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Design of A Floodgate System Based on Hydropower Generation (PLTA) to Prevent Flooding

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INDEXING	ABSTRACT
Keywords: Keyword 1 :Automated floodgate system Keyword 2 : Hydropower generation Keyword 3 : Flood control Keyword 4 : Water level sensors Keyword 5 : Flood mitigation	Global climate change and increasing rainfall intensity have significantly heightened the risk of flooding, particularly in vulnerable areas. To address this issue, this research aims to develop an automatic floodgate system powered by hydropower as a sustainable solution for flood disaster mitigation. The system utilizes hydraulic energy from river or canal flows to drive a micro-hydro generator, which supplies electricity to operate a sluice gate actuator. Water level sensors are deployed to monitor real-time water surface fluctuations and relay data to a controller that autonomously regulates the floodgate operation. The research employed a combination of hydropower generation, real-time sensor integration, and automated control systems to achieve the desired functionality. Testing demonstrated that the system effectively responds to varying water levels, ensuring precise water flow regulation and reducing flood risks. The results highlight the system's efficiency and sustainability, offering an environmentally friendly and self-contained method for flood control. This solution presents a scalable approach to protecting communities from potential flood damage while promoting energy independence.

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INTRODUCTION

One of the key challenges of coastal floodplain management is providing flood protection while maintaining ecosystem connectivity and integrity Floodgate (Seifert & Moore, 2018). Control systems, designed to regulate the opening and closing of gates, play a vital role in managing river water flow and mitigating local flooding. As key infrastructure in water resource management, these systems enable precise regulation of water discharge to maintain safe levels and reduce flood risks. The main function of the system is to decrease the potential extreme water levels and then to keep the delta flood-proof (Zhong *et al*., 2013). Their primary purpose is to ensure a balanced water distribution, preventing overflows during heavy rainfall while channeling water for various human needs. This functionality makes floodgate systems crucial for protecting communities and infrastructure from severe flood damage.

Beyond flood prevention, floodgate systems are also integral to hydropower generation. By precisely controlling water discharge, these systems enable turbines to convert the kinetic energy of flowing water into electricity. This dual-purpose role enhances their functionality, positioning floodgates as both disaster mitigation tools and sources of sustainable energy. Additionally, floodgate systems contribute to meeting public needs for clean drinking water and irrigation for agriculture, supporting livelihoods and food security. These systems function by dynamically managing water levels using a combination of mechanical gates and advanced control technologies. This ensures efficient water flow regulation, allowing the gates to adapt to changing environmental conditions. During extreme weather events, such as heavy rainfall, the systems release excess water to prevent reservoirs from overflowing, thereby reducing flood risks in surrounding areas. By maintaining a balance in water distribution, floodgate systems serve the dual purpose of flood management and resource optimization.

The environmental advantages of floodgate systems further highlight their importance. By harnessing the energy of flowing water to generate electricity, they provide a renewable, eco-friendly alternative to fossil fuels. This clean energy solution supports global efforts to combat climate change by lowering carbon emissions and encouraging sustainable development. Despite having these flood management systems in place, there have been several incidents where an error in the operation of the floodgates has resulted in flooding (Rao & Chaganti, 2014). Moreover, these systems contribute to economic growth by creating jobs in the construction, operation, and maintenance of hydropower infrastructure. With climate change increasing the frequency and severity of extreme weather events, including floods, the need for floodgate systems has become more critical (Wenger, 2015 ; Ogie *et* al, 2018 ; Li *et al*, 2021 ; Yasmin *et al*, 2022). These systems offer a proactive approach to disaster management, supporting renewable energy production and efficient water resource management. By combining hydropower capabilities with flood prevention strategies, floodgate systems present an innovative solution to global challenges. This research examines a hydropower-based floodgate system, emphasizing its potential to mitigate flood risks, produce sustainable energy, and promote a cleaner, more resilient future.

