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Development of groundwater level sensor for internet of things-based peatland fire monitoring

Abdul Muid[1,2], Nina Siti Aminah[1], Maman Budiman[1], Mitra Djamal[1]
[1]Department of Physics, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Bandung, Indonesia
[2]Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Tanjungpura, Pontianak, Indonesia

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ABSTRACT

Monitoring groundwater levels in peatlands is crucial for mitigating forest and land fires, which frequently occur in tropical regions. Current peatland groundwater level monitoring systems generally have limitations in their sensing range. Additionally, the lack of electricity and internet infrastructure around the monitoring sites presents another challenge. To address these issues, in this study, we developed a groundwater level sensor based on a float integrated with an optocoupler as a rotary encoder to monitor changes in water levels in real-time. The system is connected to an internet of things (IoT) platform through a LoRa communication module, powered by solar panels, enabling continuous wireless data transmission over a large range. To overcome the sensing range limitation, we developed a rotary encoder with a pulley driven by a long rope. Testing was conducted using transparent pipes with varying water levels to evaluate the sensor's performance. Experimental results showed that the sensor could measure water levels with a resolution of ±3.33 mm. This research provides a technique for measuring groundwater levels with an extended measurement range. Additionally, it produces a peatland fire risk monitoring system based on groundwater level parameters. It is expected can support peatland fire mitigation efforts more efficiently and effectively.

Corresponding Author:

Mitra Djamal
Department of Physics, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung
Bandung 40132, Jawa Barat, Indonesia
Email: mitra@itb.ac.id

1. INTRODUCTION

The susceptibility of peatlands to fires increases as groundwater levels drop [1]. When the groundwater level falls to 40 cm, the land becomes dry and degraded [2], [3]. The risk of land fires is significantly correlated with soil moisture [4], [5]. Accurate forecasting of groundwater level (GWL) is essential for effective management of this vital resource, but it remains a complex and challenging task [6]. An approach for classifying ground information in wildfire-affected areas using an improved UNet model has been undertaken [7]. To prevent peatland fires, it is essential to develop a groundwater level sensor to monitor the GWL of peatlands [8]. A large sensing range, real-time measurement, continuous, and energy harvesting capabilities are required to meet the specifications for a peatland groundwater level sensor [9]. To achieve this, we conducted a comparative analysis of existing methods for groundwater level measurement. The main novelty of our research lies in the development of a low-cost, float-based groundwater level sensor integrated with an optocoupler-based rotary encoder, which enables accurate and continuous measurement of groundwater levels over a large sensing range. Unlike conventional water level sensors such as pressure transducers, ultrasonic, or capacitive sensors—which often face limitations in peatland environments due to soft soil, unstable platforms, or water contamination—our proposed design is mechanically robust and environmentally adaptable.

Groundwater level measurement techniques can be divided into two main categories: direct contact and non-direct contact [10], [11]. Non-contact techniques are becoming an alternative to monitoring groundwater levels in hazardous places. However, non-contact techniques are limited on accurate and more expensive [12]. Radar, ultrasonic, image/video, and infrared sensors can be selected for non-contact type. While the contact measurement systems often provide simpler and more cost-effective measurement. Float, capacitance, pressure and fiber optic can be selected for contact type measurement [13]. Marick *et al*. [14] propose a technique for measuring groundwater level using a float sensor with a modified differential inductance electromechanical transducer, demonstrating linear characteristics. However, the design's range is limited to 25 cm. To measure changing groundwater levels in an unstable flow, Majdalani *et al*. [15] suggested using a float with an infrared sensor. This method can accurately measure groundwater levels from 0 to 3 cm with 1 mm precision, but the device is still laboratory-scale [15]. Zheng *et al*. [16] shows that groundwater levels can be measured using the gauge combines an electric DC motor. However, the device cannot measure groundwater levels continuously [16]. Therefore, we used a float integrated with an optocoupler. This is a new approach to measuring groundwater levels, as current methods are constrained by the sensing range that can be measured. On the other hand, the pressure method measures up to 0.4 m [17], and the capacitive method measures up to 0.3 m [18].

In recent years, internet of things (IoT) technology advancements have led to more efficient and innovative groundwater-level monitoring solutions [19]-[21]. Bhardwaj *et al*. [22] introduces a real-time framework based on the IoT for monitoring groundwater and issuing alerts to prompt actions, constituting the initial phase of the proposed project. In this research, we chose a contact technique because contact measurement systems are much less susceptible to environmental disturbances compared to non-contact measurements. A few researchers focused non-contact techniques and not IoT-based. There have been limited studies concerned on sensing range, real-time and continuous measurement. Therefore, this research intends to use a float integrated with an optocoupler as a new method to measuring groundwater levels in peatlands. The objectives of this research are proposed development of groundwater level sensor for internet of things-based peatland fire monitoring. This method has the potential to be a large-range groundwater level measurement technique. In addition, the system is equipped with a solar panel, a low-power and long-range data processing and transmission device, and a data processing algorithm to classify the level of peatland fire vulnerability. It is hypothesized that this system can continuously monitor peatland groundwater levels in real-time and provide warnings of peatland fire hazards.

2. METHOD

2.1. Materials

The materials for building the groundwater level sensor are available in Table 1. A new electronic board was designed for the transmitter and receiver device. It integrates the groundwater level sensing part, microcontroller, LoRa, and Wi-Fi communication on a single board to optimize size. It consists of four blocks, namely:

i) Sensing unit: comprises mechanical and electronic components, including a float, optocoupler, and microcontroller, which function collectively to detect variations in water level.
ii) Processing unit: incorporates a programmable microcontroller embedded with dedicated firmware to facilitate sensing operations and data transmission via the LoRa communication protocol.
iii) Communication unit: responsible for managing data transmission between the sensor node and the LoRa gateway, utilizing the standardized LoRa protocol to ensure reliable long-range communication.
iv) Power unit: utilizes a rechargeable battery with a capacity of 3500 mAh and an operating voltage range of 2.85 V to 4.2 V to supply power to the entire system.

