Water flow control and monitoring system in pipes using water flow sensor

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ABSTRACT

This paper discusses the design, construction, and testing of a water flow control and monitoring system in pipes that aims to detect leaks and combine water flow in real time to improve efficiency and reduce potential losses due to leaks. This system is designed using water flow sensors placed in each channel in a certain number to detect the air flow rate. The difference in air flow read from several sensors is used as an indication of a leak. This system is integrated with a microcontroller and is equipped with control via an electric solenoid valve that allows for leak handling and air flow diversion when needed. Several tests have been conducted to ensure the system is ready for use, and the results show that the system is able to control air flow well without any problems, and is able to monitor air flow in real time, detecting changes in flow when a leak occurs. This research contributes to a device for controlling and monitoring water flow in pipes to improve the efficiency of water channel handling.

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1. INTRODUCTION

Water is one of the basic human needs, and various methods are used to obtain water to meet these needs. The availability of clean water is a crucial aspect in ensuring the sustainability of human life and a healthy ecosystem [1],[2]. The need for clean water is crucial for communities, whether for drinking, cooking, bathing, or washing [3]. However, meeting clean water needs is often a challenge in areas far from water sources or near swamps, as available water drawn from wells is often dirty and smelly [4],[5]. Water conservation is necessary in areas with scarce water sources, including through monitoring to control daily water use [6].

Using clean water managed by a company is one solution with a relatively affordable cost. This clean water is taken from the water source, then collected in reservoirs before being distributed to various locations in need [7]. The distribution process is carried out using infrastructure designed to control the flow of water until it reaches its destination [8]. This system enables the sustainable availability of clean water, especially in urban areas with high water demand. With this approach, access to clean water can be significantly improved, although infrastructure evaluation and maintenance are still needed to ensure distribution efficiency [9],[10]. However, clean water management is not free from various problems. One of the main problems is cloudy water caused by broken or damaged underground pipes. As a result of this damage, water distributed to residents' homes can mix with soil, thereby reducing its quality [11],[12]. The further a house is from a water source, the greater the possibility of disruptions to the quality of the water received, such as contamination or reduced water pressure [13],[14].

Previous research conducted by [15] identified several weaknesses in the existing system, where the system only monitors water flow in pipes, such as calculating the volume of water passing through the pipe and detecting leaks. However, the system is not equipped with a control mechanism for water flow through the pipe. Water flow control must be carried out quickly when needed to conserve water use and reduce losses due to pipe leaks. Currently, water flow control is still carried out conventionally, so remote water flow control is needed to save time and energy. Another study conducted by [16] regarding the use of an automated system using a water flow sensor and NodeMCU ESP 8266. In this study, water discharge measurements were carried out using a water flow sensor to monitor water use and save water. This system functions to check whether the water flow sensor can measure the match between the existing water volume and the water volume recorded by the sensor. However, in this study, the system only monitors the results of water use measurements and sends the data to the user. Based on the problems found above, the author is interested in conducting research by creating a "Design and Construction of a Water Flow Control and Monitoring System in Pipes Using a Microcontroller-Based Water Flow Sensor" with this research it is hoped that the control and monitoring systems in pipes can be carried out properly and effectively. This system can be applied in various fields, not only for human consumption, but also in agriculture and industry. If a leak occurs, the leaking pipe section can be immediately shut off so that the level of water loss can be reduced.

2. METHOD

Tool design is an important method to be carried out to reduce errors in the tool manufacturing process. This method is useful for designing hardware and software, hardware design is designed using software that functions as a design of tools and components to be designed, while software design includes block diagrams, tool design, working principles, and flowcharts. A block diagram is a depiction of a system represented by a box or square block that has its own function to explain the system design that is made and then connected with lines that are useful for the workflow of the system. The block diagram of the final project to be designed can be seen in Figure 1.

