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Off-Grid Solar-Powered Intelligent Gate Valve System: Wireless Monitoring, Adaptive Control, and Supervisory Management for Efficient Water Distribution

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ABSTRACT

This study developed the off-grid solar-powered intelligent gate valve system that provides wireless monitoring, adaptive control, and supervisory management to improve the water distribution in the General Santos City Water District. The manual operation of underground gate valves in water distribution systems often requires 2-4 operators to turn the valve 0-17.5 full rotations to respond slowly to operations, poor monitoring, and loss of water through unstable pressure and incomplete closing of the valves, especially in remote locations with limited power and communication. This study designed an off-grid solar-powered intelligent system of a gate valve with pressure and flow sensors, fuzzy logic, cascaded PID control with a 12V DC motor to provide adaptive valve control, and uses a battery as the primary power source and a solar panel as the secondary power source, which is a solar-charged battery, ensuring continuous off-grid operation and offering a scalable solution for efficient water distribution management. Operation modes are controlled by a supervisory state machine, and LoRa technology provides long-range wireless communication of about 5-10 km for remote monitoring. The system evaluation showed that it has high system performance, with functionality results of ($\approx 4.69/5$), accuracy ($\approx 4.72/5$), effectiveness ($\approx 4.76/5$) and usability ($\approx 4.63/5$), all of these interpreted as "Excellent." These reduce manual operation, provide more accurate monitoring and control. The system is feasible because it's effective in controlling the water distribution, which helps to reduce water wastage and enhance service.

INTRODUCTION

Water is one of the most important resources in maintaining life and economic development, but its effective distribution continues to face significant challenges in many parts of the world. Nowadays, there are a lot of new technologies, like the Internet of Things (IoT), wireless communication, and intelligent control systems, which have helped improve water management and system monitoring (Mujoo *et al.*, 2021). One of the major factors behind the pipe leaks is the high-water pressure, and some of the people in certain barangays, households, and residents have experienced dirty water during maintenance. This happens when the gate valves are not completely closed, as the traditional valve key is no longer able to turn because of sand or other obstructions. The Water utilities usually face problems, like delayed leak detection, poor water flow control, and high waste loss, which are usually caused by manual operations (Lakshmi *et al.*, 2021).

To address this, the Intelligent Gate Valve System provides an innovative solution. The system uses a solar energy source, but the main power source is the battery to ensure continuous operation even without a stable power supply. It includes sensors, like the Pressure Transducer Transmitter Sensor, YF-B7 Water Flow Sensor, and a wireless communication, which is the Heltec WiFi LoRa 32, for remote monitoring and control of the gate valve. In addition, the system applies adaptive control techniques to adjust the gate valve movement accurately based on changing conditions, like to open, closing, or

for maintenance.

The main objective of this research is to design and implement a system that can reduce manual operations, minimize water loss, and improve the overall water distribution. The study is valuable because it offers a cost-effective and reliable solution that incorporates renewable energy, automated control, and remote monitoring, and can be used to manage the water in modern society, more so in locations with limited resources.

LITERATURE REVIEW

Related Literature

In today's modern world, the use of advanced technologies, like the IoT, AI and renewable resources, has improved the management of water distribution systems. Traditional water systems still rely on manual operations, which is the major cause of problems are delayed leak pipe detection, high water pressure, and maintenance. Because of this, automatic, intelligent and reliable systems are needed. Some studies show how IoT can help improve water management. Binayao *et al.* (2024) created a system that makes the operation of watering the rice fields an automated one by using the water in the irrigation, which reduces manual operations. In the same way, Abrajano *et al.* (2024) developed a system that monitors the water quality in off-grid communities, and their system helps to ensure that drinking the water is safe. There are also studies the focuses on sustainable solutions. Selerio (2024) developed a study about evaluating different decentralized wastewater treatment

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(DEWAT) options that are suitable for the Philippine context, where centralized systems are often impractical due to high population density, archipelagic geography, and limited resources. Their study shows the importance of low-cost and off-grid solutions. Same with the Te *et al.* (2024), which developed a study about the flood monitoring system using sensors, LoRa communication, and solar power. Their system can monitor environmental conditions through the sensors they're using. The two studies that were mentioned a while ago focus only on monitoring. Santos *et al.* (2021) developed a study that shows the water and power monitoring of a residential building and can show real time data to the users. Similarly, Agulto and Ella (2022) developed a system for using a cross-platform mobile application integrated with the wireless sensor networks to automate irrigation and provide real-time monitoring for upland and lowland crop production systems. There are also studies that focus on safety systems. Valle and Yara (2024) developed a gas leak detection system that sends alerts in real time. Prajwal *et al.* (2022) developed a machine-learning-based system for predicting valve failures. In another study, Boateng and Bruce (2023) developed a study that used machine learning methods to detect anomalies in industrial control systems. In addition, Daoudi *et al.* (2024) improved valve control by combining traditional methods with artificial intelligence. Bindarwish (2024) developed a study about the life cycle and supply chain of gate valves, comparing traditional manufacturing with 3D printing. Zhang *et al.* (2025) developed a study about the low-power subsea electric gate valve actuator for offshore applications. Lakshmi *et al.* (2021) created an IoT-based system for water management and leak detection. Their system uses sensors to monitor water levels and detect leaks, sending alerts through different platforms. Redekar *et al.* (2022) reviewed the use of electric actuators in renewable energy systems, highlighting their precision and compatibility with IoT. Mujoo *et al.* (2021) developed a study about a smart irrigation system that uses IoT TO control the valves, which is powered by solar energy. Their system uses soil moisture, humidity, and temperature sensors with LoRa-based communication to monitor and regulate the water distribution across the large agricultural fields. Overall, many studies show that IoT, AI, and automation can improve water systems. However, most of them focus only on monitoring or small applications. Therefore, the Intelligent Gate Valve System combines the automatic valve control, wireless communication, and off-grid power.

Related Studies

Different local studies that focus on improving the water systems that use IoT automation. Etchon *et al.* (2025) developed a study about a pipeline leak detection system that uses multiple sensors to detect water leaks and notify users through mobile and web applications for real-time monitoring. Similarly, Balerite *et al.* (2022) created a study about designing an automated water metering system

