PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 5 No. 1 (2024) 229-237
https://publisher.uthm.edu.my/periodicals/index.php/peat

Water Level Monitoring System for Flood-Prone Area Affected by Topography

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DOI: https://doi.org/10.30880/peat.2024.05.01.023

Article Info

Received: 16 January 2024
Accepted: 18 January 2024
Available online: 15 June 2024

Keywords

Water level monitoring, real-time data, ESP8266, flood prediction, cloud communication, irrigation management, topograph

Abstract

The Muar River catchment faces recurrent, severe flood events exacerbated by rapid development. This research introduces Gezeiten Technology (GZ), a Water Level Monitoring system for the plain areas alongside the Muar River. GZ aims to provide a user-friendly flood management approach, helping communities anticipate and mitigate flood impacts. The system employs NodeMCU modules to send water level sensor data to the cloud, enabling real-time monitoring and early precautions in flood hotspots.

1. Introduction

The Gezeiten Technology (GZ) water level monitoring system is essential for the automatic detection of liquid levels in rivers, providing timely information about potential water-related risks. The urgency arises from the impact of climate change on water levels, where the inadequacy of water level analysis becomes evident only in critical situations, leading to river floods. Climate change-induced fluctuations, particularly high-intensity and prolonged rainfall, result in river overflow and subsequent flooding, causing property damage and potential casualties [1]. This underscores the pressing need to address the concerning issue of river floods, which pose a significant threat to communities residing along riverbanks.

In Panchor, a low-lying area along Sungai Muar, an unexpected river flood occurred in March 2023 despite a week of no rainfall. Situated along the flow of Sungai Muar, Panchor's vulnerability is evident due to its lower elevation compared to surrounding areas like Bukit Kepong and Muar. The unforeseen flood resulted from continuous rain in the elevated zones, causing Sungai Muar to overflow and impacting Panchor due to gravity. Regrettably, residents were unprepared, leading to significant losses and potential psychological trauma [2].

The Gezeiten (GZ) system stands out as a vital solution for river flood monitoring, playing a crucial role in prediction and prevention. Specifically designed for water level monitoring, the Gezeiten system offers real-time data on water levels, empowering communities to proactively mitigate the impact of potential floods [3]. The implementation of advanced technologies like Gezeiten is imperative for building resilience and safeguarding communities against the adverse effects of fluctuating water levels and unpredictable weather patterns.

1.1 Problem Statement

The challenge in areas along the Muar River, such as Panchor and Bukit Kepong, is the occurrence of riverine floods even in the absence of rainfall. The natural flow of water from elevated plateaus to plains is a crucial aspect of shaping the Earth's surface and supporting ecosystems [4]. However, the issue arises when the water level becomes excessively high, leading to riverine floods. The uneven topography vividly depicted in Figure 1a highlights the variations in land elevation.

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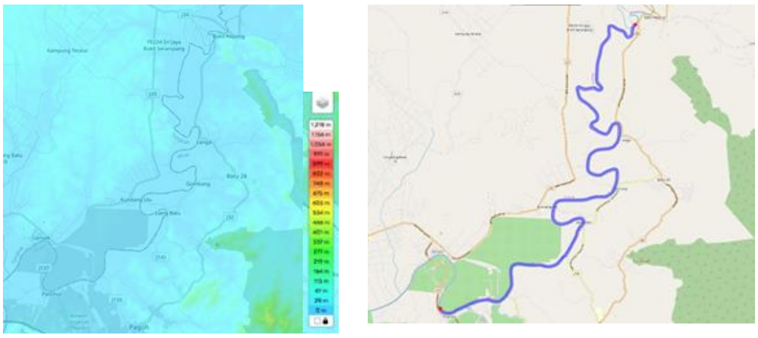
The focus areas are Muar River at Panchor and Bukit Kepong. Connecting these locations is the Muar River, as depicted in Figure 1b where water flows. The irregular ground contributes to inconsistent water levels, with lower areas experiencing higher volumes of water compared to elevated locations. Understanding that water naturally moves downhill due to gravity emphasizes the need for a monitoring system that provides real-time data and predictions for citizens [5]. The system specifications extend beyond water level monitoring, encompassing eco-friendly power supply and weatherproof casing for outdoor durability [6].