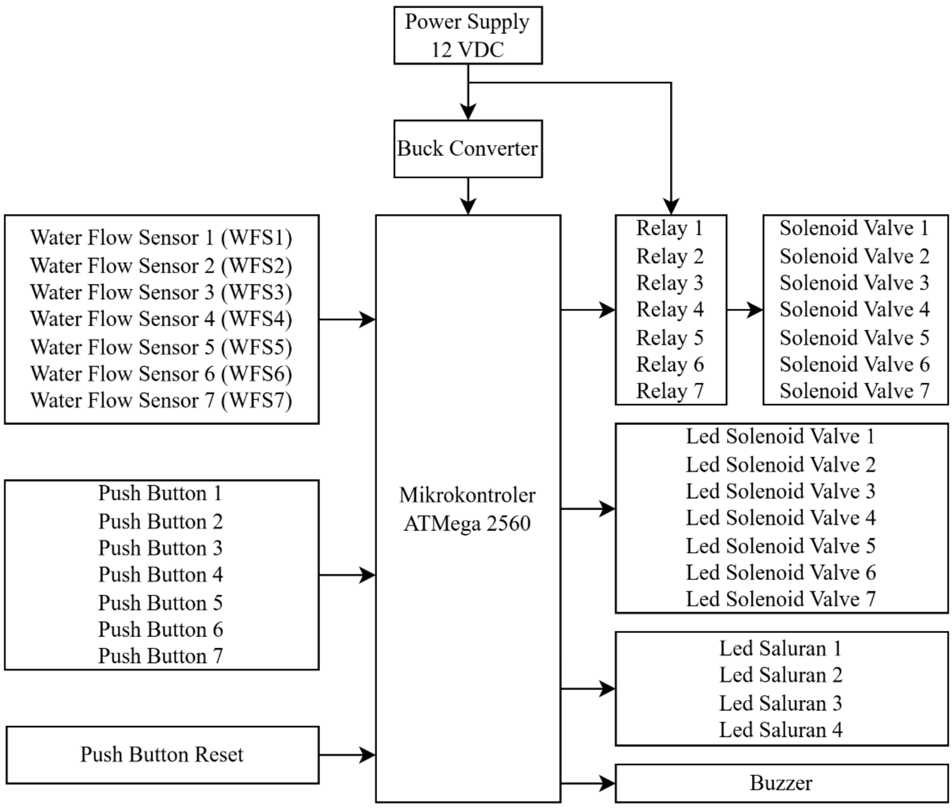

Figure 1. Block diagram of proposed system

The following is an explanation of the block diagram in Figure 1: 1) 12V DC power supply, the AC power source will be converted by the power supply into DC electricity to run the system, this power supply is used as the main power source in running the system. 2) Buck converter or DCDC step down converter, has a function to reduce the voltage from the power supply to the Arduino Mega 2560 Microcontroller. 3) The microcontroller, used is the Arduino ATMega 2560 which is used as a center for the process of exchanging and processing data from sensors and controlling the output connected to the system. 4) Water flow sensor 1 (WFS1) - Water flow sensor 7 (WFS 7), is an input component in the form of a sensor used to measure the water discharge flowing in the water pipe. 5) Push button 1 - push button 7 is an input component in the form of a push button used to control the electrical solenoid valve in active and inactive conditions. 6) Push button reset is an input component in the form of a push button used to turn off the buzzer when the system detects a line leak. 7) Relay 1 - Relay 7 is an output component in the form of a relay used as a switch to activate the electrical solenoid valve. 8) Electrical solenoid valve 1 - Electrical solenoid valve 7 is an output component used to control water flow. The electrical solenoid valve is controlled by a switch controlled by a push button. 9) LED electrical solenoid valve 1 - LED electrical solenoid valve 7 is a component used to indicate when the electrical solenoid valve is active and inactive. 10) LED channel 1 - LED channel 4 is a component used to indicate the condition of the water pipe. 11) Buzzer, used to provide an audible signal when the system detects a water pipe leak.

Basically, the working principle of this device is to control or control the direction of water flow in the water pipe and detect leaks in the water pipe using a water flow sensor to read the water flow. Controlling the direction of water flow is done by controlling the electrical solenoid valve installed in the water pipe. Controlling the electrical solenoid valve is intended to regulate water flow if a leak occurs along the water pipe and is also intended when the direction of water flow is needed. Pipeline leak monitoring is performed by detecting the water flow rate in each water channel. The water flow rate is measured using a water flow sensor. Water flow sensors operate based on the Hall effect principle. This sensor detects the speed of water flowing through the sensor. From this speed, the amount of water passing through the sensor is also determined. In the prototype, several water flow sensors are installed in each channel, each sensor calculating the water flow rate over time. The amount of incoming water is compared with the amount of outgoing water through the sensor readings.

Hardware design involves designing the components and the model/design of the device to be built. Hardware design aims to facilitate the construction of the device before its actual implementation. Hardware design encompasses mechanical and electrical design. Mechanical design is a systematic process for creating and developing mechanical components and systems that function properly and efficiently. Water flow control and monitoring in the pipes is carried out on a panel connected to the prototype, allowing for real-time monitoring and control of the water flow through the device. This panel is equipped with sensors and indicators that provide information and can detect any disturbances or leaks in the pipe system to ensure operational efficiency and safety. In mechanical design, each component of the device is designed to function as intended, thus achieving the research objectives.

