

## Applications of Fiber Optic Sensor for Monitoring and Early Warning of Soil Shift on IoT-based System

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**Abstract**— A fiber optic sensor system has been designed to monitor ground shift using a multimode FD-620-10 step-index fiber optic cable equipped with an IoT-based data transmission system. The sensor system consists of a light source in the form of a diode laser, a fiber optic cable with light waveguide, and an OPT101 photodetector. Data processing is done using the Arduino Uno R3 microcontroller and data transmission to the server using the Arduino Ethernet Shield. Localhost is a web server that displays measurement data and sends e-mail early warning notification of ground shift hazards. Optical fiber is used to measure the value of ground displacement by utilizing changes in output voltage. The change in output voltage occurs due to variations in the difference in the diameter of the optical fiber arch. The results of sensor testing obtained an average measurement error of 1.53%.

**Keywords**— fiber optic sensor; soil shift; early warning.

### I. INTRODUCTION

Landslides have claimed a lot of casualties, both material, and life because landslides are natural disasters that happen without time and occur suddenly. Landslide mitigation efforts that can be done are monitoring one of the test parameters, namely the displacement of land in landslide-prone areas. Land shift monitoring can be carried out using instrumentation devices equipped with an internet-based data transmission system. The instrumentation device that is often used for ground shift detection and monitoring is the extensometer sensor. Electrical and mechanical type extensometer sensors can detect shifting of the soil layer structure but are very vulnerable to damage due to frequent electromagnetic wave interference. Higuchi et al. in 2007 stated that the extensometer sensor is easily damaged when receiving a signal/vibration due to lightning and still has a dependence on electric current [1].

These disturbances can be overcome by innovating the making of the extensometer into a fiber-optic-based instrumentation system. Fiber-optic based instrumentation systems work on the principle of power loss due to macro bending. Hatta et al. in 2010 stated that fiber optic-based instrumentation has good sensitivity because it can detect small shifts and deformations [2]. Optical fiber has

advantages besides being light, has a large conductivity/bandwidth, does not rust easily and is oxidized and does not cause sparks [3].

Internet-based data transmission systems can be used with IoT (Internet of Things) systems. IoT is a concept where a device or sensor can be connected to the internet [5]. IoT has the ability to transfer data over the network; this system can be applied to send ground shift data so that the early warning system of ground shifting hazards can function properly. IoT can be used as a means of communication to send information to the public that can be accessed through websites and mobile-based applications [6]. IoT works by utilizing a programming algorithm that generates arguments where each argument command produces an interaction between other connected devices automatically at any distance. The internet is a medium that connects the two interactions of these devices, while the human role only serves as a regulator and supervisor of the work of the tool directly [7].

Faizah et al. carried out development in 2012 of an optical fiber-based extensometer system as a ground shift detection sensor [8]. A mechanical sensor system represents soil displacement as the pressure on optical fiber bending, so that the sensor working range is 10-40 mm with a sensor power sensitivity of  $0.67 \pm 0.02$  dB / mm. Bayuwati et al. in 2017,

designed an extensometer based on the effect of macro bending on optical fibers using a diode laser light source at a wavelength ( $\lambda$ ) = 1300 nm and a single-mode optical fiber along 50 m [9]. The results showed that the optical extensometer has a displacement measurement range of 0-25 mm with an output voltage sensitivity of 0.014 Volt / mm. Meanwhile, Wang et al. in 2017, innovated a landslide early warning system technology from fiber optic-based energy demodulation (FOS-LW for short) [10]. This landslide early warning uses optical fibers made of silica and takes advantage of the output power loss from optical fibers. Optical fiber is shaped like a spiral, and the transmission of observational data is carried out wirelessly. The results of the observations concluded that optical fibers could be used to detect and monitor ground movement as an early warning of ground motion / (landslides).

In 2016, Sandi et al. said that one of the efforts to overcome landslides, according to him, was to build an early detection system including the manufacture of detection and monitoring tools for soil movement and an information system for early detection of landslide hazards [11]. Sandi et al. have made a simple soil motion detector. In the form of soil moisture and ultrasonic sensor, so in this study, a ground shift detection sensor was made using optical fibers to monitoring using the IoT system.