(a) (b)

Fig. 1 *Map (a) different level of elevation of Bukit Kepong and Panchor; (b) river connecting from Bukit Kepong to Panchor*

1.2 Objective

a) To identify the flood hotspots along Muar river and propose suitable sensor nodes specifications including type of sensors, communication module and connectivity.
b) To develop IoT based real time monitoring system (Gezeiten Technology) to collect water level and rain sensor data for upstream and downstream flood hotspots.
c) To compare and evaluate the sensor data from both locations to provide better flood prediction and alert to the nearby community.

1.3 Scopes

a) Conduct a comprehensive study to identify the specific areas along the Muar River that are prone to flooding and propose suitable sensor node specifications, including the type of sensors required for accurate water level and rain monitoring in these identified flood hotspots.
b) Design and develop an Internet of Things (IoT) based system for real-time monitoring of water levels and rain data and implement sensor nodes at upstream and downstream locations of the identified flood hotspots.
c) Gather and analyse real-time water level and rainfall information obtained from sensor nodes strategically positioned at recognized flood-prone areas. This data is then translated into assessments of potential flood occurrences.

2. Materials and Methods

Section Describe the method used to create the Water Level Monitoring System for Plain Area Affected By Topography in greater detail. The description will include all hardware details, a system flowchart with an explanation, and a system block diagram with explanation.

Table 1 *Hardware Details*

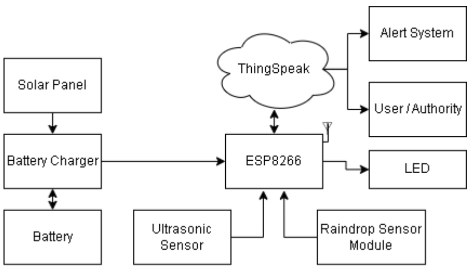
No	Part Name	Qty	Function	Cost (RM)
1	NodeMCU ESP8266	2	Used as microcontroller board to read and send data to ThingSpeak	35.00
2	Battery 1x 3.7V	2	Power source for the circuit	12.00
3	Battery Holder	2	Holds and provides connection for the battery	7.50

Table 1 *Continue*

4	Battery Charger	2	Charges the battery when connected to Solar PV	8.00
5	AJ-SR04M Waterproof Ultrasonic Sensor	2	Measures distance using sound waves	80.00
6	Solar PV	2	Converts sunlight into electrical energy and charge the battery	30.00
7	Resistor	2	Regulates current flow in the circuit	0.40
8	1N5819 Diode	2	Allows current flow in one direction from solar PV	3.60
9	Protoshield	2	Board with complete pin arrangement to fit for the microcontroller	30.00
10	Stripboard	1	Perforated board for soldering electronic components	1.60
11	Jumper Wire	1	Connects components on a circuit board	5.00
12	PVC Pipe 6 inch	2	Encloses and protects components or wires	53.84
13	PVC End Cap 6 inch	2	Closes the end of a PVC pipe	37.80
14	Weatherproof Box IP56 (6x4x3)	2	Protective enclosure for electronics in outdoor environments	14.25
15	X-Bond Construction Silicone	1	Adhesive for securing components and sealing gaps	5.90
16	Bracket 60x60 4s	1	Support structure for mounting components	2.00
17	Screw Set YLT-2020-12	1	Fasteners for securing components and brackets	2.70

2.1 System Block Diagram

The primary microcontroller driving the system is the NodeMCU ESP8266. Both Gezeiten Technology Sensor Nodes will utilize identical devices. Various components, such as the Ultrasonic sensor, Raindrop Module sensor, and power supply, will be linked to the microcontroller for both nodes. A rechargeable battery will serve as the power source for the microcontroller, with recharging facilitated by a solar panel through a battery charger. The recorded data from both nodes will be transmitted to the ThingSpeak cloud system, allowing users and authorities to monitor the information and receive alerts as necessary.