that measures household water usage, detects leaks, and integrates automated billing through a consumer mobile interface. Raagas *et al.* (2022) developed a study about a smart water tank system that automates the water level monitoring and control in household tanks. It will automatically open the valve when water reaches a critical low level and closes it when near full, while also sending notifications to the user through WiFi and real-time monitoring, preventing both tank overflow and emptying. In addition, Melgazo *et al.* (2023) developed a study about automating household water collection. Their system uses a microcontroller and contactless water-level sensors, monitors tank levels in real-time and automatically opens or closes the valve to prevent overflow or reduce it. Arante *et al.* (2025) developed a study that is all about using the IoT sensors, cloud computing, and the AI models that include fuzzy logic, LSTM, and genetic algorithms that can monitor and forecast floods in the Philippines with high accuracy while ensuring secure data transmission. Likewise, Austria and Lacbay (2025) developed a study about designing a Smart Water Management System (SWMS) for the state university that uses IoT sensors, smart meters, automated valves, cloud analytics, and machine learning to enhance water usage, detect leaks, etc. There are also foreign studies that provide an additional insight about the valve systems, automation, and intelligent control. Zhang *et al.* (2024) developed a system that uses computer vision to monitor valve positions in industrial plants. This improves safety and accuracy in detecting valve status. Similarly, Enecki *et al.* (2024) developed a study that involves all gate valves using simulation and experiments. Their study improves valve design and efficiency but does not include IoT integration or real-time automation. Magibalan and Sundar (2023) developed a study about analyzing and designing the gate valves using CFD and FEA simulations to reduce failures, including leakage, wear, and deformation, while also proposing 3D printing and design improvements for better reliability. In another study, Luan *et al.* (2025) developed a study all about reviewing the different rotary motion mechanisms that include gears, belts, chains, cams, and modern designs like magnetic and 3D-printed gears, as well as driving methods including electric, hydraulic, pneumatic, and piezoelectric. Decker *et al.* (2022) developed a study about designing soft pneumatic valves that can perform both digital logic and analog pressure regulation using membrane inversion and tube kinking. Su (2024) designed an intelligent valve control system using sensors and PID control to improve accuracy and performance in industrial systems. Ferrarese *et al.* (2022) introduced a smart control valve that can generate its own power from water flow and adjust pressure in irrigation systems. Gamit and Patel (2025) developed an IoT-based steam valve control system integrated with SCADA for real-time monitoring and automation. Wang *et al.* (2023) developed a study about an electric gate valve actuator for subsea systems, focusing on safety, reliability, and low power consumption. Liu *et al.* (2024) developed a study

about integrating the PID with AI algorithms such as TabNet and LSTM to regulate water pressure and flow using a multi-jet valve, reducing cavitation and improving efficiency in Chinese water supply networks. Therefore, all the local studies focus on monitoring, detection, and small-scale automation, while all the foreign studies show strong developments in valve design, monitoring, and intelligent control. However, most of the foreign studies focus on industrial, agricultural, or mechanical applications.

MATERIALS AND METHODS

The Intelligent Gate Valve System explains how the hardware and software for both the frontend and backend work together. The prototype of the system is made of two pipelines, which are connected to a gate valve with a pressure and flow sensor. The hardware component includes the Raspberry Pi 5 as the primary controller, and three Heltec WiFi LoRa 32 modules as the communication method, two are microcontroller nodes attached to the gate valves and sensors (the Pressure Transducer Transmitter Sensor and YF-B7 Water Flow Sensor), and the other one is for the LoRa gateway. The node modules gather all the sensor data that is going to be relayed from the gateway to the Raspberry Pi 5 for processing. Raspberry Pi 5 is supported by Raspberry Pi OS and supported by Python to intelligently make decisions by applying Fuzzy Logic, Cascaded PID Control, and a Supervisory State Machine. The sensor input is processed by the Fuzzy Logic to determine the correct valve operations. The Cascaded PID Controller controls process water pressure and valve position with external and internal loops, respectively, and the Supervisory State machine controls the operation of the system modes of normal water flow, high water pressure, leak detector, and maintenance.

Upon processing, control commands are transmitted back to Heltec nodes to be used to control the 12 V DC worm-gear motor and to control the gate valves. The Intelligent Gate Valve System is operated through a solar panel as a secondary main source, a charge controller and a battery as the main power source of the system that makes it work off-grid. Node.js and Express.js are used for creating the backend, and React.js is used for creating the frontend dashboard, while the PostgreSQL database is used to store the system data. The system offers periodic updates with which the operators are able to remotely view valve position, water pressure, flow rate and battery status, creating a complete adaptive and efficient smart water distribution system.

Research Design

The Off-Grid Solar-Powered Intelligent Gate Valve System: Wireless Monitoring, Adaptive Control, and Supervisory Management for Efficient Water Distribution used an experimental-descriptive research design. The experimental part focused on creating a working prototype that has two pipelines, and each pipeline has

a gate valve, a Pressure Transducer Transmitter Sensor, and the YF-B7 Water Flow Sensor. The hardware component includes the Raspberry Pi 5 as the primary controller, and three Heltec WiFi LoRa 32 modules as the communication method, two are microcontroller nodes attached to the gate valves and sensors (the Pressure Transducer Transmitter Sensor and YF-B7 Water Flow Sensor), and the other one is for the LoRa gateway. The sensor data are gathered by the node modules to be sent to the gateway, which is then sent to the Raspberry Pi 5 to be processed.

Raspberry Pi is powered by Raspberry Pi OS and powered by Python to intelligently make decisions by relying on Fuzzy Logic, Cascaded PID Control, and a Supervisory State Machine. The sensor input is processed by the Fuzzy Logic to determine the correct valve operations. These elements will connect and experiment with to determine how they perform together in the operation of solar power, read water data, transmit information wirelessly, and operate the valve. The descriptive part assesses the system's performance in terms of monitoring, control, and management. The data will be gathered from actual system tests and expert evaluations to determine if the system is effective, reliable, and useful in improving water distribution in off-grid areas.

Methods of Research

The Off-Grid Solar-Powered Intelligent Gate Valve System: Wireless Monitoring, Adaptive Control, and Supervisory Management for Efficient Water Distribution will use testing and description and design and build the system, using the main parts such as the Heltec WiFi LoRa 32, Raspberry Pi 5, sensors, motor, solar panel, and battery. Once the prototype is developed, it will be tested in different conditions to ensure it can monitor, control, and save power. The results from the system tests and the feedback from GSCWD will be studied together to measure how well the system can improve water distribution in off-grid areas.

The process of the intelligent gate valve system has many processes, which the Sensor Array works with the data on water pressure, flow, temperature, and current processed by Heltec LoRa 32. The Heltec WiFi LoRa 32 is used to control the Actuator Array to manipulate its position to control the gate valve. The data from the Heltec WiFi LoRa 32 is transmitted to the Raspberry Pi 5, which saves it in the PostgreSQL database and shows it in the User Interface to be monitored. The data will be sent wirelessly with the help of Heltec WiFi LoRa 32 to the Raspberry Pi 5, which is the central system that manages and controls everything.

Testing Procedure

The testing procedure for the Off-Grid Solar-Powered Intelligent Gate Valve System: Wireless Monitoring, Adaptive Control, and Supervisory Management to Improve the Efficiency in Water Distribution makes sure that all parts and the whole system work correctly.

The pressure, flow, and current sensors are then tested to be sure that they provide the correct readings. Then the Heltec WiFi LoRa 32, Raspberry Pi 5, and motor driver/actuator modules are checked to confirm that they properly send and receive commands and record data. The wireless communication using LoRa and WiFi is tested to ensure no data is lost on the way to the dashboard. The solar panel, battery, and charge controller are also tested with a view to ensuring that they can offer a stable power even when the sunlight varies. Lastly, the entire system is put to the test by ensuring that the gate valve can be operated both automatically and manually, sensors read properly, actuators respond acceptably, and the data is properly displayed on the dashboard.

Data Gathering Procedures

The proponents began by sending a request to the management of the General Santos City Water District, explaining the study's purpose, importance, and methods. After it was approved, they prepared a simple evaluation form to determine the effectiveness of the system and how easy it is to use. Ten to fifteen participants, including valve men and the ICTD administrator, were chosen because of their experience to make sure the data is accurate. The response was voluntary, and the responses were confidential. Respondents provided the

ratings of components of the system printed or in digital form, including sensor accuracy, actuator performance, communication reliability, and general usability. The answers were collected and then organized and analyzed to identify patterns and significant results. The prototype was put in the real world to explain its functionality, its reliability in monitoring wirelessly and its general efficiency.