Previous research was carried out until the characterization stage had a small measurement range and was not equipped with good data transmission. So, in this study, a ground shift monitoring and early warning system was designed using a fiber optic sensor system equipped with an IoT-based data transmission system. The benefit of this research is that it is used as a tool for monitoring and detecting land shifts in disaster mitigation. The optical fiber used is the FD-620-10 step-index multimode type with a larger core so that it is easier to handle and can use a light source such as an LED (Light-emitting diode) [12]. The measurement data is transmitted using the Arduino ethernet shield and displayed on a website page. Land shift hazard notification is sent via e-mail and can be accessed on a web browser or via an e-mail application on an android smartphone.

## II. METHOD

The research was conducted at the Electronics and Instrumentation Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, Andalas University.

### A. Tools and Materials

The tools and materials used to make the ground shift sensor circuit as a whole are the measuring instruments

consisting of the Arduino UNO which functions to control the system, the Arduino Ethernet Shield functions as a hardware connector to the server with the help of cables, the RJ-45 cable is used as a connecting cable between the Arduino Ethernet Shield with servers, laser diodes are used as light sources, OPT 101 functions as a sensor system to detect light coming out of the fiber optic cable, computers are used to write and run programs that will be embedded in the Arduino Uno R3 as well as database storage of research results, the multimeter serves to measuring voltage, resistance, and electric current, adapters are used to make the power supply as input voltage, solder is used to melt the lead when attaching components to the printed circuit board (PCB), rulers or meters are used as measuring tools for reference and comparison, buzzers are used as tools in a ground shift controller, Android smartphones are used to display data output, the FD620-10 fiber optic cable is used as a light wave guide, resistor, serves as a barrier to flowing currents (inhibits electric current), capacitors function as electricity storage and also as a frequency filter, Parallon pipes are used for the manufacture of artificial rain systems, boards are used for making artificial slopes, and the ruler is used as a measuring tool for comparison of sensor output.

### B. System Block Diagram Design

To design a fiber optic sensor system for monitoring and early warning of ground shift based on IoT, in general, requires a system. There are three parts to the system, namely the input, process, and output parts. The block diagram of the system can be seen in Figure 1. The input block is a fiber optic sensor system that functions to measure the amount of ground shift. The sensor system consists of a laser diode as a light source, fiber optic cable as a light waveguide, and OPT 101 as a light photodetector that can convert the intensity of light coming out of the fiber optic cable into voltage. The process block part consists of the Arduino Uno R3 microcontroller as a sensor output data processor.

The Arduino ethernet shield acts as a publisher to send measurement data that has been processed by the microcontroller to the web server via the internet, and a PC / personal computer functions to write and run programs to be implanted. On Arduino Uno R3 and research database storage (local server). Localhost is a web server that sends measurement data via the internet network. In the output block is a web browser to display measurement data and land shift hazard notifications sent via e-mail, which can be accessed via the Android Smartphone application.