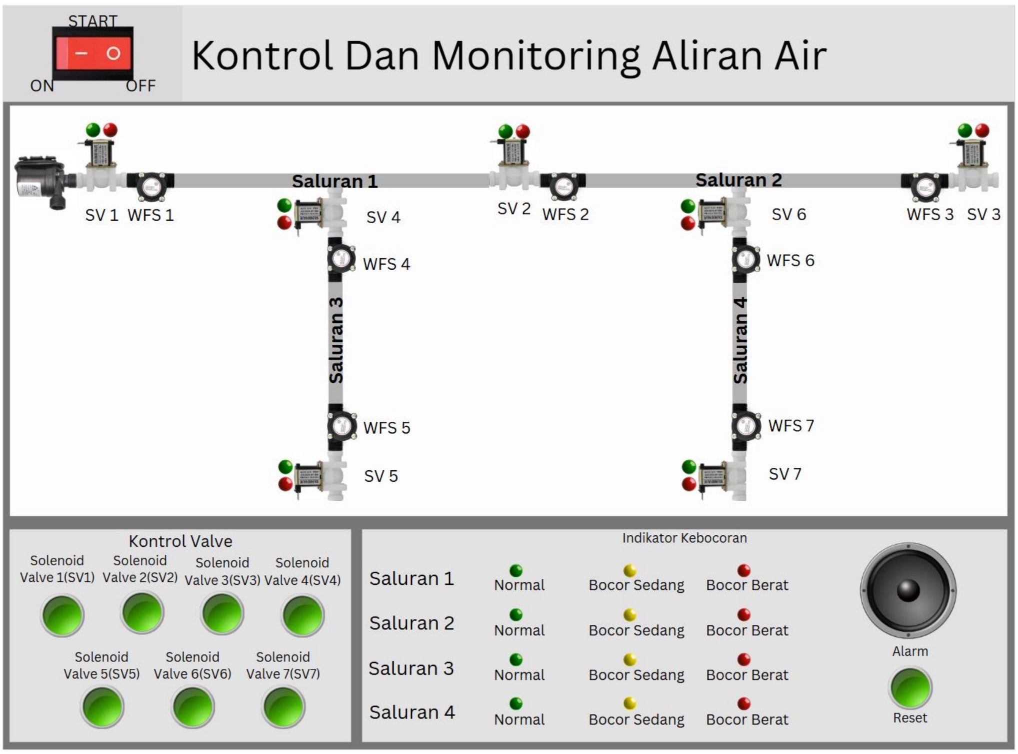

Figure 2. Water flow control and monitoring panel

Figure 2 shows the water flow control and monitoring panel, made of acrylic. This panel is ergonomically designed and equipped with various supporting components, such as an on/off push button, LED indicator lights, a buzzer, and additional push buttons for control and reset functions. In the monitoring section, the system is equipped with visual indicators in the form of LED lights that will light up to provide information on the status of water flow in each pipe and the active or inactive condition of the electrical solenoid valve. In total, there are seven physical push buttons, each of which functions to control seven electrical solenoid valves independently. In addition, there is a special push button used to reset or turn off the buzzer in the event of an alarm due to leak detection or system disturbance, so that users can easily control and respond to system conditions directly.