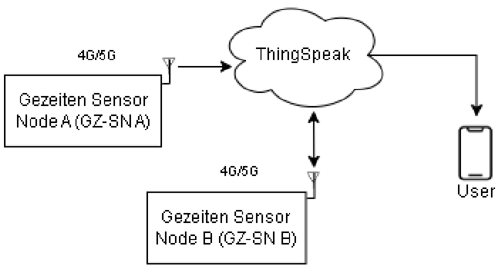


Fig. 2 Gezeiten Technology a) Sensor Nodes A and B (GZ-SN) Block Diagram b) System Connectivity Block Diagram

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The primary microcontroller driving the system is the NodeMCU ESP8266 [7]. Both Gezeiten Technology Sensor Nodes will utilize identical devices. Various components, such as the Ultrasonic sensor, Raindrop Module sensor, and power supply, will be linked to the microcontroller for both nodes [8]. A rechargeable battery will serve as the power source for the microcontroller, with recharging facilitated by a solar panel through a battery charger. The recorded data from both nodes will be transmitted to the ThingSpeak cloud system, allowing users and authorities to monitor the information and receive alerts as necessary.

2.2 System Flowchart

The system is functional when the battery is charged using the system solar panel. The process will be started from GZ-SN which continuously read and send the data of the rain intensity at the high-level ground and send it to ThingSpeak. The other GZ-SN will read the data from ThingSpeak, the system will turn on to read the water level in the low-level area based on the special condition. The data recorded will be sent to ThingSpeak.

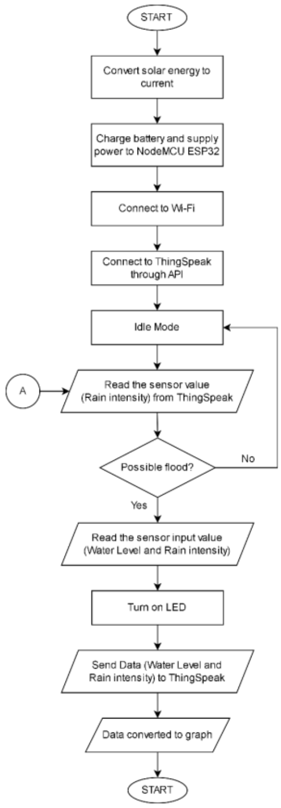


Fig. 4 System Flowchart of Gezeiten Technology

3. Results and Discussion

3.1 Results (GZ-SN Water Level Data Collection)

Water level measurements were collected at Panchor and Gersik jetties. Panchor was intentionally chosen due to observed river overflow without rainfall. Two GZ-SN devices were placed in PVC casings at each location as shown in Figure 5, immersed in the river for 2 hours simultaneously, with readings taken every 15 minutes. The devices were aligned with the river surface.

(a) (b)

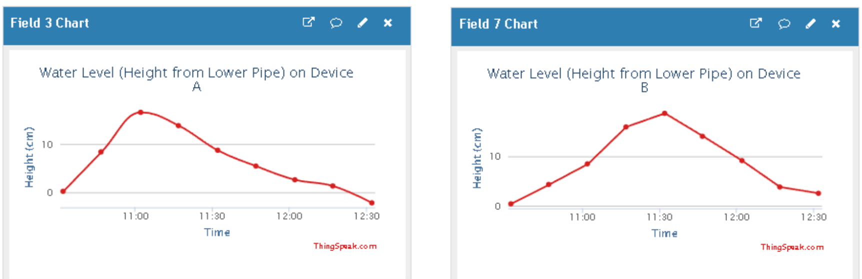
Fig. 5 *GZ-SN deployment* a) *GZ-SN A (Gersik's Jetty) b) GZ-SN B (Panchor's Jetty)*

Figure 6 depicts two locations, 5 kilometres apart, attempting to establish a relationship between distance and time for river water flow. The experiment assessed water levels during low and high tides, providing insights into river dynamics and potential overflow scenarios.

Fig. 6 *5 kilometres between Gersik and Panchor along the Muar River.*

3.2 Results (Water levels at GZ-SN A (Gersik's Jetty) and GZ-SN B (Panchor's Jetty))

Figure 7 displays the water level data collected from GZ-SN A at Gersik's Jetty on ThingSpeak, while the water level data collected from GZ-SN B at Panchor's Jetty on ThingSpeak is presented below.