2.2. Rotary encoder design based on float and optocoupler

The system consists of a mechanical float, a pulley mechanism, a rotary encoder disk, and an optocoupler sensor. The float, made from a sealed plastic bottle (100 mm in length and 50 mm in diameter), is chosen for its buoyancy and lightweight properties, allowing it to rise and fall in response to changing water levels. In this study, a groundwater level sensor was designed using a float mechanism integrated with an optocoupler to create a rotary encoder. The system operates by detecting the vertical movement of the float, which corresponds to changes in groundwater level. The float is attached to a nylon thread that is wound over a pulley, which is mechanically connected to a rotating disk mounted on the shaft of the encoder system. As the water level changes, the float moves vertically, causing rotational movement of the disk. As the float moves, the rotary encoder converts the motion into digital signals, allowing for accurate measurement of water level fluctuations. Figure 1 shows the block diagram of the groundwater level sensor. The groundwater level sensor consists of two main parts: the mechanical and electronic components, such as floats, pulley, disc, optocoupler module, microcontroller module, and transmitter module.

Table 1. Materials required

Materials	Specification	Range of operation
Float	Plastic bottle	100 mm in length, 50 mm in diameter
Disc	Plastic plates	45 mm in diameter
Optocoupler	Rotary encoder photoelectric HC-020K	Supply voltage 4.0–5.5 V Current (IR LED) < 20 mA Signal output TT (0–5 V)
Transmitter	STM32L052C8T6+SX1276 LoRa	Supply voltage 1.8 V–3.6 V Ambient temp –40 °C to +85 °C LoRa data rates 0.018–37.5 kbps Typical range 1–10 km urban, 10–15 km rural
Receiver	SX1276 LoRa + ESP32 Gateway	Supply voltage 3.0–3.6 V Operating temp –40 °C to +85 °C Wi-Fi range up to 300 m
Server	Raspberry Pi 4 Model B	Input voltage 5 V ± 5% Operating temperature 0 °C to 50 °C Wi-Fi 2.4 GHz range ~30–150 m
Solar panel	350 mm x 255 mm x 17 mm, 10 W	Rated power 10 W Voltage (Vmp) ~17–18 V Operating temperature –40 °C to +85 °C
Battery	18650, 3500 mAh	Nominal voltage 3.6–3.7 V Full charge voltage 4.2 V Charging temp range 0 °C to +45 °C

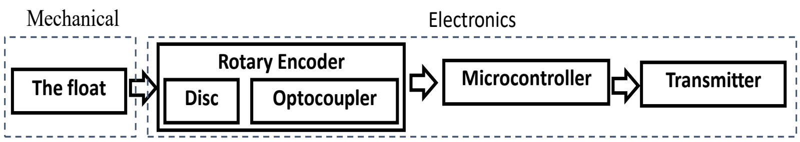


Figure 1. The block diagram of the groundwater level sensor

The rotary encoder used in this system leverages the rotation of a float connected to a rotating shaft. The optocoupler is positioned to detect the changes in shaft position by reading the rotational pattern. Each change in the float's position, driven by fluctuations in water level, generates a signal from the optocoupler, which is then transmitted to the microcontroller for processing. This rotational motion is detected by an optocoupler (photo-interrupter), which reads a series of alternating transparent and opaque segments (slots) on the encoder disk. Each slot corresponds to a specific angular displacement, which is then converted into a digital pulse. These pulses are counted by a microcontroller (STM32L052C8T6) to determine the amount of rotation and, hence, the change in water level.

The mechanical design details are illustrated schematically in Figure 2. The float and weight are connected by the rope. The length of the rope is adjusted to fit the sensing range. The dimensions of the float, weight, pulley, disc, and rotary axis are adjusted to match the field conditions. The pulleys and discs are attached to the rotary axis in order to facilitate their simultaneous rotation. The hollow disc is positioned within the gap between the optocouplers. The float is in contact with groundwater. The weight pulls the rope, and the disk rotates in response to changes in the groundwater level.

In this research, two optocouplers are employed, resulting in two outputs, "A" and "B." The distance between the optocouplers is determined to ensure that output "A" is 90° out of phase with output "B." To determine the direction of rotation, it is necessary to examine which output leads the other. If the pulse from output A is -90° out of phase with B (i.e. output B leads A), the sensor will rotate clockwise. Conversely, if output A is +90° out of phase with B (i.e. output A leads B), the sensor will rotate counter-clockwise. The number of rotations is determined by calculating the number of pulses, which is then converted into groundwater level. To improve measurement accuracy, we calibrated the system by correlating the number of encoder pulses to vertical displacement using a known conversion factor derived from the disk’s circumference and the number of slots. This enables the system to translate rotational data into precise linear water level measurements.

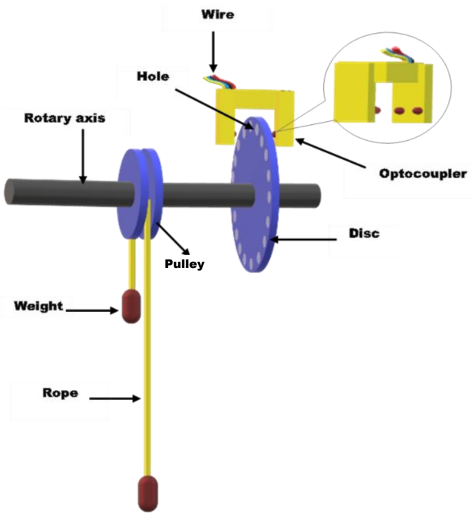


Figure 2. Design of the groundwater level sensor

2.3. Design of groundwater level measurement

A plastic bottle float sized 100 mm in length and 50 mm in diameter is used to maintain an upright position when submerged. The float is partially filled with groundwater to provide buoyancy. One end of the float is attached to a rope connected to a pulley, while the other is connected to a weight. The weight ensures that the string remains taut at all times. The mass of the float is designed to be greater than that of the weight to ensure that the float remains in contact with the groundwater surface. By filling the float with groundwater up to 75% of its volume, the pulley and its axis rotate clockwise and counterclockwise as the groundwater level rises and falls. A perforated disk is mounted on this axis and rotates with the pulley. As the water level rises, the float rises too, pulling the rope and making the pulley and disk turn. If the groundwater level goes down, the float will pull the string down, making the pulley and disk to rotate in the opposite direction.