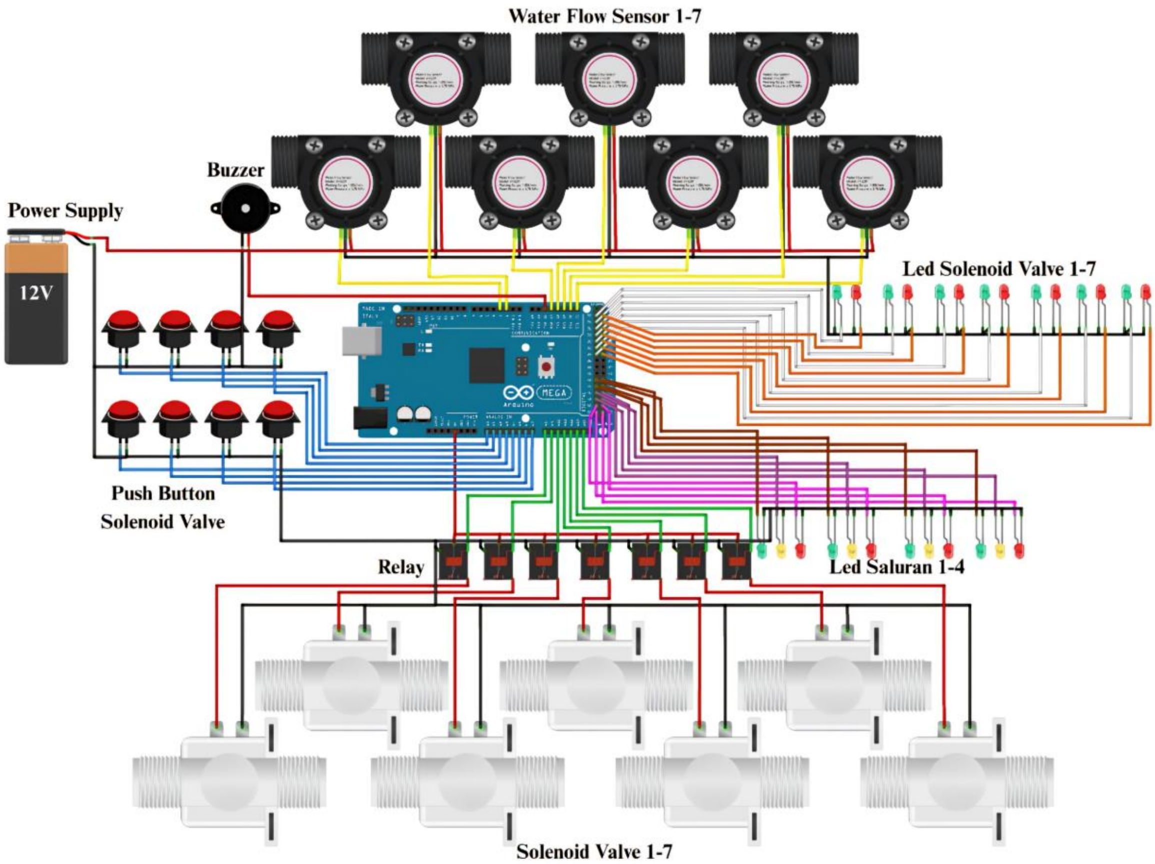

Figure 3. Electrical circuit of the proposed system

Figure 3 shows the electrical design used in the device. The purpose of the electrical design is to design the electrical path and determine the number of cables required for the device. This design will serve as a guide for the electrical installation, connecting the output and input components. Electrical design is essential during electrical installation because it will serve as a reference for the electrical installation. Flowchart planning is intended to illustrate the work process stages of the tool to be created. Flowcharts help visualize the system's workflow using graphic symbols.

Figure 4 is a flowchart of the system to be created. When the system is active, the system will initiate variables to the microcontroller. The sensors will immediately detect the water discharge in the water channel. There are 7 sensors divided into 4 channels, each sensor will read the water discharge in the channel and then compare the water discharge on each sensor. When the sensor detects a difference in water discharge, the system will read the amount of water discharge that is the difference and will then proceed to the next step, namely determining the condition of the channel. When the difference in water discharge is less than x, the channel is said to be normal and the green LED is active. When the difference in water discharge between x and y, the channel is said to be leaking moderately and the yellow LED is active. When the difference in water discharge is more than y, the channel is detected as a heavy leak, the red LED is active and the buzzer is active. The buzzer can be turned off by pressing the reset push button. When the system is active, push buttons 1-7 can be used to control the relay connected to the valve so that it can control water flow. When the valve is active, the green LED will be active, when it is inactive, the red LED will be active.