(a) (b)

Fig. 7 *GZ-SNs water level* a) *GZ-SN A (Gersik's Jetty) b) GZ-SN B (Panchor's Jetty)*

3.3 Results (Data Verification with Department of Irrigation and Drainage Malaysia Data)

The GZ-SN prototype outcomes are consistent with data from Malaysia's Department of Irrigation and Drainage (JPS), demonstrating the reliability of our findings. Figure 8 depicts the comparison and variation between datasets. However, it is important to note that JPS data is graph fitted, which may influence its subtle appearance due to a specific format.

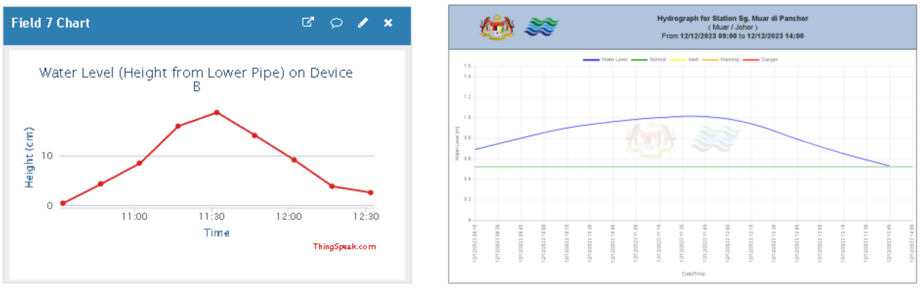


Fig. 8 *Comparative Analysis between GZ-SN and Department of Irrigation and Drainage Malaysia* [9]

3.4 Discussion (Prototype Findings)

From the prototype testing, several noteworthy observations and findings emerged. The analysis of water levels between both locations revealed essential insights into the performance and functionality of the tested prototype. These observations shed light on key aspects such as delay, rate, and extrapolation, providing valuable data to create a dependable flood prediction.

3.4.1 Analysis of Delay in Peak Water Level Detection During High Tide in Gersik's and Panchor's Jetty

The delay and peak of the river, as illustrated in Figure 9 below, provide a visual representation of the temporal dynamics associated with detecting the highest water levels during high tide events at multiple locations. This visual representation acts as a foundation for a detailed examination of the factors influencing the observed time lag in peak water level detection.

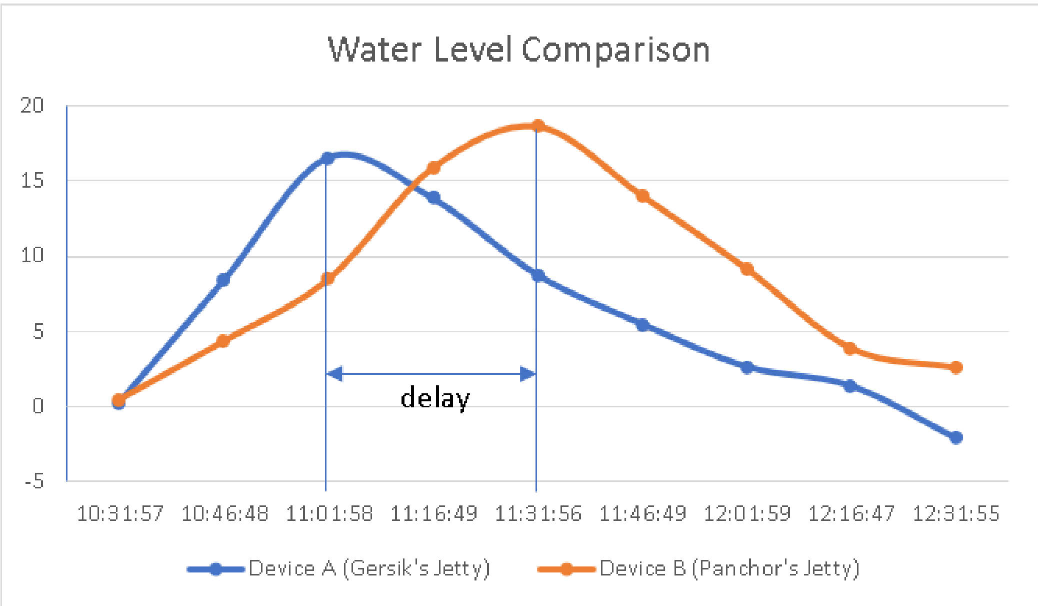


Fig. 9 *Delay in the River's Peak between Two Locations*

The delay in the river's peak can be ascertained by calculating the time difference when both sections of the river reach their respective peaks. As indicated in Figure 9, the delay in the river's peak at each location is measured at 30 minutes. The distance between the two locations along the river spans 5 kilometres.

