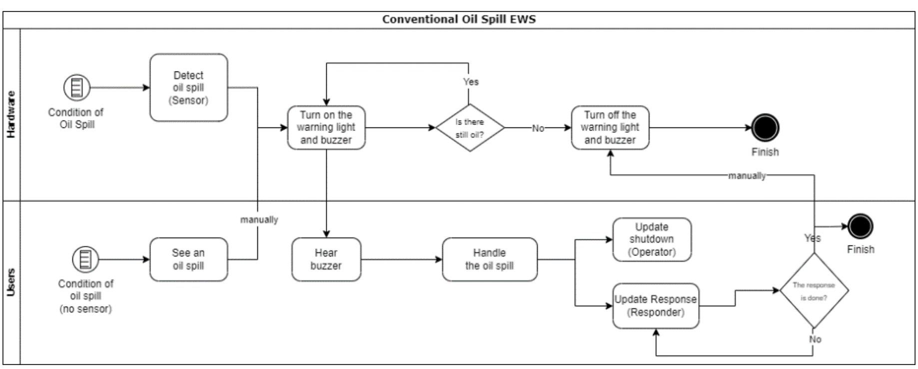


**Fig. 6.** Conventional system Activity Diagram**.**

In the developed system (Fig. 7), when an oil spill is detected by the sensor, the microcontroller will automatically turn on the warning light and buzzer. The microcontroller will also send data from this detection to the software system. Communication between hardware and software uses the IoT concept which utilizes the internet network. The software system will distribute notifications of this oil spill incident to all system users in real time via the Telegram application. Likewise, if there is an oil spill that is seen directly by one of the users. Users can report incident notifications manually with the system application. The system will also distribute notifications of this incident to all system users in real time.

When dealing with an oil spill, the operator can update the status of the closure of the oil spill source and this will be recorded by the system. Responders can also update the status of oil spill response and this will be recorded by the system. The system software will collect and process this data and present it in the Complete Incident Report information. All system users can easily view information related to oil spill incidents in this Complete Incident Report.

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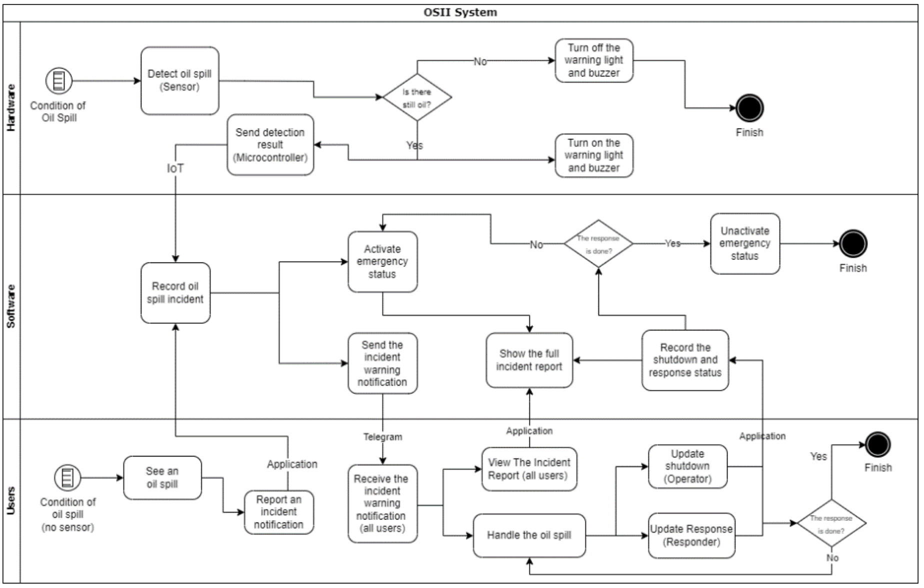


**Fig. 7.** Activity Diagram of the developed system.

The following design is the System Architecture. The system designed is IoT-based, so the architecture refers to IoT architecture. Figure 8 shows that this system has three main elements, namely physical goods, internet connection devices, and cloud data centers. Physical goods in the form of IoT components (microcontrollers), devices connecting to the internet in the form of gateways, modems or routers, as well as cloud-based application storage.