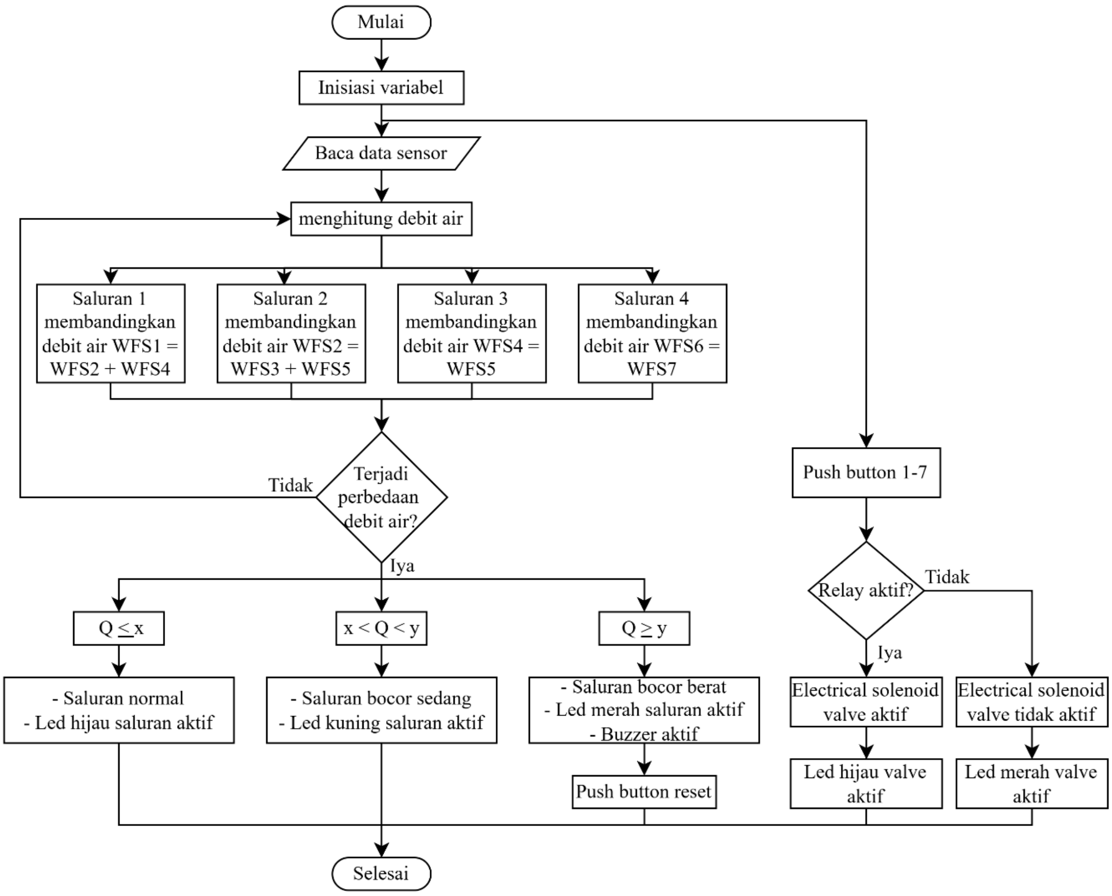

Figure 4. Flowchart of proposed system

3. RESULTS AND DISCUSSION

A water pipe control and monitoring system is a device used to detect leaks in water pipes in real time. In this study, a prototype was designed to support the creation of a water pipe control and monitoring system. The prototype was created according to the existing design. Figure 5 shows a prototype of monitoring and flow in a water pipe.

Figure 5. Prototype of monitoring and water flow

The primary purpose of this calibration is to determine how accurately the sensor can measure water flow and identify any deviations. In practice, the sensor readings are compared with manual measurements, which are considered a standard reference. If there are differences between the sensor readings and the manual measurements, corrections or recalibration are performed to obtain more precise and reliable measurement results in various applications requiring high-accuracy water flow measurements. Figure 6 shows a test on a water flow sensor.

Figure 6. Water flow sensor testing

Sensor calibration is performed by comparing the water discharge data read by the sensor with the actual water volume measured manually over a certain time, namely 1 minute. This process is carried out by flowing water through the sensor for one minute, then recording the average discharge value from the sensor and the volume of water collected during that period using a manual measuring tool such as a measuring cup. Because the measurement time is set for 1 minute, the discharge value read from the sensor can be directly compared with the manually collected volume. The water discharge in manual measurements can be obtained by dividing the measured water volume by the time of 1 minute. By comparing these two data, the difference can be calculated, and used to determine the correction factor or sensor accuracy, so that the sensor reading can be adjusted to approach the actual measurement results. By using the following formula, the sensor accuracy level value is obtained as 98.76% for sensor accuracy value 1. In the calculation of the accuracy of other sensors using the same method as the calculation for sensor 1. Table 1 describes the accuracy values of sensors 1-7.

Table 1. Level of sensor accuracy and water discharge readings

No.	Sensor	Sensor measurement results	Manual measurement results	Sensor accuracy level
1	Sensor 1	10.37 L/min	10.50 L/min	98.76%
2	Sensor 2	10.40 L/min	10.40 L/min	98.37%
3	Sensor 3	10.32 L/min	10.50 L/min	98.29%
4	Sensor 4	10.48 L/min	10.60 L/min	98.87%
5	Sensor 5	10.78 L/min	10.90 L/min	98.90%
6	Sensor 6	10.70 L/min	10.70 L/min	98.69%
7	Sensor 7	10.22 L/min	10.40 L/min	98.27%
		Average		98.59%

This calibration data, it can be concluded that all sensors have adequate performance because level accuracy is above 98%. Sensor 5 and sensor 4 can be considered as sensors with high performance. Best because own level accuracy the highest . The results of this calibration are important as a basis for making corrections to sensor readings or as a consideration in selecting the most suitable sensor for the application. certain things that need level accuracy high in water discharge measurements.

Testing electrical solenoid valve aims to evaluate effectiveness device in control water flow in the pipe. The testing process is carried out by flowing water through an electrical solenoid valve, then test its function in the following way enable and disable it. Table 2 shows the test results electrical solenoid valve.