Instruments

The main tool for this study, Off-Grid Solar-Powered Intelligent Gate Valve System: Wireless Monitoring, Adaptive Control, and Supervisory Management to Improve the Efficiency in Water Distribution, was a structured evaluation form, chosen because it is simple, cost-effective, and easy to use for collecting feedback. The form let respondents rate different features of the intelligent gate valve system using a 5-point Likert scale, showing how much they agreed or were satisfied. The evaluation focused on three main areas, which are: the degree to which the system functions (functionality), its efficiency, and its dependability. The information from the forms was also collected in a meticulous, arranged and quantified form to gauge overall performance, ease of use and efficiency of the system in water distribution management.

The Admin Dashboard interface has a Top Navigation

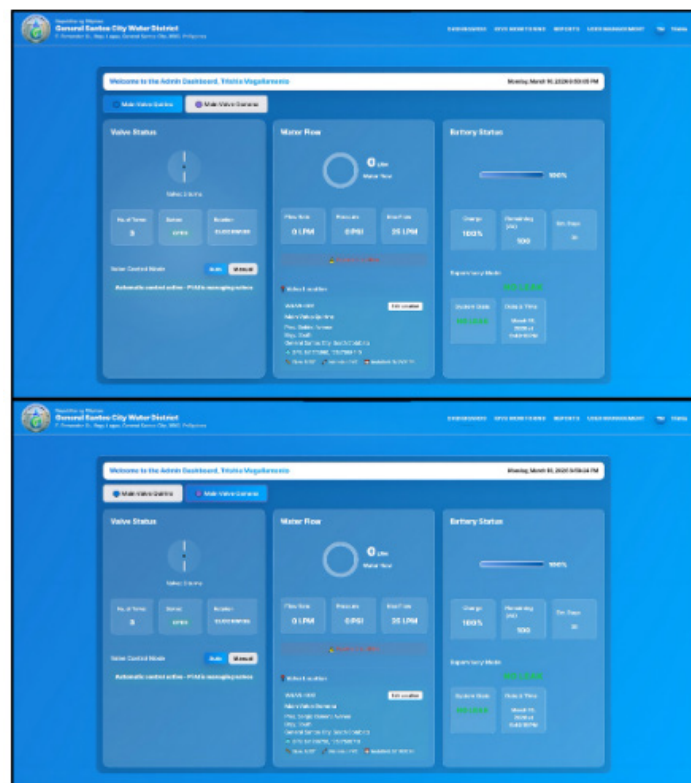


Figure 1: Admin Dashboard

Bar for Dashboards, where the admin can see the monitoring dashboards of Valve status, Water Pressure, Battery Status, and Supervisory Mode. IGVS Monitoring, where the admin can see the Monitoring for Pipeline 1 (Main Valve Quirino) and Pipeline 2 (Main Valve

Osmeña), can see the Pressure Transducer Transmitter Sensor and YF-B7 Water Flow Sensor monitoring. In the IGVS Monitoring, the admin can also remotely operate to open and close the gate valves that are connected to the Pipelines. Reports show the record, can download

the reports, and the admin can pick a date that he or she wants to download for valve status, water pressure, battery status, and supervisory mode. The admin can also see the User Management, where he or she can see the active accounts, inactive history, and Login History, and the admin can only add a new user for the Intelligent Gate

Valve System. Only the Admin has access to this, while the Engineer has their own dashboards, and they also have the same content of reports as the Admin and Valve Men have IGVS Monitoring on their own dashboard. The IGVS Monitoring interface allows the admin users to see Pipeline sensor data with Fuzzy Logic Supervisory

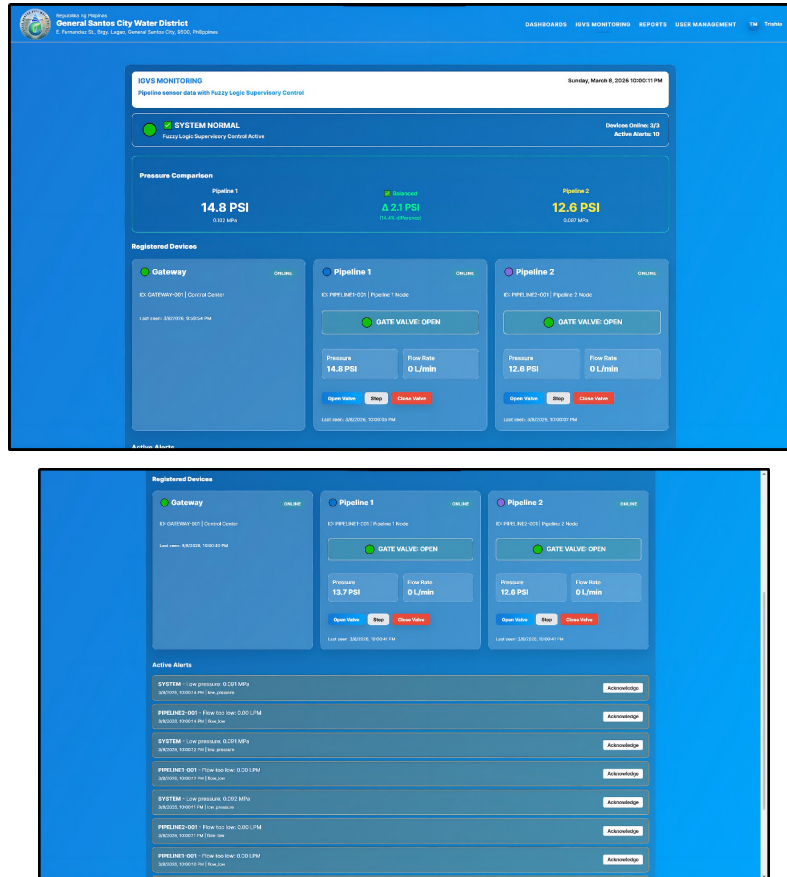


Figure 2: IGVS Monitoring

Control. The admin can also control or operate the Pipeline 1 (Main Valve Quirino) and Pipeline 2 (Main Valve Osmeña) Gate Valves remotely to open and close. Inside the IGVS Monitoring the admin user can also see the two devices of the Heltec WiFi LoRa 32 if they are Online or Offline. The admin can also see if the two

Heltec WiFi LoRa 32 devices are registered or not. If it shows that the two devices are not registered, it shows the No IGVS devices registered. It displays the data of the sensors of the Pressure Transducer Transmitter Sensor and the YF-B7 Water Flow Sensor monitoring.