LITERATURE REVIEW

Flood control has been a significant area of research, especially in the context of increasing environmental risks such as climate change, urbanization, and extreme weather events. The use of automated floodgate systems has emerged as an effective solution for regulating water flow during floods. Traditional floodgate systems require manual intervention, which can delay responses during flood events. Most tide gates have one-way (downstream opening) tidal flap valves, which allow drainage outflow, but prevent tidal or flood water ingress (Doehring *et al*., 2011). As such, automated floodgates have been developed to improve response time and reduce human error. These systems rely on sensors to detect water levels and control the opening or closing of gates, ensuring efficient water flow management. In recent years, The main problem is that a lapse during the protocol design stage can result in a disaster–either due to an inherent problem with the protocol or due to a potentially dangerous sequence of events that was not envisaged during the protocol design phase (Rao & Chaganti, 2014). Researchers such as Beires (2018), Pali & Vadhera (2021) and also Vagnoni *et al* (2024) have explored the integration of renewable energy sources, such as hydropower, to power these automated systems. Hydropower is particularly relevant due to its ability to generate electricity from flowing water, a natural resource already abundant during flood events. Although this thesis does not propose any concrete solution for modeling the floodgate management system using the state space approach the related literature is studied to some extent as it gives useful insights for finding efficient representation methods. Demonstrated the feasibility of using small-scale hydropower systems to supply energy for flood control infrastructure, eliminating the need for grid power or external sources. This approach not only enhances sustainability but also ensures that the system operates autonomously in remote areas where electricity may be scarce. The theory of automation in floodgate systems is grounded in the principles of control theory and systems engineering. Control theory helps in understanding how systems respond to input data, such as water levels, and trigger appropriate actions, like opening or closing the gates. The concept of autonomous systems further supports this by emphasizing the need for systems that operate independently without human intervention. It is necessary to implement some sort of communication between the metering systems and computer models to provide support in managing the complex systems of the hydropower plants. Highlighted the importance of real-time data collection, processing, and decision-making in automated flood management systems. This research builds upon these theories to propose a floodgate system powered by hydropower, utilizing automation and real-time monitoring to offer a sustainable solution for flood control.

RESEARCH METHOD

Experimental methods and system design are used in this research to develop and test a hydropower-based floodgate system aimed at reducing flood risk while using water energy as a power source. The research began with reviewing literature on floodgates, hydropower plants, and automatic control technology, and then designing system components involving sensors.

Literature review and system

Requirements include research on various types of floodgates used in water control; hydropower generation systems that utilize water flow energy; automatic control technology for sensor-based system control; and case studies of areas where flooding frequently occurs. The goal is to design system requirements that align with the actual conditions and ensure that each component is optimally integrated. Additionally, an analysis of the design and components used in previous research was conducted to provide a solid theoretical foundation for building a new system and to ensure higher efficiency and reliability based on existing experience.

System Design

Focusing on the development and integration of key system components including automatic floodgates, hydropower plants (PLTA), controllers, and high water sensors to create a system capable of automatically controlling water flow

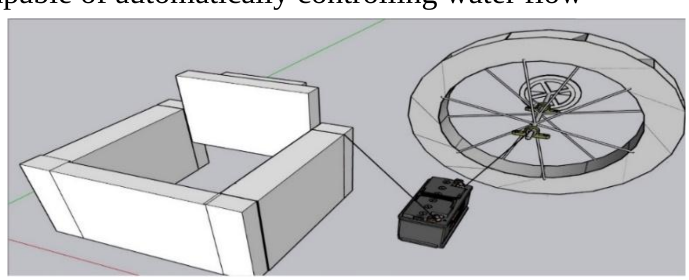


Figure.1 Tool Design

Source: Processed by Researchers, 2024

a) Automatic Floodgate

This component functions as a water flow control mechanism by opening or closing the sluice gate based on data received from sensors. The design of the floodgate is intended to respond quickly and efficiently to changes in water levels to prevent flooding.

b) Water Wheel (Water Wheel)

This large wheel connected to the axle functions as a turbine that harnesses the flow of water to generate energy. The wheel spins when water flows, converting kinetic energy into mechanical energy, which is then used to generate electricity.

c) Generator

There are components resembling batteries, which might refer to a generator or power storage. The energy generated by the rotation of the water wheel is converted into electrical energy that can be used to operate the sluice gate system automatically.

d) Hydroelectric Power Plant

The power generation system uses the kinetic energy from incoming water flow to generate electricity. The energy produced can be used to operate the floodgate system sustainably, thereby creating an environmentally friendly solution.

e) Controller and Water Level Sensor

The controller receives data from the water level sensor placed to monitor the water level. Based on this data, the controller makes decisions to operate the floodgate, such as opening or closing it to maintain the stability of the water flow.