Table 2. Testing electrical solenoid valve

No.	Electrical solenoid valve	Push button condition	Solenoid valve condition	Light indicator
1	Esv 1	On	Active	Green
		Off	Not active	Red
		On	Active	Green
2	Esv 2	On	Active	Green
		Off	Not active	Red
		On	Active	Green
3	Esv 3	On	Active	Green
		Off	Not active	Red
		On	Active	Green
4	Esv 4	On	Active	Green
		Off	Not active	Red
		Off	Not active	Red
5	Esv 5	On	Active	Green
		Off	Not active	Red
		On	Active	Green
6	Esv 6	On	Active	Green
		Off	Not active	Red
		On	Active	Green
7	Esv 7	On	Active	Green
		Off	Not active	Red
		On	Active	Green

Testing with Variations in Leak Conditions is intended to determine the leak conditions that occur in the prototype, including the location and level. leaks that can be detected by the system. Based on the principle continuity in mechanics fluid. The amount of water flowing in will be the same as the amount of water coming out. If not there accumulation or loss mass for example occurs leaks. For this reason, it is necessary to measure the water debit when there is no leak . Figure 7 is a water flow diagram. The water discharge data obtained will be used as a basis for determining classification level leaks. From this water discharge data, it can be determined Minimum limits for normal channels, moderate leak channels, and heavy leak channels. Table 3 shows the water discharge under normal conditions.

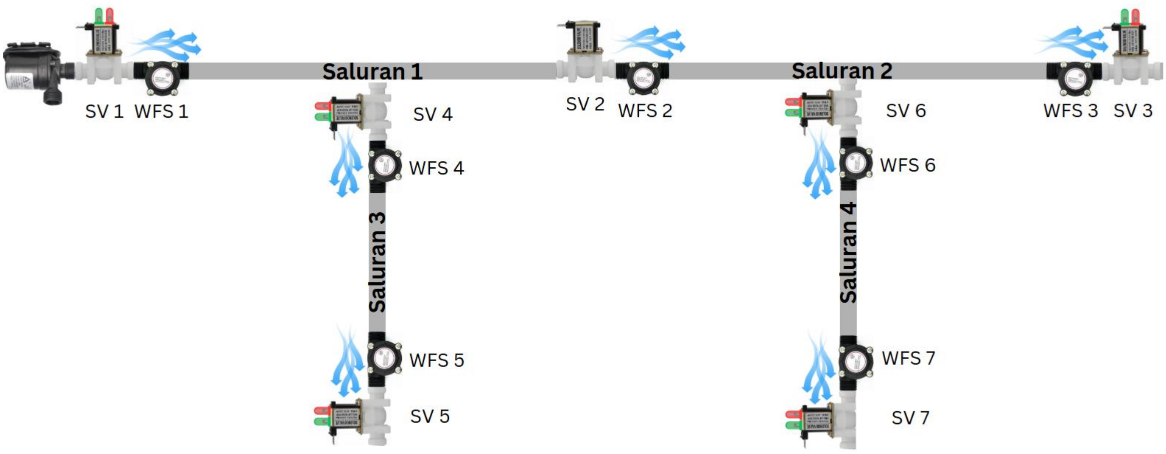

Figure 7. Water flow scheme

Table 3. Water discharge under normal conditions

Sensor	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6	Sensor 7
Water discharge	10.45	6.57	4.63	3.88	3.88	1.94	1.94

From normal water flow measurements, it's known that the amount of water flowing through each branch varies. This is influenced by the presence of valves in each branch. Therefore, the water flowing through the valves will be slower than the water flowing through the outlets. Therefore, a scaled difference value is needed to suit each channel. From Figure 7 it can be seen that in each channel has sensors that are directly connected. Based on the concept continuity so determine which sensors are used as channel inputs and outputs channels and can be used to detect leakage in each channel. These input and output values will compared to Then mark difference will be adjusted to the value water discharge scale. Table 4 is input and output configuration channel .

Table 4. Input and output configuration channel

Channel	Sensor	
	Input	Output
Channel 1	WFS1	WFS2 + WFS4
Channel 2	WFS2	WFS3 + WFS6
Channel 3	WFS4	WFS5
Channel 4	WFS6	WFS7

The system is designed to detect leaks using a scale classification certain based on water discharge value under normal circumstances . This value is calculated from difference between the initial discharge and the discharge seen in the comparison sensor . According to its normal discharge characteristics , each channel have different value limits . The scale helps the system find the leak status automatically and shows indicator proper warning . Table 5 is scale condition waterways .

Table 5. Value scale difference in water discharge for water channel conditions .