3.4.2 Analysis of Daily Rate in Peak Water River Detection During High Tide in Gersik and Panchor

The daily rate in peak water river detection during high tide refers to the measurement or assessment of the rate at which the water level in a river reaches its highest point during high tide events. This analysis helps in understanding the frequency of river flooding during high tide periods. The high and low tide frequencies of the Muar River, as depicted in Figure 10, obtained from the Department of Irrigation and Drainage (Jabatan Pengairan Dan Saliran - JPS) Malaysia.

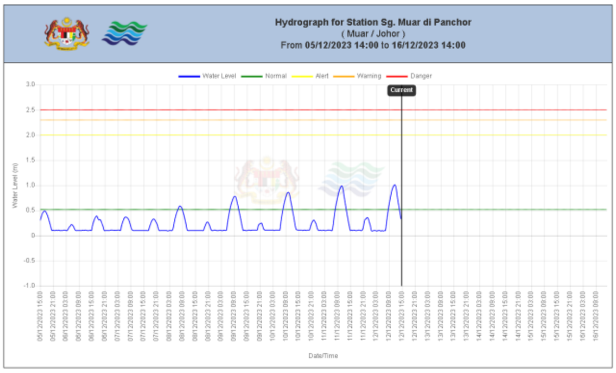


Fig. 10 *The hydrograph of the Muar River over the previous 8 days from Jabatan Pengairan Dan Saliran (JPS) Malaysia*

The area alongside Muar river experience two high and two low tides every 24 hours and 15 minutes. High tides occur five hours and 30 minutes during day and two hours during night. It takes four hours during day and 2 hours at night for the water at the shore to go from high to low, or from low to high.

3.4.3 Extrapolation of Muar River Water Peak Duration Relative to Distance

The main goal is to comprehend how the river's travel distance affects how long it takes to reach the peak water level and how this relationship can be expanded to include locations that aren't specifically listed in the dataset that is currently available. An analysis of the peak Muar's River detection delay during high tide at Gersik's and Panchor's jetty, which are 5 km apart, shows that the water moves from one place to another in 30 minutes. But as Figures 11 and 12 show, the river water at Kampung Olak Sepam, which is also five kilometres from Panchor's jetty, moves slowly—about thirty minutes.

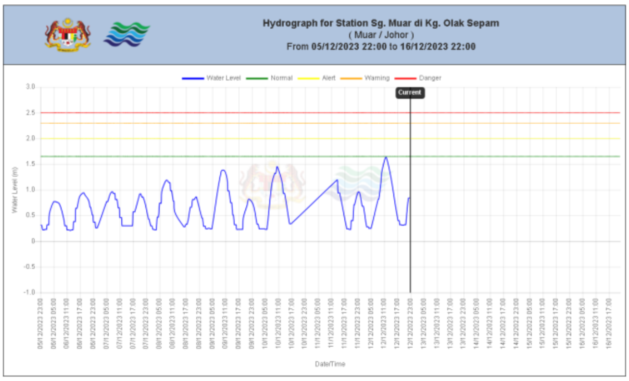


Fig. 11 *The hydrograph of the Muar River in Kampung Olak Sepam over the previous 8 days from Jabatan Pengairan Dan Saliran (JPS) Malaysia.*

Fig. 12 *The distance from Gerisek to Panchor to Kampung Olak Sepam*

Figure 13 below visually depicts the correlation between river distance and the time for peak water level at the responsive location. The x-axis represents the distance along the river, and the y-axis indicates the corresponding time duration. Each data point on the graph signifies a specific distance-time relationship, offering a visual overview of how the temporal dynamics of peak water level occurrences vary with spatial separation along the river.