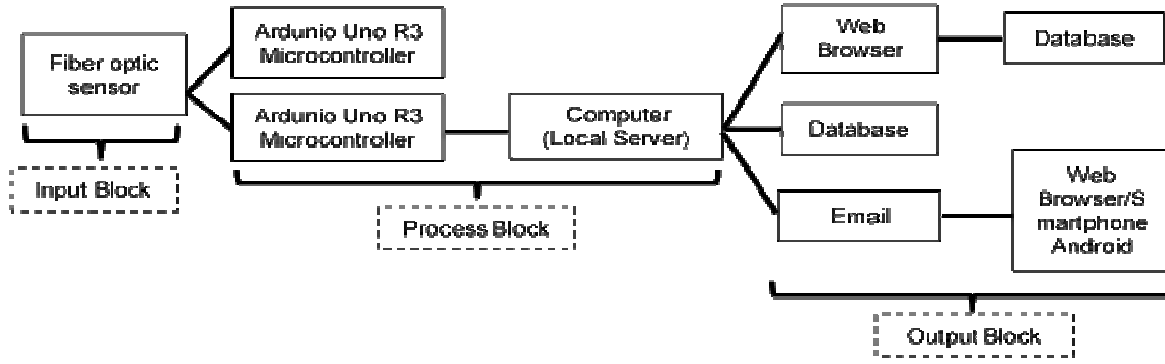


Fig. 1. Block diagram of the ground shift monitoring system

### C. Characterization of Fiber Optic Sensor Systems

Sensor characterization aims to determine whether the sensor follows the characteristics of the theory and to determine whether the sensor can function properly. The characterization of the optical fiber sensor system is carried out by varying the distance/diameter of the optical fiber curvature. From these variations, the output voltage value will be obtained. The change in the distance caused by the tensile force from the ground will result in amplified output stress. The voltage is then converted into the ADC value. A comparison between the ADC value and the distance will obtain a transfer function, which is used as an input program to determine the distance to land displacement. The transfer function will be inserted into the ATmega328 microcontroller program to produce an output in the form of an alarm sound from the buzzer, and the amount of ground shift displayed on the web browser and notifications sent via e-mail.

### D. Schematic Design of Overall Tool Physical Form

Figure 2 shows the physical design of using a fiber-optic sensor system as a ground shift sensor applied to laboratory-scale artificial slopes with dimensions of 1.5 meters long, 1 meter wide, 0.5 meters high, and a slope of 45°. The sensor system consists of optical fiber components, laser diode, photodetector OPT101, Arduino Uno R3, Arduino Ethernet Shield, and signal conditioners are arranged in one place on a fixed slope as shown in Figure 2. The sensor system is connected to a withdrawal mechanism (ball) implanted into the ground slip plane in the initial position x1.

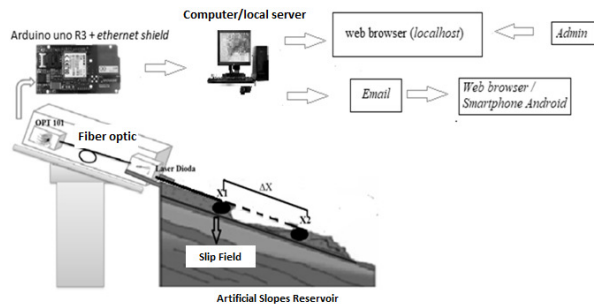


Fig. 2. Physical design of the ground shift sensor system

If the weight of the soil pushes the ball pulling mechanism so that the ball moves to the x2 position, then

the diameter of the optical fiber curve will decrease in this case, indicating that the ground displacement is ( $\Delta X$ ). The ground displacement is the change in the curvature of the optical fiber, which is  $\Delta x = \pi (d1-d2)$  where d1 is the diameter of the initial curve of the optical fiber, and d2 is the diameter of the curve of the optical fiber after the withdrawal occurs. When the optical fiber curve decreases, the indicator light will turn on according to the ground shift distance that has been programmed. This indicator light serves to provide early warning before any ground shifting hazard occurs when the maximum shift distance causes the alarm to work through the buzzer. The ground shift distance consists of three levels, namely the "alert" level if the displacement size is  $\geq 3$  cm, the "alert" level if the displacement distance is  $\geq 5$  cm, and the "alert" level if the shift distance is  $\geq 10$  cm [10]. The ground displacement distance measured by the designed tool will be compared with a standard measuring instrument, namely a ruler. E-mail notifications will be sent automatically at a shift distance of  $\geq 5$  cm with the text "Waspada longsor" and at a shift distance of  $\geq 10$  cm with the text "Awat longsor". This notification e-mail will be sent automatically to the observer's e-mail address that has been registered with the program.

### E. Overall Tool Testing and Data Analysis

Testing the ground shift measurement system begins with testing the voltage source, the Arduino Uno microcontroller, and the Arduino Ethernet shield. The fiber optic sensor system was characterized. The tool was tested with a comparison tool in the form of a ruler. The instruments were measured that have been turned on are tested, so that the output data from the measuring instrument will be displayed on the website in the form of ground shift values, sensor output voltage, ground shift hazard status, and observation time. The measurement system in this study has data analysis techniques to determine the level of accuracy and error in the measurement system. The percentage of error can be determined by Equation 1.

$$e_n = \frac{1}{n} \sum \left| \frac{Y_n - Y_0}{Y_n} \right| \times 100\% \quad (1)$$