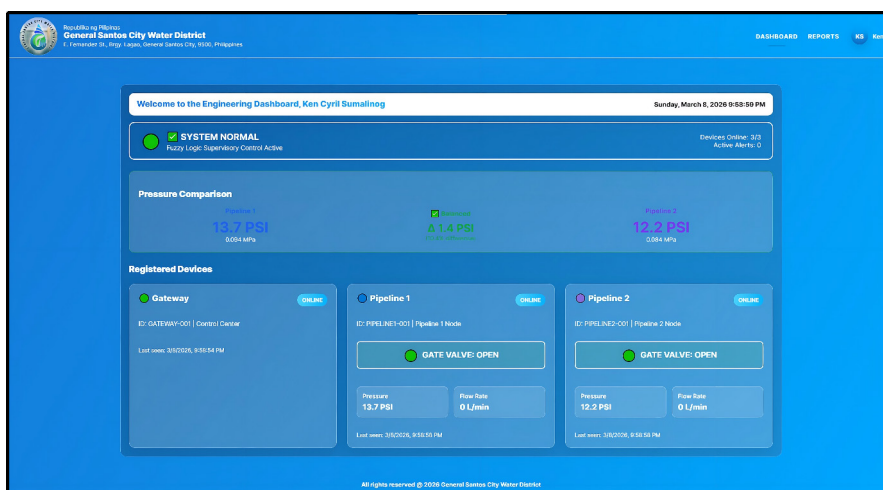


Figure 3: Engineer Dashboard

The Engineer Dashboards interface allows the Engineer user to only see the dashboards monitoring for the Valve Status, Water Pressure, Battery Status, and Leak Status. It displays the data of the sensors of the Pressure Transducer Transmitter Sensor and the YF-B7 Water Flow Sensor monitoring. The Engineer Dashboard also has Reports, where it shows the record, can download the reports, and the admin can pick a date that he or she wants to download for valve status, water pressure, battery status, and supervisory mode, which have the

same content as the reports with the Admin. The Valve Men Dashboards interface allows the Engineer user to only see the dashboards monitoring for the Valve Status, Water Pressure, Battery Status, and Supervisory Mode. It displays the data of the sensors of the Pressure Transducer Transmitter Sensor and the YF-B7 Water Flow Sensor monitoring. The Valve Men Dashboard has an IGVS Monitoring where the engineers can remotely operate to open and close the gate valves that are connected to the Pipelines.

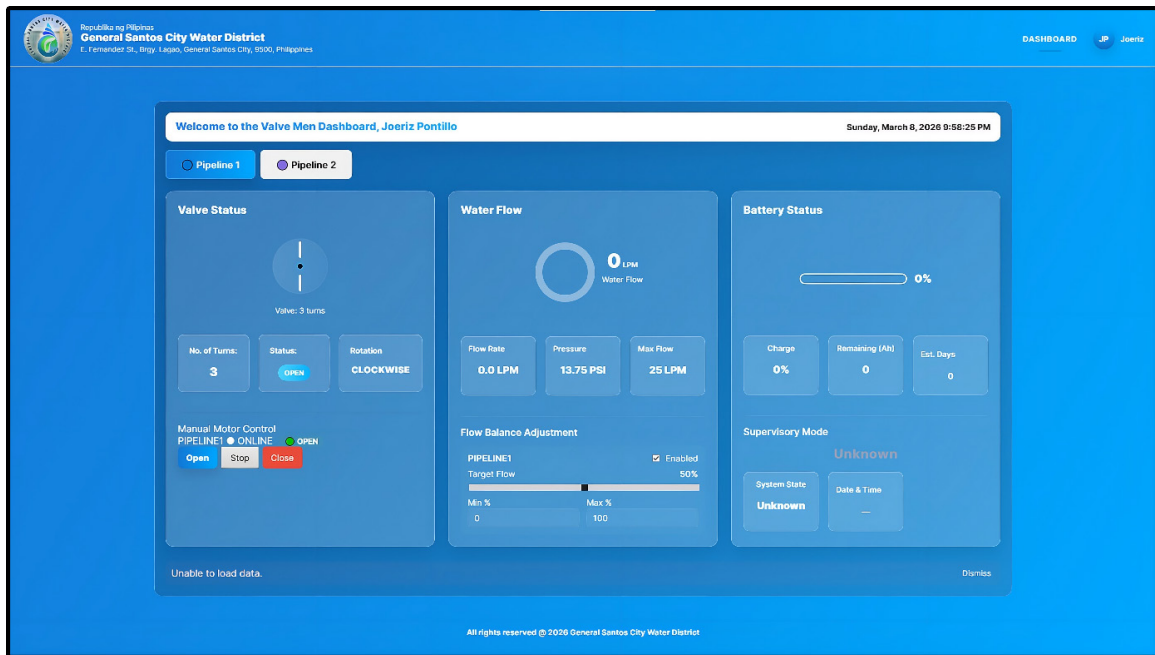


Figure 4: Valve Men Dashboard

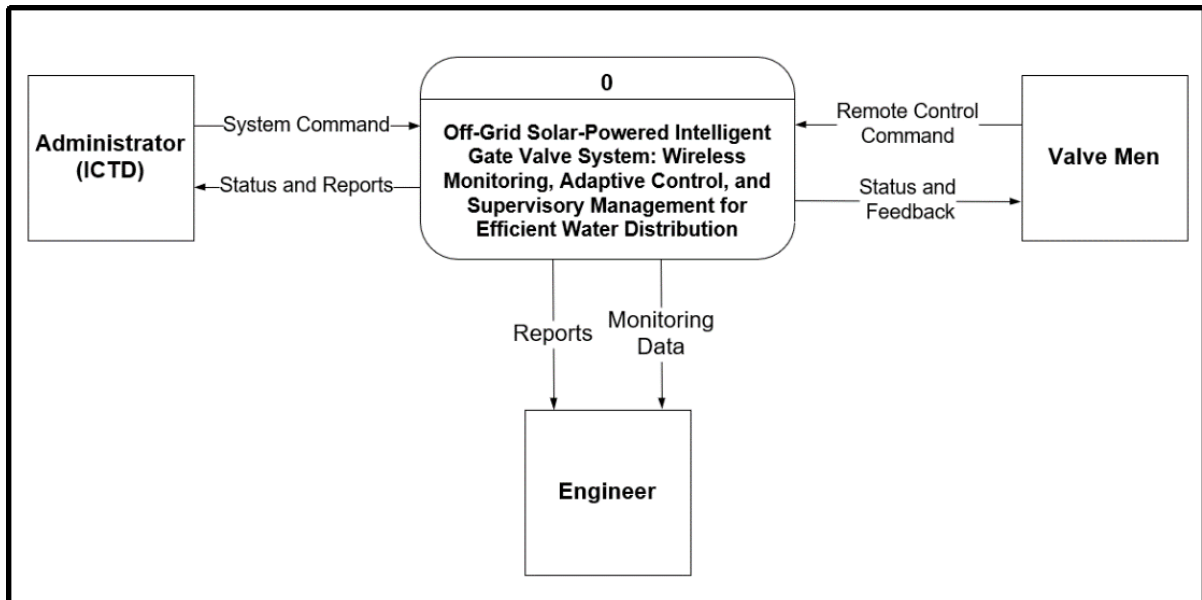


Figure 5: Data Flow Diagram Level 0

The figure illustrates the flow process of the Data Flow Diagram Level 0 of the Intelligent Gate Valve System, and it has 3 entities. The Administrator (ICTD) sends system commands and receives generated reports. The Valve Men can control the gate valve; they can open,

stop, and close the valves remotely, which are connected to the pipelines where the water flows, and when they perform maintenance on the system, the Valve Men can receive status and feedback from the system. The system also provides monitoring to the engineer through

the monitoring dashboard, which includes the Pressure Transducer Transmitter Sensor, YF-B7 Water Flow Sensor, Valve Status, Water Pressure, Battery Status,

and Leak Status, and displays a Calendar picker and has 4 buttons for reports. The users may also download the PDF reports and print them PDF reports.