Figure 3 illustrates the design of the electronic and mechanical circuit for the groundwater level sensor. The sensor circuit is mounted on a pipe with a diameter of 3 inches and a length of 4 meters. The middle and bottom parts of the pipe are perforated to allow groundwater to enter, while the top end is sealed to protect the mechanical and electronic components. The optocoupler is connected to a microcontroller, which is then connected to an LCD for displaying measurement results. In this research, sensor data transmission over long distances is achieved using LoRa (long range) modules. The reason for employing LoRa modules is their low-power consumption, long range, and low cost [23], [24].

The experimental procedures, especially the simulation of water level fluctuations, calibration processes, and how the sensing range was as follows:

i) Simulation of water level fluctuations

To simulate real water level variations under controlled conditions, we used a vertical transparent tube water column with a height of 3.5 meters. The float sensor system was installed within this column, and water levels were adjusted incrementally (e.g., 10 cm per step) by adding or removing water using a graduated container. The float's vertical movement generated corresponding rotational motion, which was recorded by the optocoupler-based rotary encoder.

ii) Calibration process

Calibration was performed by measuring the number of encoder pulses generated for each known water level increment. We established a linear relationship between pulse count and water level height. For example, if the encoder disk had 20 slots and one full rotation corresponded to 40 pulses, each pulse represented approximately 3 mm. This calibration factor was stored in the microcontroller for real-time conversion of pulses to water level measurements.

iii) Evaluation of sensing range

To determine the maximum sensing range, we tested the system with varying water heights from 0 cm up to the full depth of the test column (350 cm). The float mechanism successfully tracked water levels across this full range, demonstrating its suitability for groundwater table monitoring. The design is scalable for deeper applications, depending on the length of the thread and the float chamber depth in field deployment.

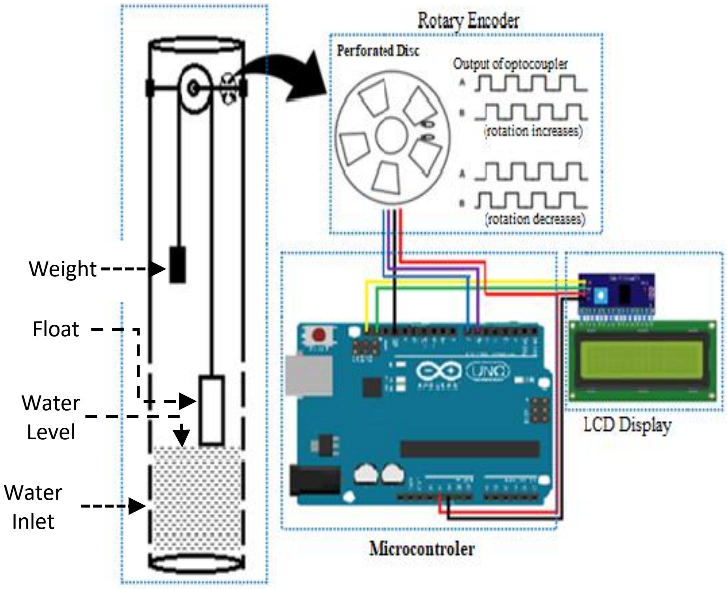


Figure 3. Mechanical and electronic circuit connections

2.4. Design of communication system

Once the water level data is processed, the microcontroller transmits this data using a LoRa communication module to a designated data center or IoT platform. LoRa was chosen for its capability to transmit data over long distances with low power consumption, making it suitable for monitoring wide and remote peatland areas. The received data on the IoT platform is then visualized in graphical form and analyzed to monitor real-time changes in groundwater levels.

This study presents the design of a communication system between the sensor node and the gateway, as well as between the gateway and the IoT device. The sensor node is composed of the STM32L052C8T6 microcontroller module, SX1276RF96 LoRa module, and optocoupler including mechanical part. The gateway receives groundwater level sensor data using the LoRa protocol and transmits the data to the server using the message queuing telemetry transport (MQTT) protocol. The Raspberry Pi 4B is used as the server and is embedded with IoT supporting application software such as InfluxDB, Node-RED, and Grafana. It serves as a local server for storing, processing, handling, and displaying the database. Figure 4 depicts the network scheme of the IoT technique in this study.

The station involves a gateway, a local server, and a Wi-Fi router module. The Wi-Fi router acts as a bridge between the local server and users via the internet network. The user refers to the devices that users use to access data through internet browsing applications. This research employs InfluxDB and Node-Red applications for data storage. The groundwater level sensor provides the data, which is transmitted to the Raspberry Pi device via MQTT and processed in Node-Red. The data is then converted into JavaScript Object Notation (JSON) format and stored in the InfluxDB database. Each transmitter and receiver has unique JSON data with distinct values for geohash metadata that indicate their location.