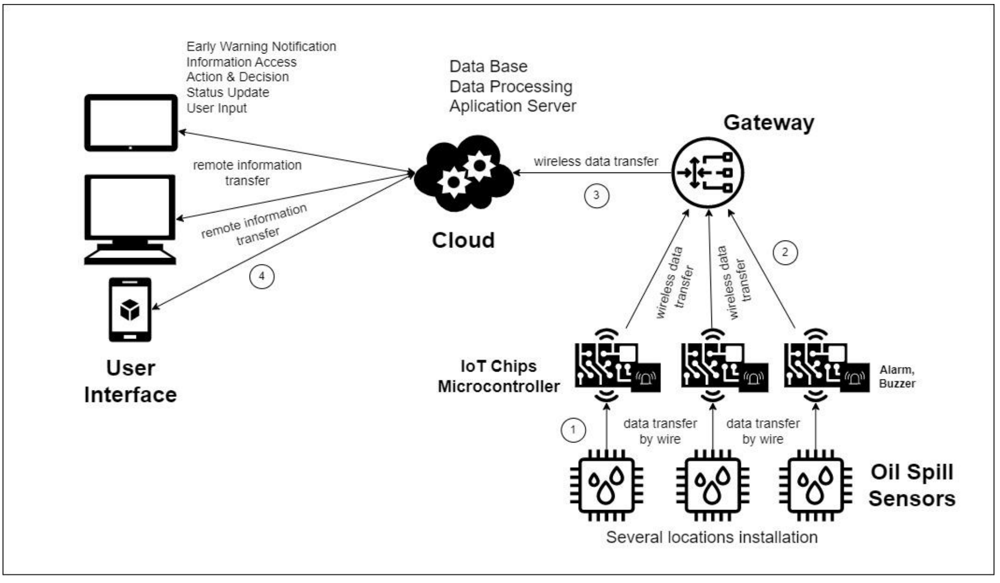


**Fig. 8.** System Architecture.

The Database Model Design for an Oil Spill Incident Information System is shown with a Class Diagram (CD) in Figure 9 below. CD shows the relationship from one entity to another entity, and shows what data is contained in each entity. This figure shows that the main entities in this system consist of Admin, Device_Sensor, Oil_Spill, Management, Other, Operator, Shut_Down, Responder, Response, and Incident_Report.