Channel	Scale		
	Normal (x)	Moderate Leakage (x<Q<y)	Heavy Leak (y)
Channel 1	Q < 2	2 < Q < 8	Q > 8
Channel 2	Q < 2	2 < Q < 4	Q > 4
Channel 3	Q < 2	2 < Q < 3	Q > 3
Channel 4	Q < 1	1 < Q < 1.5	Q> 1.5

Table 6. Detection of location and condition of pipe leaks .

No.	Leak Test		Sensor Reading Value			System Reading	
	Leak Location	Size of the Faucet Opening	Sensor	Debit	Difference	Leak Indicator	LED Indicator
1	Channel 1	14°	(in) 1 (out) 4	10.45 L/m 2.78 L/m	1.13 L/m	Normal	Green
		45°	(in) 1 (out) 4	10.45 L/m 2.23 L/m	4.24 L/m	Moderate Leak	Yellow
		79°	(in) 1 (out) 4	10.45 L/m 1.13 L/m	8.26 L/m	Heavy Leak	Red
2	Channel 2	23°	(in) 2 (out) 6	6.57 L/m 1.67 L/m	1.21 L/m	Normal	Green
		37°	(in) 2 (out) 6	6.57 L/m 1.12 L/m	3.02 L/m	Moderate Leak	Yellow
		66°	(in) 2 (out) 3 (out) 6	6.12 L/m 1.60 L/m 0.32 L/m	4.2 L/m	Heavy Leak	Red
3	Channel 3	15°	(in) 4 (out) 5	4.63 L/m 2.86 L/m	1.77 L/m	Normal	Green
		52°	(in) 4 (out) 5	4.63 L/m 1.96 L/m	2.67 L/m	Moderate Leak	Yellow
		77°	(in) 4 (out) 5	4.63 L/m 1.56 L/m	3.07 L/m	Heavy Leak	Red
4	Channel 4	22°	(in) 6 (out) 7	2.27 L/m 1.84 L/m	0.43 L/m	Normal	Green
		46°	(in) 6 (out) 7	2.27 L/m 0.93 L/m	1.34 L/m	Moderate Leak	Yellow
		62°	(in) 6 (out) 7	2.27 L/m 0.32 L/m	1.95 L/m	Heavy Leak	Red

Table 6 explains scale mark difference to determine the channel conditions on each channel . Because on each channel obtained mark different sensor readings, then boundary values for x and y must be determined moreover first. The values of x and y are obtained by subtracting from the limit values obtained during normal water discharge testing. The x and y values refer to the system flowchart. Simulation leaks are checked by turning the tap that has been determined, then the system will reading the water discharge passing through the pipe and providing information via the electrical panel, classifying level leakage from moderate to weight. Detection of leak conditions is done by adjusting size tap opening so that the system can differentiate between normal pipe conditions, moderate leaks, and severe leaks, providing warning early to potential problems with the channel based on magnitude faucet opening measured in degrees (°). Table 6 shows the test results detect the location and condition of pipe leaks.

Based on test results, it can be concluded that the *monitoring system* used to determine the location of the leak The results were quite satisfactory. The system was successful read various simulated leak conditions during testing. All components worked as expected. This success demonstrates that the system can be relied upon to support the existing water distribution system. water distribution can be managed better. There are some development suggestions that can be considered to improve functionality . Added status indicators to the control panel in the form of an LCD screen so that the channel conditions are clearer. Additional features history of channel conditions to find out anytime there is indication leak.

4. CONCLUSION

Overall the prototype developed has succeed fulfill the main objective of the research, namely capable control effective water flow at a time detect location and level leaks in water distribution pipes. This system works by integrating water flow sensors, actuators such as solenoid valves, and logic control based microcontroller that allows monitoring and control real-time flow. The system's ability to detect difference rate flow in each pipe segment provides clear indication to potential leaks , either from in terms of location and level severity. This success shows that the prototype has mark highly applicable and can be a practical solution to overcome problem water loss in the distribution system.

REFERENCES

[1] S. Basu, A. Ahmed, H. Pareek and P. K. Sharma, "Autonomous Water Flow Control And Monitoring System," *2022 Interdisciplinary Research in Technology and Management (IRTM)*, Kolkata, India, 2022, pp. 1-4, doi: 10.1109/IRTM54583.2022.9791534.

[2] A. A. S. Chowdhury, Y. Arafat and M. S. Alam, "IoT-GSM Based Controlling and Monitoring System to Prevent Water Wastage, Water Leakage, and Pollution in the Water Supply," *2022 International Conference on Innovations in Science, Engineering and Technology (ICISET)*, Chittagong, Bangladesh, 2022, pp. 567-572, doi: 10.1109/ICISET54810.2022.9775876.