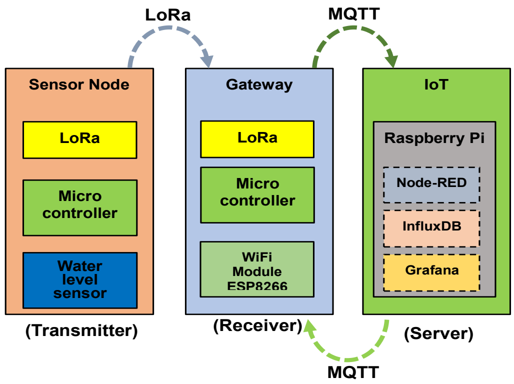


Figure 4. Block diagram of IoT scheme

Figure 5 illustrates the groundwater level monitoring system algorithm. The algorithm starts by requesting groundwater level data from the InfluxDB database. The obtained groundwater level values are then checked, and decisions are made based on them. The data is categorized into two groups: "Danger" if the groundwater level exceeds 400 mm and "Safe" if the groundwater level is less than or equal to 400 mm. The groundwater level is presented through numerical values, graphs, and colors. Green indicates a level of 400 mm or less, signifying safety, while red is used for level exceeding 400 mm, indicating danger. The monitoring system dashboard also displays a map of the peatland area with the sensor placements.

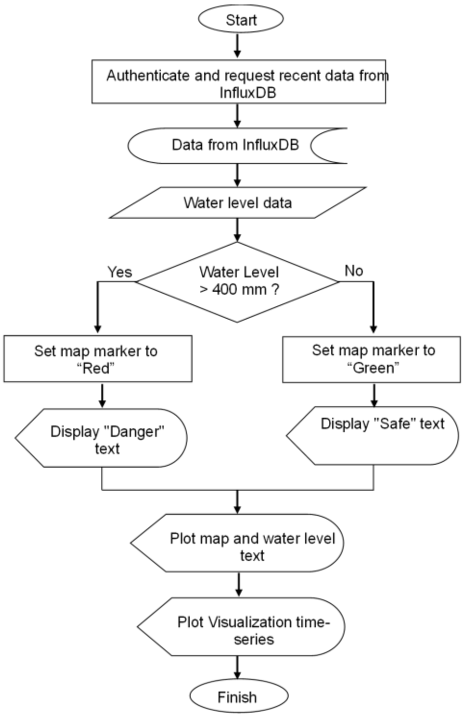
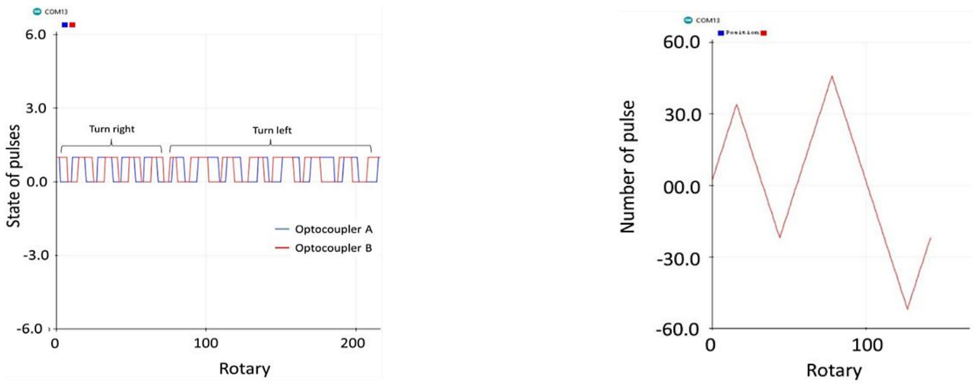


Figure 5. Groundwater level monitoring system algorithm in the Grafana application

3. RESULTS AND DISCUSSION

3.1. Evaluation of rotary encoder performance

Experiments have been conducted to evaluate the performance of the rotary encoder. We did two different simulations. The first simulation rotated the disc in a clockwise direction, while the second simulation rotated the disc in a counterclockwise direction. During the simulation, the behavior of the rotary encoder is analyzed. The simulation results are given in Figure 6. The first simulation was to examine the optocoupler program code in terms of pulse waves. The resulting data provided insight into the state of the pulse as a function of disc rotation direction. Data obtained from the experiments showed that the direction of the rotary encoder's disk affects the phase of the square wave produced by the optocoupler. Figure 6(a) depicts the serial monitor display observed on the Arduino IDE dashboard. The results indicate that the rotary encoder generates a square wave. The experiments showed that the direction of the rotary encoder's disk affects the phase of the square wave produced by the optocoupler. When the disc rotates to the right (clockwise), the square wave exhibits a gradual transition from low to high levels, while counterclockwise rotation results in a transition from high to low. Optocoupler A is in the '0' state while optocoupler B is in the '1' state, with a phase difference of 90°. In other words, optocoupler square wave B precedes optocoupler square wave A. If the disc is rotated to the left (counterclockwise), optocoupler wave A precedes optocoupler wave B. The second simulation aims to evaluate the rotary encoder program code in terms of pulse counting. Data was obtained on the number of pulses generated by the rotary encoder as a function of the number of disc rotations. Figure 6(b) presents a screenshot of the serial monitor display of the data plot curve, illustrating the number of pulses versus disc rotation. The simulation results show that the number of pulses generated by the rotary encoder increases if the disc is rotated clockwise and the number of pulses decreases if the disc is rotated counterclockwise. It can be interpreted that the number of pulses increases if the water level increases, and the number of pulses decreases if the water level decreases. The number of pulses is then converted into a water level value from the sensor calibration process.