$e_n$  is the percentage of error, n is the amount of data retrieved,  $Y_n$  is the true value, and  $Y_0$  is the value read on

the measuring instrument. The percentage of measurement accuracy of  $A_n$  can be determined through Equation 2

$$A_n = 1 - \frac{1}{n} \sum \left| \frac{Y_n - \bar{Y}}{\bar{Y}} \right| \times 100\% \quad (2)$$

### III. RESULTS AND DISCUSSION

The design of a fiber optic sensor system application for monitoring and early warning of IoT-based ground shifts has been carried out in stages, accompanied by testing or characterization. Testing is done both on hardware and software. This test aims to determine whether the system is designed to function properly or not with an analysis for each result under the theoretical basis concerned.

The ground shift monitoring and early warning system is divided into three system blocks. The input block consisting of a diode laser as a light source, FD 620-10step-index-multimode fiber optic cable, which is used to detect ground displacement, and OPT 101 is used as a light detector, and output from the optical fiber. The process block part consists of the Arduino Uno R3 microcontroller as a data processing processor, the Arduino Ethernet shield as a data link for the Arduino Uno R3 to the internet network, a computer, and a localhost web server as a ground shift data viewer. The output block consists of web browser and an Android Smartphone.

#### A. Shifting Characterization of Output Voltage of Fiber Optic Sensor System

Measurements were made ten times to obtain accurate results. Figure 4 shows the relationship between the average output voltage produced by OPT 101 and the variation in the reduction in the curvature of the optical fiber.

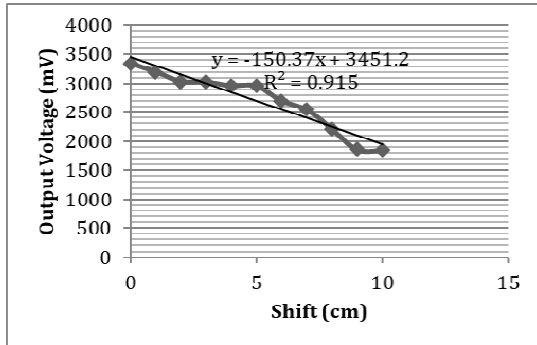


Fig. 3. Graph of the effect of curvature drawing on the output voltage of the fiber optic sensor

The transfer function in Figure 3 shows a linear relationship between the pulling/shifting of optical fibers; from the transfer function, the sensor sensitivity value is 150.3 mV/cm and a good degree of linear correlation, namely  $R^2 = 0.915$ . Based on Figure 3, it can be seen that there is a decrease in the output voltage when the drawdown is greater. The smaller the diameter of the optical fiber curve, the smaller the sensor output voltage. This event is caused because part of the light is transmitted out of the optical fiber core, which is called the power loss in the curved part of the optical fiber [13]. According to Silvestre in 2017, the smaller the radius of curvature, the

value is closer to the refractive index value of the sheath/cladding so that more light comes out of the fiber core or the greater the power loss [14]. This power loss is used as a ground shift sensor.

#### B. Testing Fiber Optic Sensor System as Ground Shift Sensor

The amount of ground shift on the sensor can be seen from the reduction in the diameter of the optical fiber curvature. Sensor testing is done to see the accuracy of the sensor system that has been designed. The test is carried out by comparing the results of measuring the curvature diameter of the optical fiber produced by the optical fiber sensor system with the results of measuring the curvature of the optical fiber using a comparison tool in the form of a ruler. Comparison data of shifts using a fiber optic sensor system and a ruler can be seen in Table 1.

TABLE I  
DATA OF SENSOR MEASUREMENT AND COMPARISON TOOLS

No	Tool readable shift (cm)	Shift read by comparator (cm)	Percentage of error (%)
1	1.07	1	7
2	2.09	2	4.5
3	3.03	3	1
4	4.03	4	0.75
5	5.03	5	0.6
6	6.02	6	0.33
7	7.02	7	0.29
8	8.02	8	0.25
9	9.04	9	0.44
10	10.01	10	0.1
Average percentage of error (%)			1.53

Table 1 shows the test results of the fiber optic sensor system as a ground shift sensor. Testing is done by comparing the shift value measured by the optical fiber sensor system with the measured shift using a comparator in the form of a ruler. The test results of these measurements, using equation 1 and equation 2, obtained an average error percentage of 1.53% with an average measurement accuracy of 98.47%. Based on the data obtained, it can be concluded that the designed fiber optic sensor system has been successfully implemented even though there are still differences in data with comparison tools.