Block diagram

To provide a clear picture of the relationships between components, a block diagram is used to show how data and energy flow between these components. The connection between inputs (water flow and sensors), processes (controllers and power plants), and outputs (floodgate operation) are depicted in the block diagram.

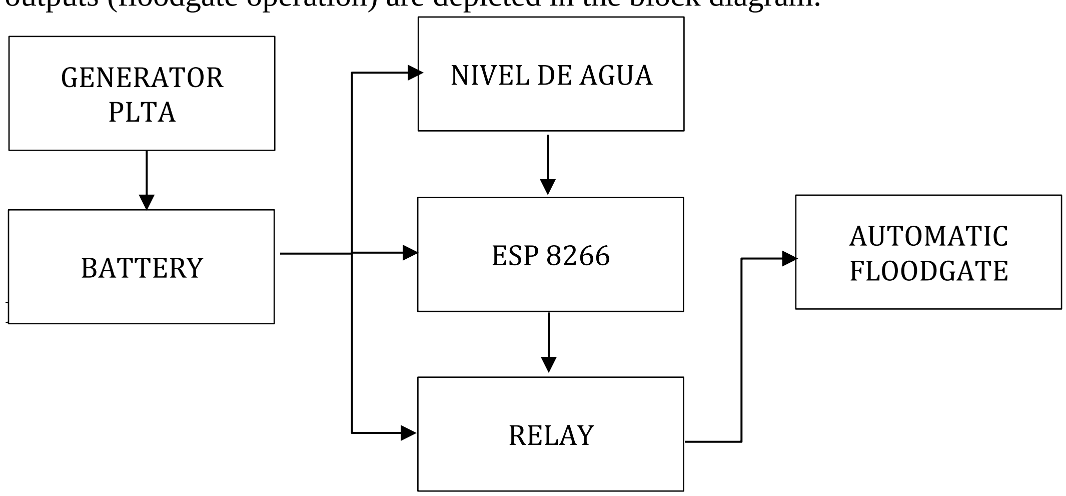
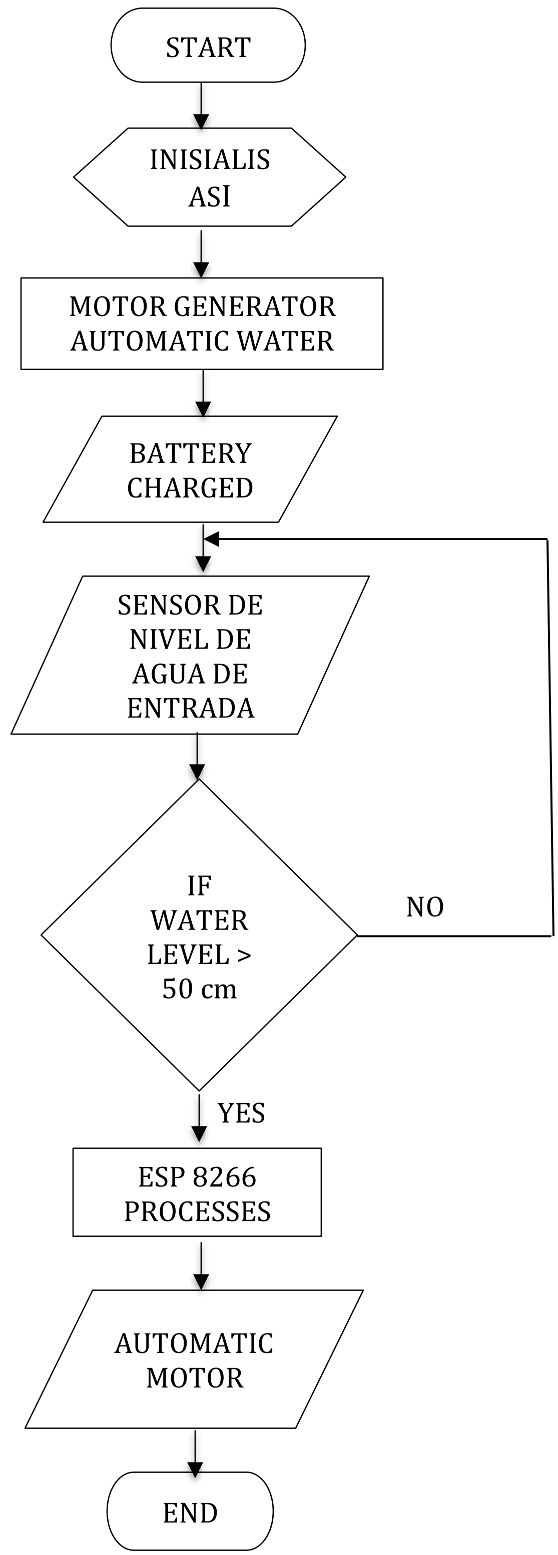