(a) (b)

Figure 6. The performance of the rotary encoder: (a) optocoupler A and B produce square waves with a phase difference of 90° and (b) the number of pulses following the direction of rotation of the disk

3.2. Testing the sensor sensitivity and resolution

We conducted simulations using two discs of different sizes to test the sensor's sensitivity and resolution. The first simulation uses discs with a diameter of 45 mm, and the second simulation uses discs with a diameter of 25 mm. Figure 7 shows the simulation using the first disc. The number of holes that can be made in the first disc is 20, while the number of holes in the second disc is 11. During the simulation, the number of pulses generated by the optocoupler is observed. The results show that when using the first disc the optocoupler generates 40 pulses per rotation of the disc, while when using the second disc, it generates 22 pulses. In this study, the number of pulses is converted into a groundwater level value. Sensor sensitivity refers to the change in output (water level) per unit of input variation (number of pulses). The first simulation achieved a sensor sensitivity of 3 mm/pulse, while the second disc achieved a sensitivity of 6 mm/pulse. Groundwater level sensor resolution refers to the smallest water level difference that the sensor can detect and measure accurately. The first simulation obtained a sensor resolution of 3.33 mm, while the second simulation resulted in a sensor resolution of 6.05 mm. It was found that the number of holes in the disc affects the sensitivity and resolution of the sensor. The number of holes in the disc is determined by the diameter of the disc. In a greater disc diameter, more holes can be created, resulting in higher sensitivity and resolution compared to discs with a smaller diameter.

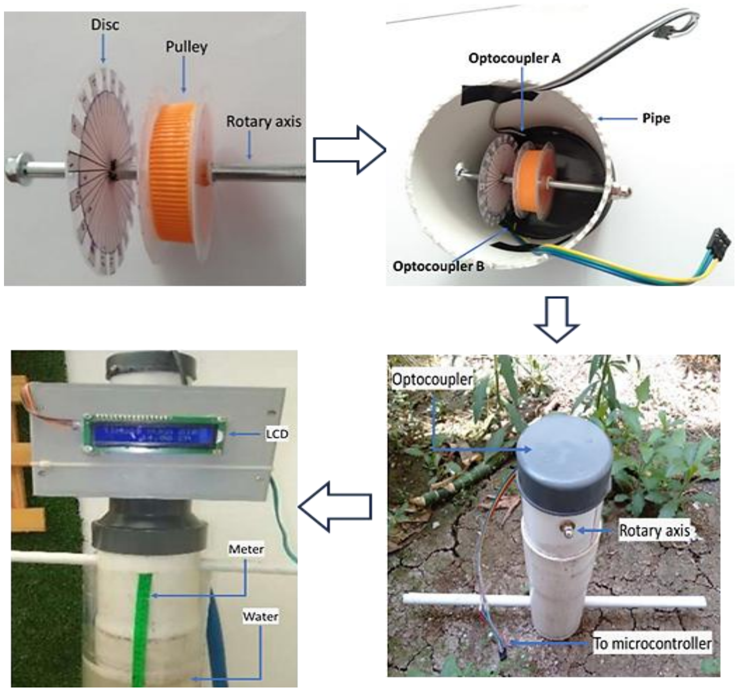


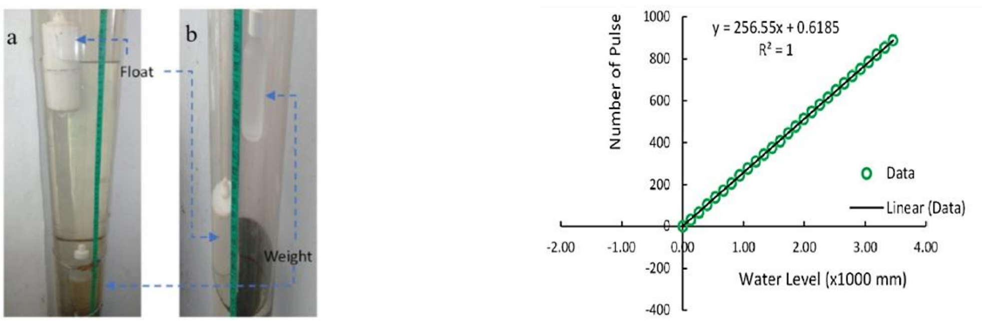
Figure 7. The realization of the mechanics part of the water level sensor

3.3. Evaluation of the sensor's sensing range

In this study, the sensing range of the proposed method was evaluated through the simulation of a water level fluctuation event using transparent pipes, as illustrated in Figure 8. We can control the fluctuation of the water level in the transparent pipe using a water pump. A meter is attached to the side of the transparent pipe to know the actual water level. We conducted the test with two different simulations. The first simulation uses an increased water scenario, and the second simulation uses reduced water. In each scenario, we used two different lengths of rope. In the first simulation, we used a rope with a length of 2 meters. While the second simulation, we used a rope with a length of 3.5 meters. Simulation results show that the maximum sensing range of the sensor reaches 2 meters when using a rope with a length of 2 meters; while using a rope with a length of 3.5 meters, the maximum sensing range reaches 3.5 meters. During the simulation, the sensor's behavior is analyzed. Based on the experiment, the relationship between water level and the number of pulses was obtained Y = 256.55X + 0.6185, where Y is the number of pulses and X is the water level. The test results indicate that the sensor has linear characteristics. The findings of the research indicate that the proposed groundwater level sensor is able to measure the groundwater level up to the length of the rope used. In other words, the maximum sensing range of the sensor is aligned with the length of the rope utilized. This capability is well-suited to meet the requirements of measuring groundwater levels in peatlands, where water depths fluctuate from shallow to deep.

The study demonstrates the interconnection of the groundwater level sensor with the STM32L052C8T6 microcontroller module and SX1276 LoRa module on the printed circuit board (PCB). Figure 9 shows the part of the IoT device. The power supply is from solar panels and is stored on batteries, as illustrated in Figure 9(a). Figure 9(b) shows part of the gateway and server. The voltage source is a regulated direct current (DC) voltage derived from an 18650 battery. The LoRa device operates at a frequency of 915 MHz.

The solar panel used has dimensions of 350 mm × 255 mm × 17 mm and can produce a maximum power output of 10 W peak under intense sunlight conditions. It has an open-circuit voltage of 21.96 V and a short-circuit current of 0.63 A. The measured output voltage of the solar panel during sunny conditions is 20.20 V. The power source is equipped with two 18650 batteries, each with a capacity of 3500 mAh and a voltage range of 2.85 V to 4.2 V, depending on the battery capacity. The TP5100 rechargeable module can be charged with a maximum current of 2 A and has an input voltage of 9 V.