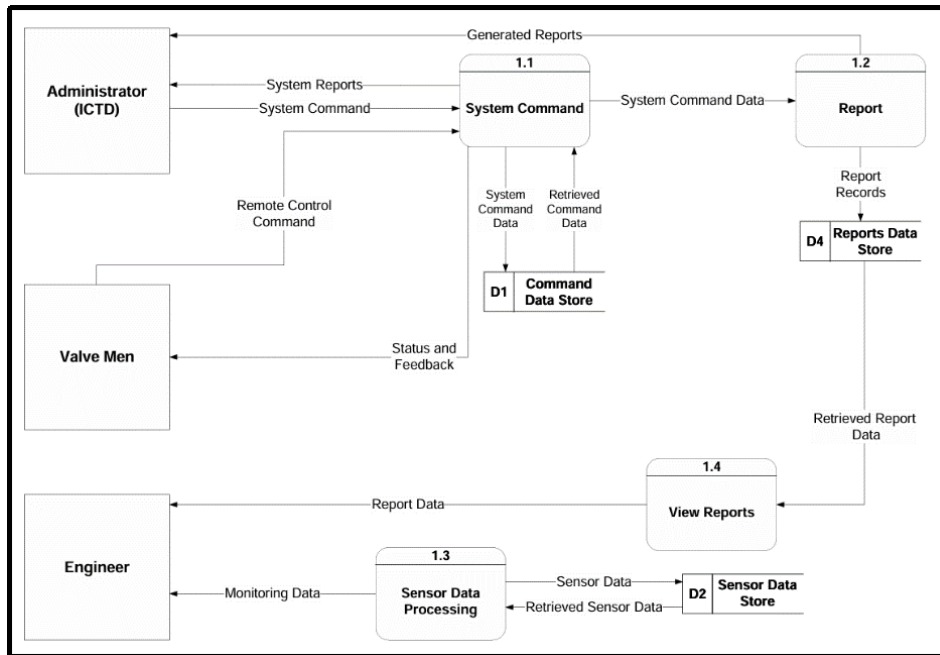


Figure 6: Data Flow Diagram Level 1

This figure illustrates the Data Flow Diagram (DFD) Level 1 for the Intelligent Gate Valve System. The administrator (ICTD) and Valve Men send commands to the system command process to remotely control the gate valves to open and close, which are connected to the pipelines, while the system will send status and feedback back to them. The sensor data processing

process collects and stores sensor data, like Pressure Transducer Transmitter Sensor and YF-B7 Water Flow Sensor, which is provided to the engineer as monitoring data. The reports process generates a PDF report and stores it in the reports data store. While the engineer can access these reports through the view reports process for monitoring.

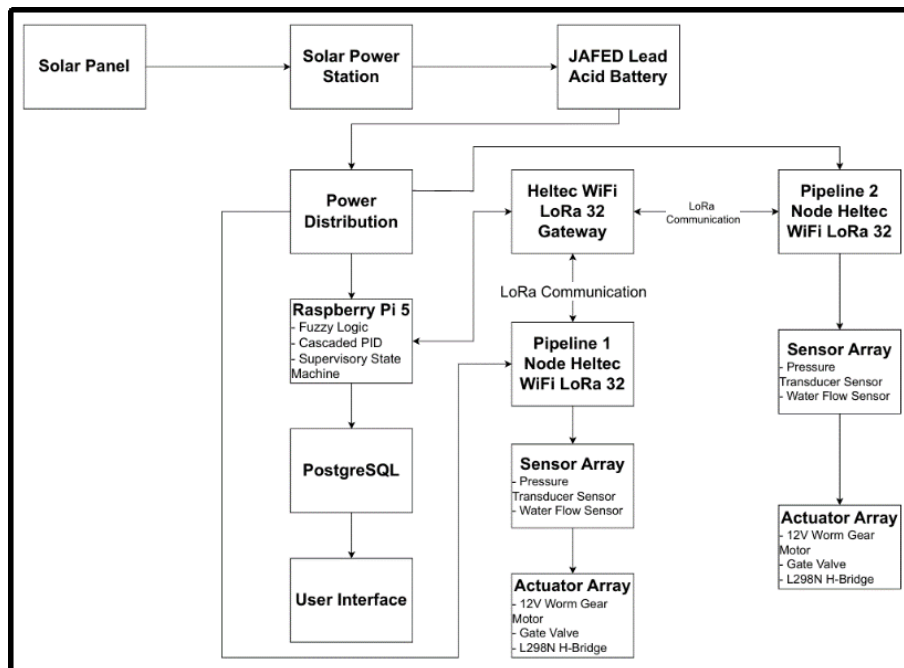


Figure 7: System Block Diagram

The System Block Diagram illustrates how the Intelligent Gate Valve System input and output system works,

which presents how the major components of the system hardware interact with each other to collect data, process data, and regulate the water flow. The hardware

component includes the Raspberry Pi 5 as the primary controller, and three Heltec WiFi LoRa 32 modules as the communication method, two are microcontroller nodes attached to the gate valves and sensors (the Pressure Transducer Transmitter Sensor and YF-B7 Water Flow Sensor), and the other one is for the LoRa gateway. The module node gathers sensor data to be transmitted to the gateway, which is sent to the Raspberry Pi 5 to be processed. Raspberry Pi has Raspberry Pi OS and Python, which control it intelligently based on Fuzzy Logic, Cascaded PID Control, and Supervisory State Machine. The Fuzzy Logic processes the sensor input to calculate the right valve operations.

The Cascaded PID Controller controls process water pressure and valve position with external and internal loops, respectively, and the Supervisory State machine controls the operation of the system modes of normal water flow, high water pressure, leak detector, and maintenance. Upon processing, control commands are transmitted back to Heltec nodes to be used to control the 12 V DC worm-gear motor and to control the gate valves. The Intelligent Gate Valve System is operated through a solar panel as a secondary main source, a charge controller and a battery as the main power source of the system that makes it work off-grid. The system offers periodic updates with which the operators are able to remotely view valve position, water pressure, flow rate and battery status, creating a complete adaptive and efficient smart water distribution system.

RESULTS AND DISCUSSIONS

Implementation Results

The Intelligent Gate Valve System was tested to evaluate its performance and usability before final implementation in the GSCWD. During the implementation, system users were instructed on how the system operates in both software and hardware to properly interpret the features of the software and integrate them with the functionality of the hardware. After the actual testing of the Intelligent Gate Valve System in the GSCWD, the proponents collected survey forms completed by the ICTD Administrator and the valve men. The questionnaire was divided into five categories: Functionality, Accuracy, Effectiveness, Usability, and Hardware. The survey questionnaire included 10–15 respondents, as targeted by the study, specifically the ICTD Administrator and valve men of the General Santos City Water District, located at E. Fernandez Street, Barangay Lagao, General Santos City.

Results of Evaluation

The proponents of the study administered a survey questionnaire to the General Santos City Water District, located at E. Fernandez Street, Barangay Lagao, General Santos City. Below are the results of the survey conducted by the proponents.