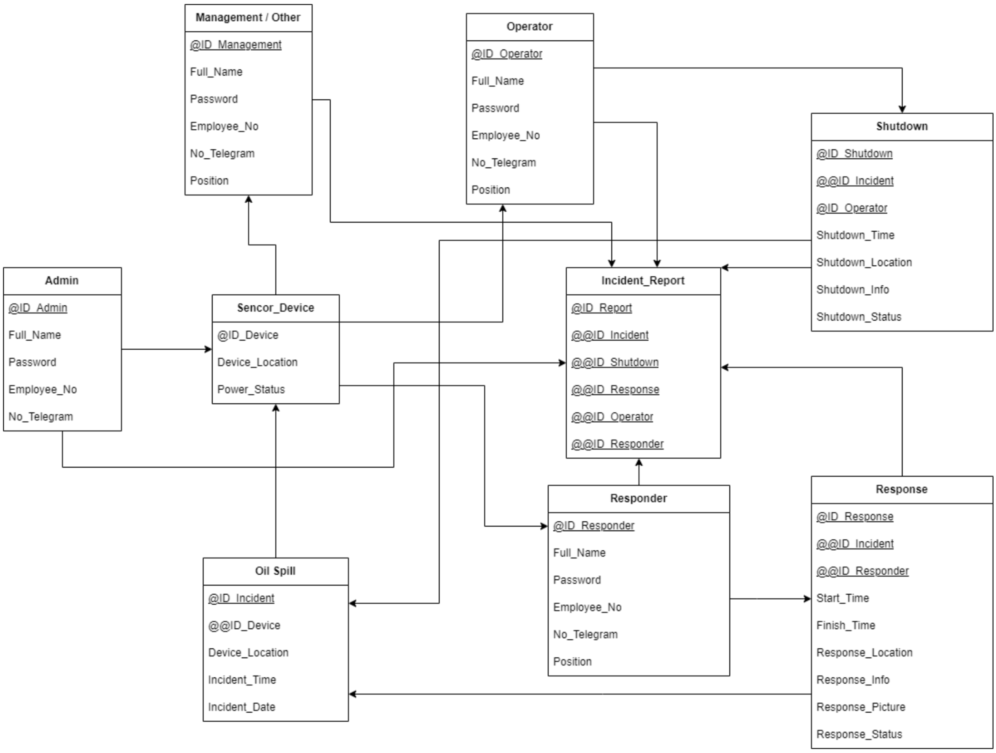


**Fig. 9.** Class Diagrams**.**

### 3.3 System Implementation

Based on the system design results, the next stage is assembling the sensor device which consists of an oil spill sensor, power sensor, and microcontroller circuit. Special commands are given to the microcontroller using Arduino IDE software. The software system was also built based on the PHP language using Visual Studio Code software. The php file that has been created is then uploaded to the specified hosting so that it can be accessed via the internet as a web-based application. The database has also been created in accordance with the data model design and system requirements. The oil spill Early Warning System is ready to be implemented. This Oil Spill Early Warning System is named "Oil Spill Incident Information System" (OSII System). An illustration of this oil spill early warning system in an industrial environment (Refinery Unit) can be seen in Fig. 10.

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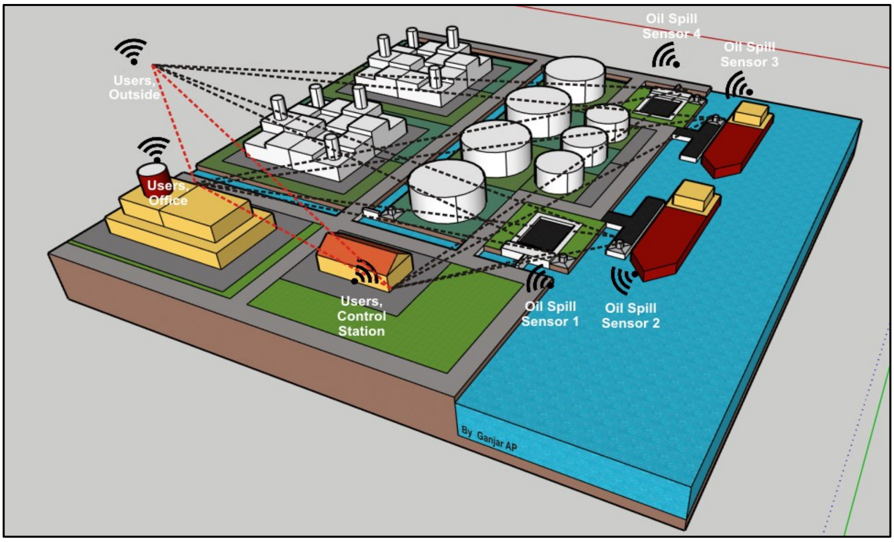


**Figure 10.** Illustration of an early warning system for oil spills in an industrial environment [2]

The fluorometric non-contact Spill Sensor (Fig. 11) functions to detect oil spills in water that passes underneath. The way this sensor works is to read light waves. Water that is not polluted by oil will reflect light waves that are different from water that is polluted by oil. The sensor will recognize the oil, because it reflects a specific wavelength, which is in the range of 450 to 650 nm [18]. The ability of the sensor detection distance usually depends on the type and brand.