(a) (b)

Figure 8. The sensing range test of the sensor: (a) the fluctuation of the water level in the transparent pipe and (b) the curve of the number of pulses as a function of water level

(a) (b)

Figure 9. Realization of IoT devices: (a) sensor node and (b) gateway and server

3.4. The groundwater level monitoring system

In this study, the Lora module was chosen as the communication network due to its ability to provide long-range, low-power wireless communication, which is essential for environmental monitoring applications in remote and infrastructure-poor areas such as peatland and forest regions. LoRa operates effectively over distances of several kilometers even in non-line-of-sight (NLoS) conditions and consumes significantly less power compared to Wi-Fi or cellular technologies, making it ideal for battery-powered IoT sensor nodes.

Additionally, LoRa's support for star network topologies and high link budget allows it to cover large areas with minimal infrastructure, which aligns with the deployment requirements of a distributed early warning system. Other wireless options such as Bluetooth and ZigBee are limited in range, while cellular communication is more power-hungry and requires paid network access, making LoRa the most cost-effective and scalable choice for the research application.

Figure 10 shows the visualization of the groundwater level monitoring system. The user interface dashboard is created using Grafana. Grafana is an open-source analytics and interactive visualization web application. The dashboard includes a map of the monitored location, with colored points indicating sensor locations and groundwater level status. Real-time clock and groundwater level values are presented on the right in both numerical and graphical formats. We compared the groundwater level value shown on the Grafana dashboard with the actual value. The average relative error of this experiment was found to be 1.67%.

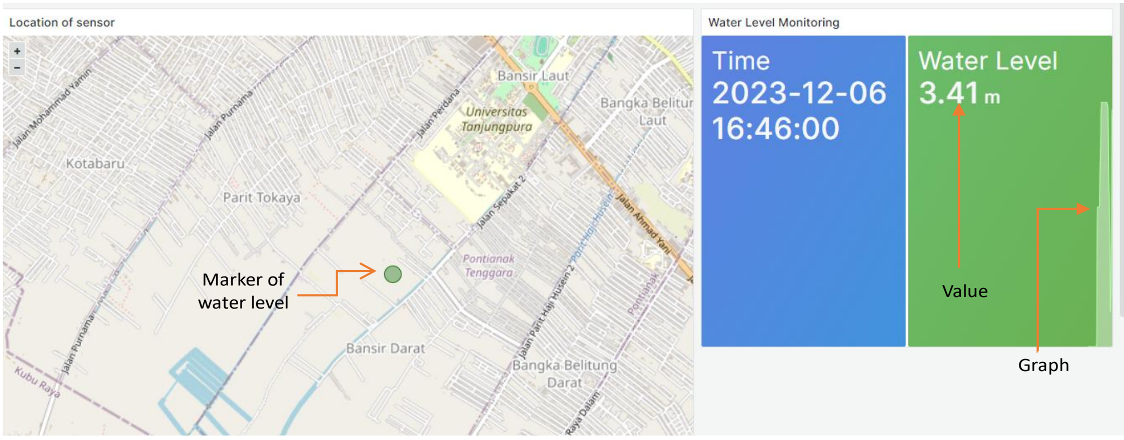


Figure 10. The groundwater level monitoring system dashboard on the visualization web application

The findings of this research highlight an innovative IoT-based application for monitoring peatland fire vulnerability based on peatland groundwater level parameters. Existing groundwater level sensors are not mostly able to be applied to peatlands, which require the qualifications of large sensing range, real-time, autonomous, and energy harvesting. Employing the proposed new method using IoT-based optocoupler sensors can address these gaps. This new method can be developed in future research with different scales and fields. The results of this study show that the combination of a float and an optocoupler sensor is a feasible way of measuring groundwater levels to depths of more than 3.5 meters. A wider operational sensing range (up to 3.5 meters and extendable), longer than research by [14], [17], [18]. This is supported by the experiment that shows that the length of the sensing range follows the length of the rope. In addition, the proposed method produces instrumentation with higher resolution than other methods [25]-[27]. The groundwater level sensor with the proposed new method is shown to have the necessary qualifications for peatland water level monitoring. This provides an opportunity to improve the efficiency and effectiveness of peatland fire early warning systems. For field deployment, the system can be installed in wells or custom-designed access tubes placed within peatland ecosystems. Maintenance is simplified by the mechanical durability of the float-pulley mechanism and the energy autonomy provided by the solar-powered battery system. Moreover, data from multiple sensor nodes can be centrally managed using cloud-based platforms such as Node-RED, InfluxDB, and Grafana, allowing for real-time visualization, storage, and historical analysis.