Table 1: Functionality Criteria

Functionality	Mean	Description
1. The system performs all the tasks it is intended to do.	4.60	Strongly Agree
2. The features provided by the system are useful in GSCWD.	4.93	Strongly Agree
3. The functions of the system respond correctly without errors.	4.53	Strongly Agree
4. The system is always consistent when in use.	4.60	Strongly Agree
5. The system’s functionality meets the needs of its intended users.	4.80	Strongly Agree
Total Mean:	4.69	Strongly Agree

Table 1 shows the Functionality Criteria of the Intelligent Gate Valve System and also displays the overall results for functionality. All five statements were marked as Strongly Agree, indicating that the respondents were satisfied with the performance of the Intelligent Gate Valve System. The system provides the necessary functions to monitor data through the users’ dashboards and to regulate the gate valve system in the General Santos City Water District. The respondents of the GSCWD also provided comments and suggestions in the survey questionnaires. The statement “The features of the system are useful in the GSCWD” resulted in a mean of 4.93. The statement “The functions of the system respond correctly without any mistakes” received a mean of 4.53 and was also

Table 2: Accuracy Criteria

Accuracy	Mean	Description
1. The system presents accurate and reliable sensor readings.	4.60	Strongly Agree
2. Periodic updates are well represented by the data produced by the system.	4.67	Strongly Agree
3. The measurements within the system assist the user in the right decision making.	4.87	Strongly Agree
4. The system is reliable and accurate in the values recorded.	4.80	Strongly Agree
5. Accuracy level is in line with the requirements by the water district.	4.67	Strongly Agree
Total Mean:	4.72	Strongly Agree

regarded as Strongly Agree. Respondents raised some questions about the operations of the Intelligent Gate Valve System, particularly regarding how the system can remotely control the gate valve to open and close, along with recommendations for improvement. Overall, the five functionality questions yielded a total mean of 4.69 from the 15 respondents.

Table 2 shows the Accuracy Criteria of the Intelligent Gate Valve System and also presents the overall results for accuracy. It displays the respondents' ratings of the Pressure Transducer Transmitter Sensor and the YF-B7 Water Flow Sensor used by the proponents, with all five questionnaire items interpreted as Strongly Agree.

The measurements within the system assist users in making correct decisions through the algorithms and fuzzy logic applied, which received a top score of 4.87 from the GSCWD respondents. The overall mean score was 4.60, still interpreted as Strongly Agree. The five accuracy-related questions yielded a total mean of 4.72 from the 15 respondents, also interpreted as Strongly Agree.

Table 3: Effectiveness Criteria

Effectiveness	Mean	Description
1. The system enhances the monitoring performance of the water distribution.	4.73	Strongly Agree
2. The system is helpful in supporting the operational activities.	4.80	Strongly Agree
3. The system assists in decreasing the number of manuals when dealing with gate valve operations.	4.87	Strongly Agree
4. When the system is actually being tested and used, it works well.	4.73	Strongly Agree
5. The system gets involved in the realization of the desired operation results.	4.67	Strongly Agree
Total Mean:	4.76	Strongly Agree

Table 3 represents the Effectiveness Criteria of the Intelligent Gate Valve System and also displays the overall results for effectiveness. All survey questionnaire items were interpreted as Strongly Agree, indicating that the Intelligent Gate Valve System can remotely control the opening and closing of the two gate valves through IGVS Monitoring, allowing water to flow into the pipelines.

The reduction of manual work during gate valve operations received the highest mean score of 4.87, while the lowest mean score of 4.67 was still interpreted as Strongly Agree. Overall, the five effectiveness-related questions yielded a total mean of 4.76 from the 15 respondents, also interpreted as Strongly Agree.

Table 4: Usability Criteria

Usability	Mean	Description
1. The system is simple to master.	4.60	Strongly Agree
2. The system is easily navigated.	4.80	Strongly Agree
3. Users are able to fulfill their tasks with little effort.	4.73	Strongly Agree
4. The system has instructional feedback and directions.	4.40	Agree
5. The system is user-friendly and efficient to use.	4.60	Strongly Agree
Total Mean:	4.63	Strongly Agree

Table 4 shows the Usability Criteria of the Intelligent Gate Valve System and also presents the overall results for usability. The results indicate that the respondents find the Intelligent Gate Valve System easy to learn and operate.

Despite these positive results, the respondents from the GSCWD expressed amazement at the output and raised some questions about the operations of the Intelligent Gate Valve System, particularly regarding how the system can remotely control the gate valve to open and close, along with recommendations for improvement. The five usability-related questions yielded a total mean of 4.63 from the 15 respondents, which was interpreted as Strongly Agree.

Table 5: Hardware Criteria

Hardware	Mean	Description
1. The system's hardware components are durable and reliable.	4.53	Strongly Agree
2. The sensors are also stable in operation and give accurate readings.	4.60	Strongly Agree
3. The motor and actuator work efficiently with minimal noise and vibration.	4.80	Strongly Agree
4. Solar panel and battery give sufficient power to run all the time.	4.73	Strongly Agree
5. The hardware configuration in general is proper and can be used in the field.	4.73	Strongly Agree
Total Mean:	4.68	Strongly Agree

Table 5 shows the Hardware Criteria of the Intelligent Gate Valve System and also presents the overall results

for hardware. The five hardware-related questions yielded a total mean of 4.68 from the 15 respondents, interpreted as Strongly Agree. This indicates that all respondents from the GSCWD believe the hardware components of the system are suitable for industrial use, which they also noted in their comments on the Intelligent Gate Valve System.

Summary of Findings

The Intelligent Gate Valve System has undergone different procedures and used different materials, from the software side to the hardware side, which is part of building the system. For this study to be done, one of the steps that proponents took was to ask for permission first from the General Manager of the General Santos City Water District to conduct a study and to gather data. After that, the proponents also asked the Acting Department Manager of ICTD about the different problems faced by GSCWD in operating their Gate Valves. The proponents came up with this study because the project that we did during our OJT last summer was also related to the gate

valves.

The proponents integrate one AI and Two Algorithms that include the Fuzzy Logic, Cascaded PID Control, and a Supervisory State Machine. The sensor input is processed by the Fuzzy Logic to determine the correct valve operations. The Cascaded PID Controller controls process water pressure and valve position with external and internal loops, respectively, and the Supervisory State machine controls the operation of the system modes of normal water flow, high water pressure, leak detector, and maintenance.

The results showed that the system was highly evaluated across all categories. The functionality obtained a mean of 4.69, while the accuracy had 4.72, effectiveness 4.76, usability 4.63, and hardware 4.68 for all 15 respondents. All survey questionnaire interpreted as “Strongly Agree,” except for question number 4 under usability, which was only rated as “Agree.”

CONCLUSIONS

The results of the survey conducted at the General Santos City Water District led the proponents to conclude that the study, Off-Grid Solar-Powered Intelligent Gate Valve System: Wireless Monitoring, Adaptive Control, and Supervisory Management for Efficient Water Distribution, successfully addressed all the objectives of the research. The system provides an effective and user-friendly solution for managing underground gate valves. Respondents found the Intelligent Gate Valve System interface highly helpful and expressed strong appreciation for its usability. In the survey questionnaires, most respondents rated the system as Strongly Agree across the different evaluation criteria.