**Fig. 11.** Fluorometric non-contact oil spill sensor.

The microcontroller circuit (Fig. 12) functions to receive data from oil spill sensor devices and send it via the internet so that it can be conveyed to all system users wherever they are in real-time (IoT concept). The main component of this circuit is the ESP 32 microcontroller, which can automatically regulate data input and output. This type of microcontroller is equipped with a WiFi receiving device so that it can connect to the internet [19]. The WiFi connection settings in this microcontroller need to ensure that the SSID and password are the same as the WiFi network to which it will be connected. The components of the microcontroller circuit shown in Fig 12 consist of:

a. Antenna
b. LCD 20x4 I2C
c. Warning Lights

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d. Buzzer / Alarm Sound
e. Oil Sensor Connection Cable
f. Power button
g. ESP 32 microcontroller
h. Voltmeter
i. Step-down Regulator
j. Battery 18650 2100mAh 3.7V x 4

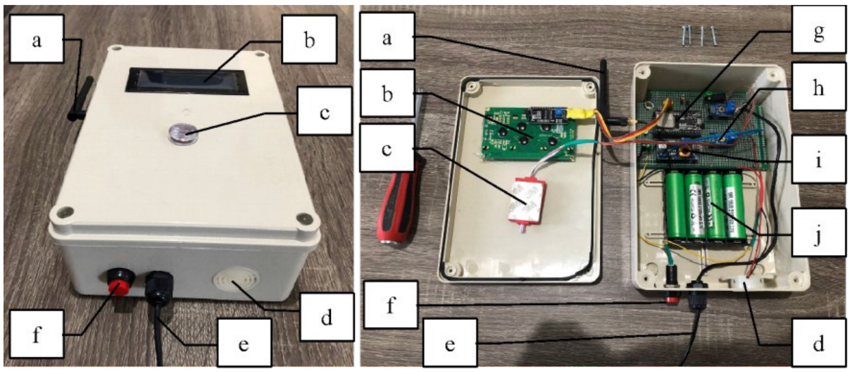


**Fig. 12.** Microcontroller Circuit**.**

The flow of communication begins with the input made by the hardware and the user. Data is sent using the internet network which is then received and processed by the software, so that the output in the form of information can be received by the user. All communication system components in the transfer of data and information utilize the internet network. Users can receive information from any location and do it in real time, this can be done because this system uses the Internet of Things concept.

The operation section of this system contains the main steps in operating or using this OSII System. Before operating this system, make sure the SSID and wifi password are the same as those on the microcontroller, to ensure that the sensor device is connected to the internet. If the SSID and Wifi Password are different, they need to be changed first through the program code and uploaded back to the microcontroller. Then make sure the user's smartphone and PC are also connected to the internet. Users also need to install the Telegram application on their smartphones. The main steps of operating the system are grouped into: Registration and User Login; Incident Notification; Facility Closure Updates; Oil Spill Response Update; and View the Full Incident Report. Users enter the OSII System application by accessing the link: https://osii.ganjar-ap.top using a web browser on a PC or smartphone. Furthermore the following figures represent the operation and interface of the OSII system software.