4. CONCLUSION

The main objective of this research is to develop a sensor for IoT-based peatland fire monitoring. Existing research mostly uses ultrasonic, infrared, and resistive sensors. Peatland is land where the water level varies (from shallow to deep) and generally lacks electricity and internet. To address these challenges, a groundwater level detection new method is required that can measure groundwater levels large sensing range, in real-time, continuously, with an independent power supply. To meet these requirements, we propose a new method that integrate float and optocouplers. The sensor systems result a large sensing range groundwater level measurement method. Evaluation of the sensing range shows that the sensor can achieve the sensing range according to the length of the rope. In this study, the sensor is able to measure up to 3.5 meters because it uses ropes 3.5 meters of long. The study found a way to adjust the sensitivity and resolution of the sensor. A linear correlation was found between the groundwater level and the sensor output. The test results showed the sensitivity of the sensor is 3 mm/pulse and the resolution is 3.33 mm. The average error percentage is 1.67%. The groundwater level sensor in this study is different from others in terms of the large sensing range. Existing sensors have limitations in groundwater level sensing range. While the sensor we developed can measure up to a range of 3.5 meters. Furthermore, this research produced a monitoring system for peatland fire vulnerability based on IoT-based groundwater level parameters. The current prototype has not yet been tested for long-term operation under actual peatland conditions, which are known to be corrosive, humid, and filled with organic matter. The mechanical float-pulley system is also susceptible to physical disturbances from animals or environmental factors such as strong winds or water surges. To improve durability, we plan to enclose the mechanical system within a weather-resistant casing and explore the use of corrosion-resistant materials such as stainless steel or high-grade polymers. To optimize power consumption, especially for remote deployments, we intend to integrate an adaptive sleep-wake cycle in the microcontroller firmware and explore energy harvesting options such as solar charging. Our contribution results in a novel mechanical-electronic integration using optocoupler-based rotary sensing for water level monitoring and a design tailored for large sensing range, suitable for deep or fluctuating groundwater in peatlands. Future research can add other sensors and artificial intelligence algorithms to predict fires that will occur in real-time.

This study successfully developed a groundwater level monitoring system based on the IoT using a float sensor and optocoupler to detect real-time changes in water levels. The system has significant potential to contribute to early warning efforts for peatland fires, particularly in disaster-prone areas. Socially, the implementation of this system can enhance community resilience to fire risks, provide early alerts to stakeholders, and support data-driven decision-making. This research also aligns with several Sustainable Development Goals (SDGs), especially SDG 13 (Climate Action) through the mitigation of peatland fire risks that contribute to carbon emissions; SDG 15 (Life on Land) through the protection of vulnerable peatland ecosystems; therefore, the findings of this study are not only technically relevant but also offer broad positive impacts on society and the environment.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the first author, [AM], upon reasonable request.

REFERENCES

[1] A. Sulaiman *et al.*, "Peatland groundwater level in the Indonesian maritime continent as an alert for El Niño and moderate positive Indian Ocean dipole events," *Scientific Reports*, vol. 13, no. 1, p. 939, Jan. 2023, doi: 10.1038/s41598-023-27393-x.

[2] S. Silviana, B. Saharjo, and S. Sutikno, "Fire risk analysis based on groundwater level in rewetting peatland, Sungaitohor village, kepulauan Meranti district, Riau province," *IOP Conference Series: Materials Science and Engineering*, vol. 796, no. 1, p. 012041, Mar. 2020, doi: 10.1088/1757-899X/796/1/012041.

[3] T. W. Yuwati *et al.*, "Restoration of degraded tropical peatland in Indonesia: a review," *Land*, vol. 10, no. 11, p. 1170, Nov. 2021, doi: 10.3390/land10111170.

[4] I. S. Hikouei, K. N. Eshleman, B. H. Saharjo, L. L. B. Graham, G. Applegate, and M. A. Cochrane, "Using machine learning algorithms to predict groundwater levels in Indonesian tropical peatlands," *Science of The Total Environment*, vol. 857, p. 159701, Jan. 2023, doi: 10.1016/j.scitotenv.2022.159701.

[5] B. Kartiwa *et al.*, "Water level and soil moisture monitoring for peatland fire risk indicator," *IOP Conference Series: Earth and Environmental Science*, vol. 1201, no. 1, p. 012066, Jun. 2023, doi: 10.1088/1755-1315/1201/1/012066.

[6] K. B. W. Boo, A. El-Shafie, F. Othman, M. M. H. Khan, A. H. Birima, and A. N. Ahmed, "Groundwater level forecasting with machine learning models: A review," *Water Research*, vol. 252, p. 121249, Mar. 2024, doi: 10.1016/j.watres.2024.121249.

[7] S. Wei, H. Hao, M. Luo, and Z. Yang, "Classification of ground information during wildfires: using an improved UNet model," *International Journal of Disaster Risk Reduction*, vol. 116, p. 105157, Jan. 2025, doi: 10.1016/j.ijdrr.2024.105157.

[8] Aminah, C. Krah, and Perdinan, "Forest fires and management efforts in Indonesia (a review)," *IOP Conference Series: Earth and Environmental Science*, vol. 504, no. 1, p. 012013, May 2020, doi: 10.1088/1755-1315/504/1/012013.

[9] R. Teguh and H. Usup, "Realtime monitoring for groundwater level and local climate based on universal communication system," *Computer Science and Information Technologies*, vol. 2, no. 2, pp. 67–76, Jul. 2021, doi: 10.11591/csit.v2i2.p67-76.

[10] Z. Wu, Y. Huang, K. Huang, K. Yan, and H. Chen, "A review of non-contact water level measurement based on computer vision and radar technology," *Water*, vol. 15, no. 18, p. 3233, Sep. 2023, doi: 10.3390/w15183233.

[11] P. Mohindru, "Development of liquid level measurement technology: a review," *Flow Measurement and Instrumentation*, vol. 89, p. 102295, Mar. 2023, doi: 10.1016/j.flowmeasinst.2022.102295.

[12] J. R. Hanni and S. K. Venkata, "Does the existing liquid level measurement system cater the requirement of future generation?," *Measurement*, vol. 156, p. 107594, May 2020, doi: 10.1016/j.measurement.2020.107594.

[13] K. Loizou and E. Koutroulis, "Water level sensing: state of the art review and performance evaluation of a low-cost measurement system," *Measurement*, vol. 89, pp. 204–214, Jul. 2016, doi: 10.1016/j.measurement.2016.04.019.

[14] S. Marick, S. K. Bera, and S. C. Bera, "A float type liquid level measuring system using a modified inductive transducer," *Sensors & Transducers*, vol. 182, no. 11, pp. 111–118, 2014.

[15] S. Majdalani, J.-P. Chazarin, and R. Moussa, "A new water level measurement method combining infrared sensors and floats for applications on laboratory scale channel under unsteady flow regime," *Sensors*, vol. 19, no. 7, p. 1511, Mar. 2019, doi: 10.3390/s19071511.