Additionally, respondents provided comments and suggestions that further validate the system’s potential and highlight areas for improvement. These include: “A very innovative idea to reduce safety risks during operations,” “For closer real-world application, the use of a 5-inch or larger gate valve is suggested,” “The system is a highly efficient way to manage water control without the high expense of running utility lines,” “The system has potential for industrial use,” “Well done,” and “Both the device and the website are fully functional and have a good user interface.” These remarks emphasize the system’s innovation, efficiency, and applicability, while also offering constructive feedback for future development.

Recommendations

The results of the Off-Grid Solar-Powered Intelligent Gate Valve System: Wireless Monitoring, Adaptive Control, and Supervisory Management for Efficient Water Distribution, the following recommendations are suggested. To install the Intelligent Gate Valve System in selected locations of General Santos City, to conduct more tests and evaluate the performance of the system. Additional sensors or features in the monitoring interface may be included by future proponents to improve the accuracy and performance of the system. One of the

Table 8: Descriptive Statistical Analysis Using Weighted Mean

Section	Respondents	Q1	Q2	Q3	Q4	Q5
Functionality	1	4	5	4	4	5
	2	5	5	5	5	5
	3	5	5	5	5	4
	4	4	5	5	5	4
	5	4	5	4	4	5
	6	4	5	4	4	5
	7	5	5	5	5	5
	8	5	5	4	5	5
	9	5	5	5	5	5
	10	4	4	5	4	4
	11	5	5	5	5	5
	12	5	5	5	5	5
	13	4	5	4	4	5
	14	4	5	3	4	5
	15	5	5	5	5	5
MEAN:		4.6	4.93333333	4.53333333	4.6	4.8
TOTAL MEAN:	4.69233333					
<hr/>						
Section	Respondents	Q1	Q2	Q3	Q4	Q5
Accuracy	1	4	5	5	5	4
	2	5	5	5	5	5
	3	5	5	5	5	5
	4	5	5	4	5	5
	5	4	4	5	5	5
	6	4	5	5	5	5
	7	5	5	5	5	4
	8	5	5	5	5	5
	9	5	5	5	5	5
	10	5	4	5	5	4
	11	5	5	5	5	5
	12	5	5	5	5	5
	13	4	4	4	4	4
	14	4	3	5	4	4
	15	4	5	5	5	5
MEAN:	4.72	4.6	4.66666667	4.66666667	4.6	4.66666667
TOTAL MEAN:	4.72					
<hr/>						
Section	Respondents	Q1	Q2	Q3	Q4	Q5
Effectiveness	1	5	5	5	5	5
	2	5	5	5	5	5
	3	4	5	5	5	5
	4	4	5	5	5	4
	5	5	5	5	5	5
	6	5	5	5	5	5
	7	5	5	4	5	5
	8	5	5	5	4	5
	9	5	5	5	5	5
	10	4	4	4	5	4
	11	5	5	5	5	5
	12	4	5	5	5	4
	13	5	4	5	4	4
	14	5	4	5	4	4
	15	5	5	5	5	5
MEAN:	4.76	4.73333333	4.8	4.86666667	4.73333333	4.66666667
TOTAL MEAN:	4.76					
<hr/>						
Section	Respondents	Q1	Q2	Q3	Q4	Q5
Usability	1	4	5	5	4	5
	2	5	5	5	5	5
	3	5	5	5	5	5
	4	5	5	4	4	5
	5	4	5	4	4	5
	6	5	5	5	4	5
	7	5	5	5	4	5
	8	4	4	4	4	4
	9	5	5	5	5	5
	10	5	5	5	5	5
	11	5	5	5	5	5
	12	5	5	5	5	4
	13	4	4	5	4	4
	14	3	4	4	4	3
	15	5	5	5	5	5
MEAN:	4.6	4.6	4.73333333	4.4	4.6	
TOTAL MEAN:	4.62666667					
<hr/>						
Section	Respondents	Q1	Q2	Q3	Q4	Q5
Hardware	1	4	4	5	5	5
	2	5	5	5	5	5
	3	4	5	5	5	5
	4	5	5	5	5	5
	5	4	4	5	4	5
	6	4	4	5	4	5
	7	5	5	5	5	5
	8	5	5	5	5	5
	9	5	5	5	5	4
	10	5	4	5	4	4
	11	5	5	5	5	5
	12	4	5	5	5	5
	13	4	4	4	4	4
	14	4	4	5	3	4
	15	5	5	5	5	5
MEAN:	4.68	4.53333333	4.6	4.8	4.73333333	4.73333333
TOTAL MEAN:	4.68					

respondents from GSCWD recommended that a 5-inch or larger gate valve be used to bring the real-world applications closer. To further develop the Intelligent Gate Valve System, future proponents may add more features, such as real-time monitoring (since the system currently provides only periodic updates), predictive maintenance, or improved automation. GPS mapping may be added for the location areas of all the gate valves implemented by the proponents.