[3] M. V. C. Caya, A. G. Narciso, M. C. A. Roque and W. -Y. Chung, "Integration of Water Control with a Drip Irrigation System for Agricultural Application," *2019 IEEE 11th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM)*, Laoag, Philippines, 2019, pp. 1-5, doi: 10.1109/HNICEM48295.2019.9072773.

[4] U. G. Sharanya, K. M. Birabbi, B. H. Sahana, D. M. Kumar, N. Sharmila and S. Mallikarjunaswamy, "Design and Implementation of IoT-based Water Quality and Leakage Monitoring System for Urban Water Systems Using Machine Learning Algorithms," *2024 Second International Conference on Networks, Multimedia and Information Technology (NMITCON)*, Bengaluru, India, 2024, pp. 1-5, doi: 10.1109/NMITCON62075.2024.10698922.

[5] X. Cui, Y. Gao, Y. Ma, Y. Liu and B. Jin, "Variable Step Normalized LMS Adaptive Filter for Leak Localization in Water-Filled Plastic Pipes," in *IEEE Transactions on Instrumentation and Measurement*, vol. 71, pp. 1-11, 2022, Art no. 9600511, doi: 10.1109/TIM.2022.3169526.

[6] Y. A. Putra and M. Yuhendri, "Smart Monitoring Pompa Air Otomatis Berbasis Human Machine Interface Dan Internet Of Things," *JTEIN J. Tek. Elektro Indones.*, vol. 4, no. 2, pp. 863–876, 2023.

[7] P. M. Bach and J. K. Kodikara, "Reliability of Infrared Thermography in Detecting Leaks in Buried Water Reticulation Pipes," in *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 10, no. 9, pp. 4210-4224, Sept. 2017, doi: 10.1109/JSTARS.2017.2708817.

[8] M. Fahmy and O. Moselhi, "Automated detection and location of leaks in water mains using infrared photography," *J. Perform. Constructed Facilities*, vol. 24, pp. 242–248, 2010.

[9] S. Ge and S. Sinha, "Failure analysis, condition assessment technologies, and performance prediction of prestressed-concrete cylinder pipe: State-of-the-art literature review," *J. Perform. Constructed Facilities*, vol. 28, pp. 618–628, 2014.

[10] A. Gunatilake and J. V. Miro, "Multimodel Neural Network for Live Classification of Water Pipe Leaks From Vibro-Acoustic Signals," in *IEEE Sensors Journal*, vol. 24, no. 9, pp. 14825-14832, 1 May1, 2024, doi: 10.1109/JSEN.2024.3379476.

[11] A. Soldevila, J. Blesa, T. N. Jensen, S. Tornil-Sin, R. M. Fernández-Cantí and V. Puig, "Leak Localization Method for Water-Distribution Networks Using a Data-Driven Model and Dempster–Shafer Reasoning," in *IEEE Transactions on Control Systems Technology*, vol. 29, no. 3, pp. 937-948, May 2021, doi: 10.1109/TCST.2020.2982349.

[12] J. M. Aitken *et al.*, "Simultaneous Localization and Mapping for Inspection Robots in Water and Sewer Pipe Networks: A Review," in *IEEE Access*, vol. 9, pp. 140173-140198, 2021, doi: 10.1109/ACCESS.2021.3115981.

[13] A. Cataldo, G. Cannazza, E. De Benedetto and N. Giaquinto, "A New Method for Detecting Leaks in Underground Water Pipelines," in *IEEE Sensors Journal*, vol. 12, no. 6, pp. 1660-1667, June 2012, doi: 10.1109/JSEN.2011.2176484.

[14] A. Lay-Ekuakille and P. Vergallo, "Decimated Signal Diagonalization Method for Improved Spectral Leak Detection in Pipelines," in *IEEE Sensors Journal*, vol. 14, no. 6, pp. 1741-1748, June 2014, doi: 10.1109/JSEN.2014.2302394.

[15] M. Liu, S. Li, S. Liu, G. Guo, M. Cai and Z. Dai, "Leak Location for Urban Elbowed Water Pipe Based on Complex-Optimized FastICA Blind Deconvolution," in *IEEE Sensors Journal*, vol. 23, no. 4, pp. 4033-4042, 15 Feb.15, 2023, doi: 10.1109/JSEN.2023.3236034.
[16] M. R. Islam, S. Azam, B. Shanmugam and D. Mathur, "An Intelligent IoT and ML-Based Water Leakage Detection System," in *IEEE Access*, vol. 11, pp. 123625-123649, 2023, doi: 10.1109/ACCESS.2023.3329467.