[16] G. Zheng, H. Zong, X. Zhuan, and L. Wang, "High-accuracy surface-perceiving water level gauge with self-calibration for hydrography," *IEEE Sensors Journal*, vol. 10, no. 12, pp. 1893–1900, Dec. 2010, doi: 10.1109/JSEN.2010.2050138.

[17] D. Paczesny, M. Marzęcki, M. Woyke, and G. Tarapata, "System for water level measurement based on pressure transducer," in *Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2016*, R. S. Romaniuk, Ed., Sep. 2016, p. 100312H, doi: 10.1117/12.2249455.

[18] S. I. Abdullahi, M. H. Habaebi, and N. A. Malik, "Capacitive electrode sensor: design and testing," in *2018 7th International Conference on Computer and Communication Engineering (ICCCE)*, IEEE, Sep. 2018, pp. 34–37, doi: 10.1109/ICCCE.2018.8539287.

[19] N. Cvar, J. Trilar, A. Kos, M. Volk, and E. S. Duh, "The use of IoT technology in smart cities and smart villages: similarities, differences, and future prospects," *Sensors*, vol. 20, no. 14, p. 3897, Jul. 2020, doi: 10.3390/s20143897.

[20] M. Majid *et al.*, "Applications of wireless sensor networks and internet of things frameworks in the industry revolution 4.0: a systematic literature review," *Sensors*, vol. 22, no. 6, p. 2087, Mar. 2022, doi: 10.3390/s22062087.

[21] C. Bouras, A. Gkamas, and S. A. K. Salgado, "Energy efficient mechanism for LoRa networks," *Internet of Things*, vol. 13, p. 100360, Mar. 2021, doi: 10.1016/j.iot.2021.100360.

[22] A. Bhardwaj *et al.*, "Smart IoT and machine learning-based framework for water quality assessment and device component monitoring," *Environmental Science and Pollution Research*, vol. 29, no. 30, pp. 46018–46036, Jun. 2022, doi: 10.1007/s11356-022-19014-3.

[23] A. K. Dikshit, B. Narasimhan, B. Kumar, and A. K. Patel, Eds., *Innovative trends in hydrological and environmental systems*, Lecture Notes in Civil Engineering, vol. 234. Singapore: Springer, 2022, doi: 10.1007/978-981-19-0304-5.

[24] O. H. Kombo, S. Kumaran, and A. Bovim, "Design and application of a low-cost, low- power, LoRa-GSM, IoT enabled system for monitoring of groundwater resources with energy harvesting integration," *IEEE Access*, vol. 9, pp. 128417–128433, 2021, doi: 10.1109/ACCESS.2021.3112519.

[25] A. Andang, N. Hiron, A. Chobir, and N. Busaeri, "Investigation of ultrasonic sensor type JSN-SRT04 performance as flood elevation detection," *IOP Conference Series: Materials Science and Engineering*, vol. 550, no. 1, p. 012018, Jul. 2019, doi: 10.1088/1757-899X/550/1/012018.

[26] R. Tawalbeh, F. Alasali, Z. Ghanem, M. Alghazzawi, A. Abu-Raideh, and W. Holderbaum, "Innovative characterization and comparative analysis of water level sensors for enhanced early detection and warning of floods," *Journal of Low Power Electronics and Applications*, vol. 13, no. 2, p. 26, Apr. 2023, doi: 10.3390/jlpea13020026.

[27] M. Mousa, X. Zhang, and C. Claudel, "Flash flood detection in urban cities using ultrasonic and infrared sensors," *IEEE Sensors Journal*, vol. 16, no. 19, pp. 7204–7216, Oct. 2016, doi: 10.1109/JSEN.2016.2592359.

BIOGRAPHIES OF AUTHORS

Abdul Muid is a lecturer who teaches in the field of sensors, instrumentation and electronics in the Physics Department, Faculty of Mathematics and Natural Sciences, Tanjungpura University, West Kalimantan. His research interests including sensor development, instrumentation design, internet of things (IoT), and machine learning. He can be contacted at email: muid@physics.untan.ac.id.

Nina Siti Aminah is a lecturer and researcher in the Physics Department at Institut Teknologi Bandung (ITB). Her expertise is instrumentation and computational physics. She researches material-based sensor development, internet of things-based instrumentation design and machine learning, and computational-based data analysis. She guides undergraduate and postgraduate students to work on their thesis and dissertation final assignments in Electronics and Instrumentation Physics Laboratory, Department Physics, Institut Teknologi Bandung. She collaborated with laboratories in Thailand and Korea. She can be contacted at email: nina@itb.ac.id.

Maman Budiman is a lecturer and researcher in the Physics Department at Institut Teknologi Bandung (ITB). His Ph.D. degree was obtained at Tokyo Institute of Technology, Tokyo - Japan. He has expertise in the field of electronic devices, measuring devices, and controllers for industrial equipment. He led a student work group in the Internet of Things Lab in the Physics Department of ITB. Experienced in making electronic circuits and programming based on microcontrollers. His research focuses on the topic of energy conservation. He can be contacted at email: maman@itb.ac.id.

Mitra Djamal is a professor in the Physics Department at Institut Teknologi Bandung (ITB). He is a lecturer and researcher in the Physics Instrumentation and Electronics Laboratory. Postgraduate from Universitat der Bundeswehr Munchen, Munchen - Germany and also a Ph.D. holder in electrical engineering from the same university. He has more than three decades of teaching experience and guided the students for their postgraduate as well as doctorate degrees. His areas of expertise are sensors, instrumentation, and electronic devices. He has experience in the development and design of sensor-based measuring instruments and the development of materials for sensors. He led research in collaboration with researchers in Thailand, Korea, and Germany. He can be contacted at email: mitra@itb.ac.id.