REFERENCES

- Abrajano, J. V., Apanay, J., Botangen, K. A., Nabua, J., & Peña, C. F. (2024). IoT-Based Water Quality Monitoring System in Philippine Off-Grid Communities. *ArXiv*. <https://arxiv.org/pdf/2410.14619>
- Agulto, E. S., & Ella, V. B. (2022). Development of a Mobile Application for Wireless Sensor Networks for Efficient Irrigation Water Management. *ResearchGate*. https://www.researchgate.net/publication/361469450_Development_of_mobile_application_for_wireless_sensor_networks_for_efficient_irrigation_water_management
- Arante, H. R. C., Sybingco, E., Roque, M. A., Ambata, L., Chua, A., & Gutierrez, A. N. (2025). Development of a Secured IoT-Based Flood Monitoring and Forecasting System Using Genetic-Algorithm-Based Neuro-Fuzzy Network. *MDPI*. <https://www.mdpi.com/1424-8220/25/13/3885>
- Austria, L. A., & Lacbay, M. M. (2025). Smart Water Management System in a State University in the Philippines: Challenges and Opportunities. *ResearchGate*. https://www.researchgate.net/publication/393328344_Smart_Water_Management_System_in_a_State_University_in_the_Philippines_Challenges_and_Opportunities
- Balerite, D. M., Dela Rosa, L. G., Morfe, R. K. M., Saga, J. B., Bucuda, A. C., Gorres, R. C., Dacuso, P. G., & Delizo, R. A. (2022). An Automated Water Consumption Management System with Water Leak Detection Using Mobile Application. *ResearchGate*. https://www.researchgate.net/publication/362823240_An_automated_water_consumption_management_system_with_water_leak_detection_using_mobile_application
- Bindarwish, S. (2024). A Study of Gate Valve Supply Chain and Life Cycle Impacts. *Rochester Institute of Technology*. <https://repository.rit.edu/theses/12194/>
- Binayao, R., Mantua, P. V., Namocatcat, H. R. M., Seroy, J. K. K., Sudaria, P. R. A., Gumonan, K. M. V., & Orozco, S. M. (2024). Smart Water Irrigation for Rice Farming through the Internet of Things. *ArXiv*. <https://arxiv.org/pdf/2402.07917>
- Boateng, E. A., & Bruce, J. W. (2023). Unsupervised Ensemble Methods for Anomaly Detection in PLC-based Process Control. *ArXiv*. <https://arxiv.org/pdf/2302.02097>
- Daoudi, P., Mavkov, B., Robu, B., Prieur, C., Witrant, E., Barlier, M., & Dos Santos, L. (2024). Improving a Proportional Integral Controller with Reinforcement Learning on a Throttle Valve Benchmark. *ArXiv*. <https://arxiv.org/pdf/2402.13654>
- Decker, C. J., Jiang, H. J., Nemitz, M. P., Root, S. E., Rajappan, A., Alvarez, J. T., Tracz, J., Wille, L., Preston, D. J., & Whitesides, G. M. (2022). Programmable Soft Valves for Digital and Analog Control. *ResearchGate*. https://www.researchgate.net/publication/363879390_Programmable_soft_valves_for_digital_and_analog_control
- Enekci, S., Demir, U., & Yilmaz, K. (2024). Investigation of a Standard Gate Valve in Terms of Flow Rate, Opening Distance and Wedge Angle with CFD. *ResearchGate*. https://www.researchgate.net/publication/383922652_Investigation_of_a_standard_gate_valve_in_terms_of_flow_rate_opening_distance_and_wedge_angle_with_CFD
- Etchon, F. M. M., Sunico, R. J. A., & Sulima, R. A. (2025). Design and Development of the Pipeline Leak Detection System Using Sensor Technology with Mobile and Web Applications. *IJFMR*. <https://www.ijfmr.com/papers/2025/4/50078.pdf>
- Ferrarese, G., Pagano, A., Fratino, U., & Malavasi, S. (2022). On the Potential of a Smart Control Valve System for Irrigation Water Network Management. *MDPI*. <https://www.mdpi.com/2673-4931/21/1/66>
- Gamit, J. D., & Patel, S. (2025). IoT-Based Steam Control Valve Integration with SCADA System. *IJERT*. <https://www.ijert.org/research/iot-based-steam-control-valve-integration-with-scada-system-IJERTV14IS040087.pdf>
- Liu, F., Xiang, Y., & Tang, J. (2025). Water-Saving Control System Based on Multiple Intelligent Algorithms. *ResearchGate*. https://www.researchgate.net/publication/382005620_Water-saving_control_system_based_on_multiple_intelligent_algorithms
- Luan, X., Yu, H., Ding, C., Zhang, Y., He, M., Zhou, J., & Liu, Y. (2025). A Review of Research on Precision Rotary Motion Systems and Driving Methods. *MDPI*. <https://www.mdpi.com/2076-3417/15/12/6745>
- Lakshmi, R. S., Praba, G. C., & Abhirami, K. (2021). Automated Water Management and Leakage Detection System using IoT. *IJRTE*. <https://www.ijert.org/research/automated-water-management-and-leakage-detection-system-using-iot-IJERTCONV9IS05084.pdf>
- Mujoo, S., Sharma, A., Gaikwad, K., Madhe, S., Joshi, A., Sista, S., & Khatape, M. (2021). Smart Irrigation System using IoT-based Control Valve. *ResearchGate*. https://www.researchgate.net/publication/355075501_Smart_Irrigation_System_using_IoT_based_Control_Valve
- Magibalan, S., & Sundar, S. (2023). A Review: Analysis and Modelling of Gate Valve with Prevention System Fabrication 3D Printing Method. *IRJMETS*. https://www.irjmets.com/uploadedfiles/paper//issue_2_february_2023/33375/final/fn_irjmets1675915185.pdf

- Melgazo, D. E. K. M., Raagas, D. P., & Caluza, L. J. B. (2023). User Evaluation of the Smart Water Tank Technology. *Research Gate*.
https://www.researchgate.net/publication/368788989_User_Evaluation_of_the_Smart_Water_Tank_Technology
- Prajwal, B. N., Yelchuri, H., Shastry, V., & Prabhakar, T. V. (2022). PreMa: Predictive Maintenance of Solenoid Valve in Real-Time at Embedded Edge-Level. *ResearchGate*. https://www.researchgate.net/publication/365661928_PreMa_Predictive_Maintenance_of_Solenoid_Valve_in_Real-Time_at_Embedded_Edge-Level
- Raagas, D. P., Melgazo, D. E. K. M., Ergina, D. C. S., & Verecio, R. L. (2022). Smart Water Tank System using Wi-Fi-based Microcontroller Unit. *South Florida Journal of Development*. <https://ojs.southfloridapublishing.com/ojs/index.php/jdev/article/view/1366>
- Redekar, A., Deb, D., & Ozana, S. (2022). Functionality Analysis of Electric Actuators in Renewable Energy Systems—A Review. *MDPI*. <https://www.mdpi.com/1424-8220/22/11/4273>
- Selerio, E. F. (2024). Multicriteria Analysis of Decentralized Wastewater Treatment Technologies for the Philippines. *ArXiv*. <https://arxiv.org/pdf/2410.22484>
- Santos, L. Q., Bautista, J. C. D., Estanque, M. W. S., Paloa, C. J. B., & Villaran, A. B. A. (2021) Development of an IoT-based Water and Power Monitoring System for Residential Building. *Semantic Scholar*.
<https://pdfs.semanticscholar.org/8eb0/ce2678c11dc63f156f54e0dd7d8e3197b43f.pdf>
- Su, J. (2024). Design and Research of Intelligent Valve Control. *ResearchGate*. https://www.researchgate.net/publication/342246624_Design_and_Development_of_a_Solar-Powered_Smart_Irrigation_System-An_Adaptive_Process_Model
- Te, M. C. L., Bautista, J. A. T., Dimacali, S. M. E. V., Lood, A. V. M., Pangan, M. G. M., & Chua, A. Y. (2024). A Smart IoT Urban Flood Monitoring System Using a High-Performance Pressure Sensor with LoRaWAN. *HighTech and Innovation Journal*. <https://hightechjournal.org/index.php/HIJ/article/view/929/pdf>
- Valle, J. D., & Yara, F. (2024). An Event-Driven Mobile Application for Gas Leakage Monitoring and Detection using Firebase and IoT. *ResearchGate*. https://www.researchgate.net/publication/380637009_An_Event-Driven_Mobile_Application_for_Gas_Leakage_Monitoring_and_Detection_using_Firebase_and_IoT
- Wang, H., Wen, F., Liu, G., Jia, P., Yun, F., Wang, L., Wang, Y., & Li, C. (2023). An All-Electric Gate Valve Actuator for Subsea Production Control Systems, Part A: Prototype and Test. *MDPI*. <https://www.mdpi.com/2077-1312/11/5/1043>
- Zhang, W., Jia, P., Zheng, H., Wang, G., Wang, T., Wang, X., Yun, F., & Wu, M. (2025). A Low-Power Consumption Deepwater Subsea Electric Gate Valve Actuator, Part A: Prototype and Test. *MDPI*. <https://www.mdpi.com/2077-1312/13/2/302>
- Zhang, Z., Zhou, Q., Jin, H., Li, Q., & Dai, Y. (2024). A Real-Time Intelligent Valve Monitoring Approach through Cameras Based on Computer Vision Methods. *MDPI*. <https://www.mdpi.com/1424-8220/24/16/5337>