#### C. Overall Tool Testing

Testing the overall tool design includes combining hardware and software on laboratory scale artificial slopes shown in Figure 4. Tests are carried out to determine the workability of each block when used simultaneously. The ground shift sensor system is operated using a voltage source from PLN by using an adapter and input voltage for the device, namely 5 V. The input block consists of a light source in the form of a diode laser, a fiber optic cable as a waveguide, and an OPT 101 photodetector. From Arduino UNO R3, Arduino Ethernet Shield, and computers. Meanwhile, the output block is a display of data that has been processed in the process block. The measurement data of the land shift sensor system will be displayed on a website page, while the ground shift early warning

notification will be sent via e-mail that has been registered in advance to the program.

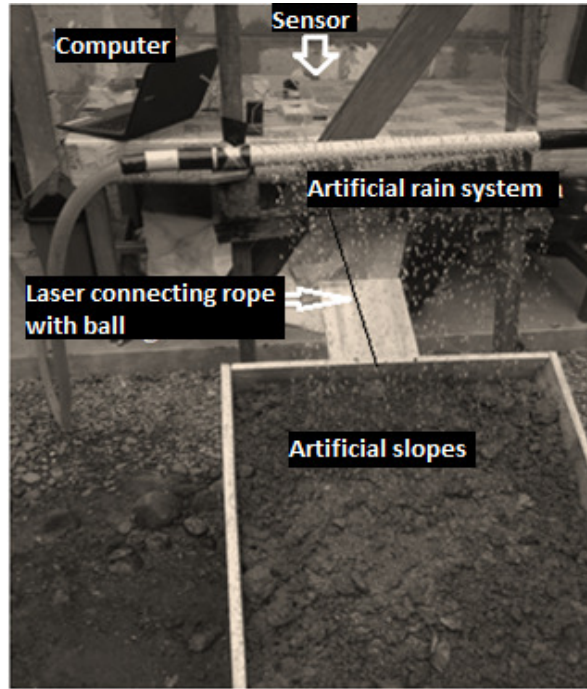


Fig 4. Testing the whole tool

Soil displacement occurs when the slope has been given artificial rain, so the soil tends to move downward, putting pressure on the towing ball. Simultaneously with the pulling of the towing ball, causing the connecting rope to be pulled together, so does the optical fiber. The diameter of the optical fiber curve decreases according to the amount of ground displacement that occurs. Reduction of the circumference and curvature of the optical fiber results in a decrease in light intensity caused by bending changes that occur in the optical fiber. Changes in light intensity will be detected by the OPT 101 photodetector, which changes the physical quantity in the form of light intensity into an electrical quantity in the form of the output voltage. The output voltage from the photodetector is then read through pin A0 on the Arduino UNO. The output voltage from pin A0 is read through the ADC data, which is then programmed using the transfer function obtained by characterizing the effect of reducing the curvature of the optical fiber on the output voltage. The transfer function is used as an output voltage converter that reads the shift value using the Arduino UNO programming. Arduino UNO data programming requires a digital signal that is high and low as input data. The resulting output voltage will be processed into a ground shift value which will be sent to the output block via the Arduino Ethernet shield to the internet network. The displacement value will be displayed on a website page and an e-mail notification of early warning of land shift on the registered observer's e-mail. The overall results of the tool testing can be seen in Table 2.

TABLE II  
WHOLE TESTING THE TOOL

No	Shift (cm)	Website Condition	Posting Condition (status)	Buzzer Condition	E-mail Condition
1	1	Data sent	Secure	off	No e-mail
2	2	Data sent	Secure	off	No e-mail
3	3	Data sent	Standby	off	No e-mail
4	4	Data sent	Standby	off	No e-mail
5	5	Data sent	Alert	off	Sent
6	6	Data sent	Alert	off	Sent
7	7	Data sent	Alert	off	Sent
8	8	Data sent	Alert	off	Sent
9	9	Data sent	Alert	off	Sent
10	10	Data sent	Watch out	On	Sent