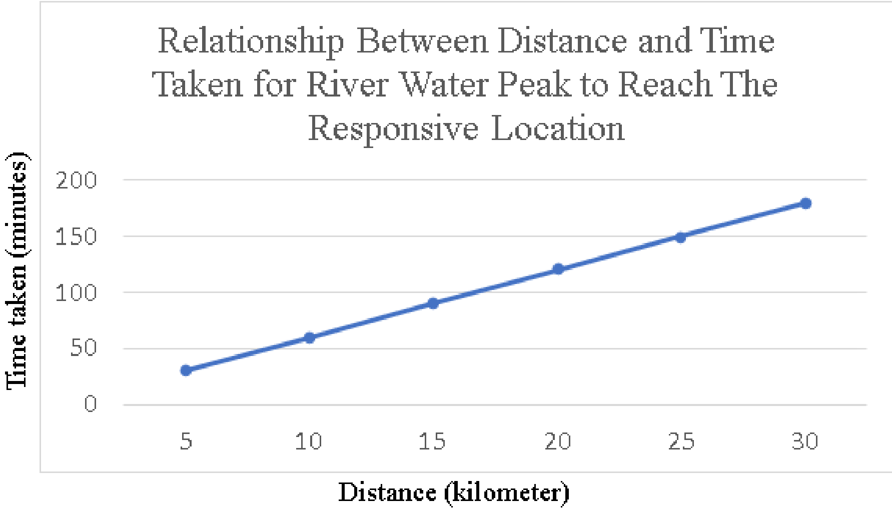


Fig. 13 *Relationship Between Distance and Time Taken for River Water Peak to Reach the Responsive Location*

Notably, as can be seen at the jetty locations in Gersik and Panchor, it takes about half an hour for river water to move five kilometres. The accuracy of flood predictions is increased by this extrapolation, which helps to predict peak water durations for different locations.

3.5 Discussion (Flood Prediction based on Results)

The data indicates a consistent 30-minute lag in peak water detection between Gersik and Panchor jetties, providing crucial insights into Muar River's temporal dynamics during high tide events. Analysis reveals a pattern of two high and two low tides occurring every 24 hours and 15 minutes, offering invaluable information for flood anticipation and preparation.

Extrapolating the distance-time relationship for peak water level occurrences, as illustrated in Figure 13, provides important insights. The graphical representation demonstrates a linear relationship between the river's length and the time it takes for the water to peak at the responsive location. Expressing this relationship as the linear equation:

$$WL=6d, \tag{1}$$

where 'WL' represents water level in meter, 'd' is the distance in km along the river and '6' signifies the slope (rate of change), offers a mathematical model capturing the intrinsic connection between distance and water level. For example, if the distance between two point is 5km, then it takes 30 minutes for the peak water level to reach the end location.

This mathematical model serves as a valuable tool for flood prediction, enabling extrapolation of future water levels at various river points under different conditions. Derived from collected data, it enhances our ability to forecast flood risks and implement timely preventive measures, fostering community resilience to high tide events along the Muar River.

4. Conclusion

The project's implementation has significantly improved our understanding of the dynamics of peak water level occurrences through data gathered from prototype testing and water level analysis along the Muar River. The comparison of delay analysis, examination of daily rates, and extrapolation of Muar River water peak duration in relation to distance has facilitated a better comprehension of factors influencing flood events. These findings serve as the foundation for creating an effective flood prediction system, crucial for refining models and issuing timely alerts to vulnerable communities.

Additionally, it is noteworthy that the data obtained has been validated with the government Jabatan Pengairan Dan Saliran (JPS) Malaysia's data. The project has demonstrated the capability to predict floods accurately, providing an exact value of the delay and formulating an equation depicting a rise in the rate of one hour for every 10 km. Based on the collected data, the Gezeiten technology has shown the ability to predict floods at a rate of 6 minutes per km, showcasing its potential in proactive flood management and community safety.

Acknowledgement

The authors extend sincere gratitude to the Faculty of Engineering Technology (Department of Electrical Engineering Technology) at Universiti Tun Hussein Onn Malaysia for their invaluable support throughout the research. The guidance, provision of information sources, and continuous assistance from the faculty were crucial in the successful completion of this project.

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