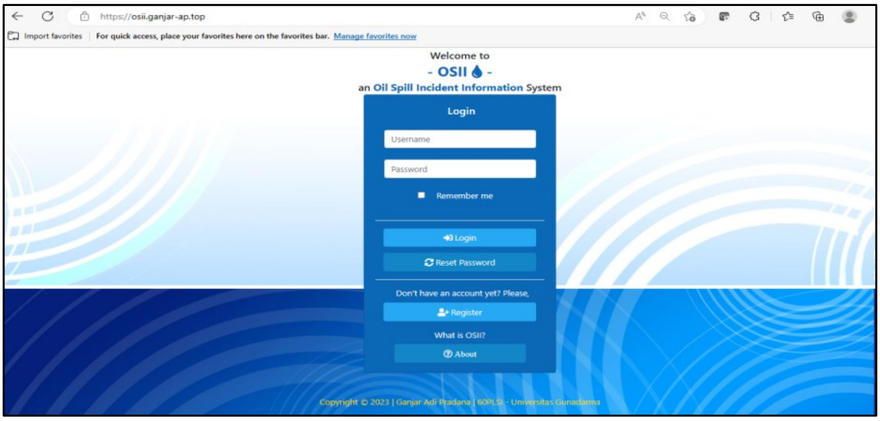


**Fig. 13.** "OSII System Login" page.

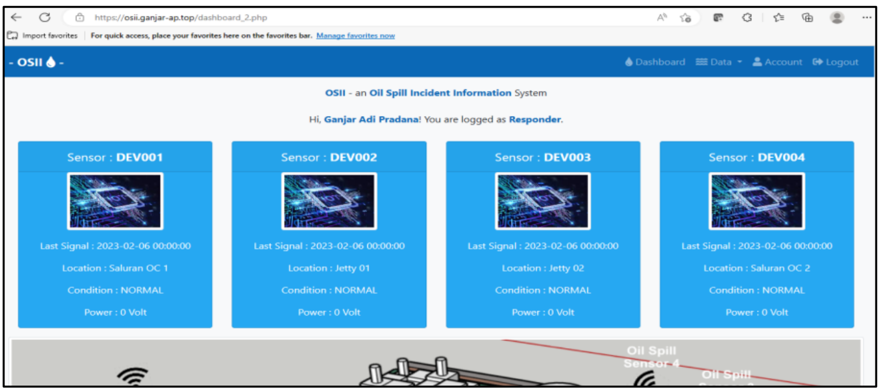


**Fig. 14.** "OSII System Dashboard" page.

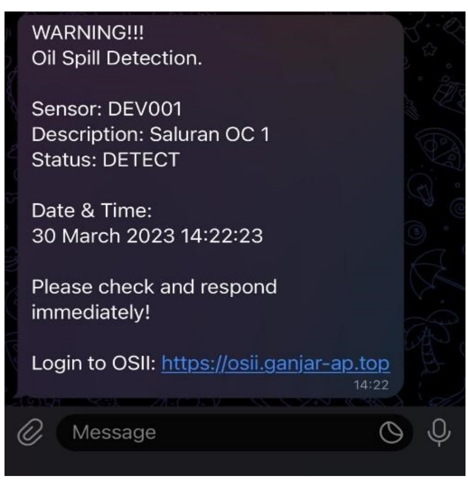


**Fig. 15.** Telegram message from "OSII System" regarding notification of oil spill incidents detected by sensors.

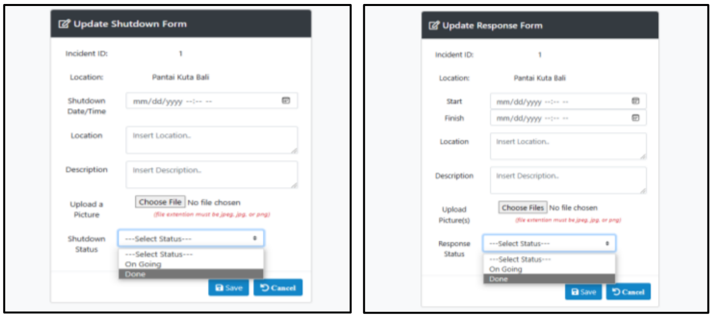


**Fig. 16.** "Update Shutdown Form" and "Update Response Form" pages.

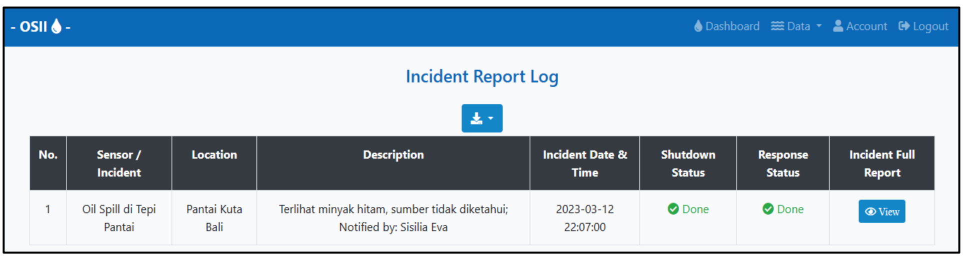


**Fig. 17.** "Incident Report Log" page.

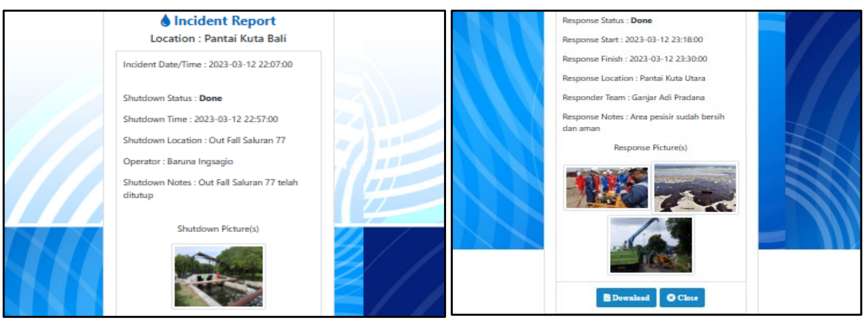


**Fig. 18.** Incident Report page.

## 3.4 System Testing

System testing carried out includes: 1. Validation Testing (Black-box), 2. Compatibility Testing, and 3. User Acceptance Testing. Black-box test results for "OSII System" are grouped according to users in this system, including: Admin, Management / Other, Operators, Responders, and Sensor Devices. A total of 34 functional tests have been prepared in this black box test. These tests cover all functions based on the needs of all users and systems. The black-box test results show that the system has been able to successfully run 100% of all functional requirements that have been determined at the system requirements analysis stage. The obstacle faced was the speed of receiving oil spill incident notifications which varied for each (smartphone) user via telegram messages. This is indeed a system limitation that relies heavily on the quality of the internet network signal. The process of sending notifications by this system can take place real-time or fast (less than 3 seconds) in good internet network conditions.