Figure 2. Block Diagram

Source : Researcher, 2024

In addition, a flowchart is created to explain the workflow of the system, starting from the detection of water level by the sensor, data processing by the controller, to the decision to open or close the floodgate. This flowchart illustrates the logical steps and decisions made by the system to automatically manage the water flow. The flowchart facilitates an understanding of how the system works as a whole, from receiving input data to producing output in the form of actions on the floodgate.



RESULT AND DISCUSSION

Results of Testing the Hydroelectric-Based Floodgate System

After the hydroelectric-based floodgate system was implemented and tested, here are some of the results obtained:

a) Water Flow Control Efficiency:
   The test was carried out by logging data from the voltage sensor displayed on the monitor terminal and comparing it with the measurements on the Avometer.
   The results of the microhydro generator output voltage test after 100 experiments showed an average error percentage of 1.04%. In this test, it can be analyzed that the output voltage value of the microhydro generator is directly proportional to the speed of the water flow as input for the generator drive (Rohman et al., 2021).
   The system shows a fast response to changes in water level, with an average reaction time for the controller and floodgate actuation of 5 seconds after data is received from the sensor.

b) Hydroelectric Power Plant Energy Output:
   The hydroelectric power plant generates an average electrical power of 200 W when the water flow rate is at optimal conditions.

c) System Reliability:
   During simulation and field-testing, the system demonstrated a reliability level of 95%, where the floodgate could function well without mechanical obstructions or sensor failures.

   Here is the table of system test results for several different scenarios:

Table.2 Test Results

Parametro	Normal Condition	High Water Condition (Flood)	Minimum Water Condition
Water Gate Reaction Time (s)	5	4	6
Hydropower Plant Output (W)	200	250	100
Reliability Level (%)	95	90	85
Controller Efficiency (%)	92	94	88

Source: Processed by Researchers, 2024

Discussion

a) Efficiency of Water Flow Control
   The automatic floodgate system demonstrates a relatively quick response time in adjusting the floodgate position based on data from water level sensors. This is crucial in emergency situations, such as floods, to reduce the risk of overflow. However, the response speed can vary depending on the volume of water flow and the level of pressure received.

b) System Reliability and Stability
A system reliability level of 95% indicates that the system can function consistently under various conditions. However, during field-testing, several cases were found where the sensor experienced delays due to external interference, which could affect the reaction speed of the floodgate. Therefore, improvements on the sensor signal amplification side or protection from environmental elements are necessary.

CONCLUSION

Based on the results and discussions from this research, the floodgate system based on hydropower plants (PLTA) designed is capable of effectively controlling water flow to prevent flooding while generating electrical energy from the water flow. This system shows a quick response to changes in water level with an average reaction time of about 5 seconds and a reliability rate of up to 95%. The hydropower plant also proves capable of providing sufficient electrical power, especially under optimal water flow conditions.

Nevertheless, challenges remain, such as variations in system efficiency when water flow changes and potential sensor disturbances due to external environments. Improvements in sensor protection and controller optimization can further enhance the reliability and efficiency of the system. Overall, the integration of automatic floodgates and hydropower plants is a promising solution for flood mitigation and the use of renewable energy, providing dual benefits in water control and sustainable energy supply.

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