Table 2 displays the results of the overall tool testing. The results of testing the tool as a whole show that the entire system can work well. When a 1-2 cm shift, the data is sent to the website with a "safe" status and a shift of  $\geq 3$  and  $< 5$  cm, the data is sent to the website with a "standby" status with no e-mail notification of ground shift early warning. Shifts of  $\geq 5$  and  $< 10$  cm, the data is sent to the website with the status of "alert" and e-mail notification of ground shift early warning contains the text "landslide alert". Shift  $\geq 10$  cm, the data is sent to the website with the status of "alert" and the e-mail notification contains the text "Awat Longsor". When the shift condition is  $\geq 10$  cm the buzzer is active and sounds. The data display on the website page can be seen in Figure 5. The data consists of five columns. The first column is the serial number of the data, the second column is the amount of ground shift, the third column is the amount of the sensor output voltage, the fourth column is the status of the ground shift value, and the fifth column is the time of observation.

No	Pergeseran Tanah(cm)	Tegangan (mV)	Status	Waktu
1	2.21	3201.37	aman	2020-01-20 03:57:35
2	5.06	2727.27	waspada	2020-01-20 03:57:41
3	5.29	2688.17	waspada	2020-01-20 03:58:12
4	4.85	2761.49	siaga	2020-01-20 03:58:18
5	2.89	3088.95	aman	2020-01-20 03:58:39
6	4.47	2625.02	siaga	2020-01-20 03:59:01
7	1.06	3059.63	siaga	2020-01-20 03:59:22
8	4.5	2820.14	siaga	2020-01-20 03:59:43
9	3.91	2917.89	siaga	2020-01-20 04:00:04
10	3.53	2981.43	siaga	2020-01-20 04:00:30
11	2.77	3108.5	aman	2020-01-20 04:00:47
12	3.38	3005.86	aman	2020-01-20 04:01:06
13	3.84	2913	aman	2020-01-20 04:01:29
14	2.92	3084.07	aman	2020-01-20 04:01:51
15	4.68	2790.81	siaga	2020-01-20 04:02:12
16	2.83	3068.73	aman	2020-01-20 04:02:33
17	2.56	3142.72	aman	2020-01-20 04:02:54

Fig 5. Display data on website pages

The overall test results show that the ground shift sensor is working as expected, namely taking land shift measurements, sending the measurement results using the internet network to the computer as a monitoring medium. The advantages obtained from this system are similar to the research of Priyanto et al. In 2015, where this tool has the ability to send data using the GSM network [15]. This research used data transmission to the server using the



Arduino Ethernet Shield, and data display using Localhost, which is a web server. It could display measurement data and an early warning notification of ground shifting hazards sent via e-mail, where it works the same as using a GSM network. An E-mail notification of ground shift early warning can be seen in Figure 6.

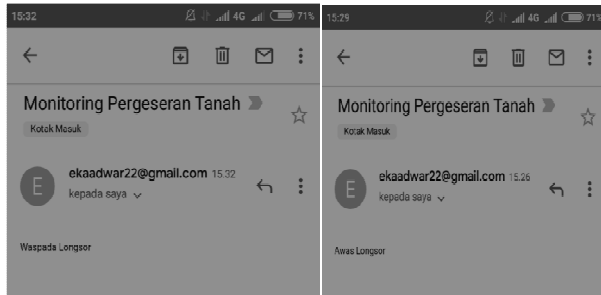


Fig 6 Display of e-mail notification of ground shift early warning, (a) land shift  $\geq 5$  cm and (b) soil shift  $\geq 10$  cm.

#### IV. CONCLUSION

Based on the tests and analyzes that have been carried out, it can be concluded that the results of designing a fiber optic sensor system as a ground shift sensor can detect soil displacement with a sensitivity of 150.3 mVolt / cm degree of linear correlation  $R^2 = 0.915$ . The smaller the curved diameter of the optical fiber, the smaller the output voltage produced by the photodetector. The results of the design of the ground shift monitoring system on optical fiber with a comparison tool have an average error of 1.53% and an accuracy of 96.4% measurement. The results of real-time ground shift measurements based on IoT have worked well, which are displayed on the website page, and ground shift early warning notifications are sent via e-mail

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