Compatibility testing for the "OSII System" was carried out using Sortsite software developed by PowerMapper. The results of compatibility testing for this system are presented in Fig. 19. The results of compatibility testing against these systems may reveal browser-specific behavior, or may trigger bugs. The browsers used in this test are the latest popular browsers with the latest versions (such as: Edge, Firefox, Safari, Opera, iOS, and Android). The test results show that there were no problems, bugs, or performance and function problems found when the OSII System was run on these browsers. This test provides a positive value for the "OSII System".

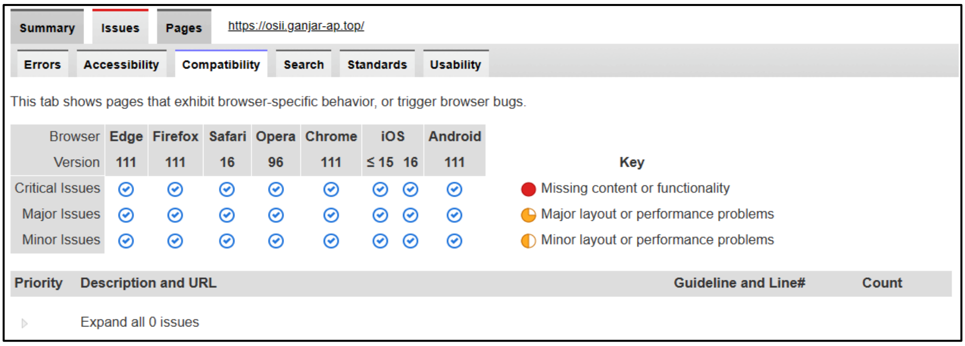


**Fig. 19.** Results of "OSII System" compatibility testing.

User acceptance testing was carried out involving 10 respondents from PT. XYZ on March 30, 2023. The results of the user acceptance test show that this system has a score (index %) of 93.75%. These results show that the "OSII System" received a good appraisal from respondents who came from a real industrial environment. All aspects of the assessment show no significant problems and get a score of 3 or 4. Based on the appraisal classification in Table 2, this result is included in the "Very Good" classification. This test provides a positive value for the "OSII System". This user acceptance test can be developed by involving other companies or organizations with a larger number of respondents in future research.

### 3.5 System Maintenance

Maintenance of this system is grouped into two stages. The first stage is a solution to the bugs and constraints found after the system development stage (corrective maintenance). Several obstacles were discovered during the system development process and can be overcome so that the system can run well. Then the second stage is a suggestion for further system development. Currently the OSII system application is built on a web-based basis. This is done on the grounds that web applications are simpler and more flexible. In the future, this application can also be built based on Android and iOS systems. Users can access this system more quickly and practically. The current system utilizes the chatbot feature in the Telegram application to send messages and notifications to system users in real-time. This is done because the features in the Telegram application can be done at no cost or for free. There are no significant problems with this. However, the WhatsApp application is a more popular chat application. This system can also utilize the WhatsApp application, other messaging application, or even Short Message Service (SMS) as alternatives to sending messages and notifications to system users in real-time. For the record, this WhatsApp chatbot feature is subject to a subscription fee.

The sensor used in this study is a fluorometric oil sensor that reads UV wavelengths. Other sensors that can detect oil spills are possible to be used in this system. For example detection: drastic pressure changes in a pipeline, overflow of an oil reservoir, remote sensing, or others. The oil sensors used today are quite simple. All light waves that have been assigned to oil will be considered oil. Meanwhile, the types of oil currently available are very diverse. Light to heavy oils have different characteristics, hazards and mitigation methods. If sensors can differentiate the type of oil that is spilled, this will further assist the response team in dealing with oil spills. Oil detection testing in this study was carried out during the day. Testing for further research also needs to be carried out at night. This ensures that the sensor can be used both day and night. Oil spills can occur at any time, day or night.

The number of sensor devices used in this study is one set. In actual applications in an industrial work area, oil sensors can be installed in several locations that are at risk of oil spills. So that the early warning system, especially sensors, can cover all facilities and activities that have the potential for oil spill incidents in an industrial work area. The speed of receiving incident notifications to system users is greatly influenced by the quality of the internet network connection. This system is very dependent on the quality of the internet network connection. Sensor devices used in industrial environments need to be made in such a way that they use a stable internet network. This is done to avoid system failure in detecting oil or sending notifications of oil spill incidents. If sensors are forced to be placed in areas where there is no internet network and in remote areas, this can be overcome by using Long Range Wide Area Network (LoRaWAN) technology. LoRaWAN is a wireless communications technology that combines very low power consumption with effective long range [20].

## 4 Conclusions

Based on the results and discussion of the research that has been carried out, several conclusions have been obtained. An Oil Spill Incident Early Warning System Using IoT (OSII System) has been successfully built. This system is a combination of hardware and software. The types of "OSII System" users are grouped into: Admin, Management, Operator, Responder, Others (Other), and Sensor Devices. The main functional requirements of this system are: to be able to send notifications of oil spill incidents in real-time, to be able to update the status of closures and countermeasures for certain users, and to provide accurate information regarding incident status to system users. The Telegram chat-bot application is utilized in this "OSII System" to send notifications to system users in real-time, for reasons of functionality and effectiveness. OSII System" utilizes IoT technology, therefore the performance of this system is highly dependent on the quality of the internet network at the location of sensor devices and system users. The results of the validation test (black-box) indicate that the system has been able to successfully run 100% of all predetermined functional requirements. The results of the compatibility test show that there are no problems, bugs, or performance and function disturbances found when the system is run on some of today's popular browsers. The results of user acceptance testing show that this system obtained a score (index %) of 93.75%. This result is included in the very good category.

There are suggestions for system development and further research. This system can also be developed based on Android and iOS, users can access the system more quickly and practically. This system can also utilize the Whatsapp application, other messaging application, or even Short Message Service (SMS) as alternatives to sending messages and notifications to system users in real-time. Sensors other than fluorometric can also be used as oil spill detectors. For example, detection: drastic pressure changes in a pipeline, overflow of an oil reservoir, remote sensing, or others. Development in the sensor sector so that it can distinguish the type of spilled oil will further assist the response team in tackling oil spills. Testing for further research also needs to be carried out at night. This ensures that the sensor can be used both day and night. Sensor devices used in industrial environments need to be made in such a way that they use a stable internet network. This is done to avoid system failure in detecting oil or sending notifications of oil spill incidents. LoRaWAN technology can be used in remote areas where there is no internet network.

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