



Automatic Flow Controller Using Hall Effect Sensor

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Abstract- This article presents a smart fluid flow controller system using Hall Effect sensors to monitor real-time liquid levels or flow rates. The system uses an ESP32 and Atmega328p microcontroller to process sensor data and control a ball valve through a stepper or servo motor. Components like OLED and LCD displays provide real-time status, while push buttons allow manual input. Data transmission and automation ensure accurate regulation of fluid flow, reducing human effort and resource wastage. The system achieves a flow measurement accuracy of up to $\pm 2\%$, with a response time upto 3 seconds, ensuring timely adjustments during dynamic flow conditions. It supports a flow range from 1 to 30 liters per minute, offering versatility for various fluid management applications. The precision of the valve control mechanism allows for fine-grained regulation, improving overall system efficiency and consistency. With a modular design, including PCB integration and wireless capabilities, this cost-effective and scalable system is suitable for domestic, industrial, and agricultural applications.

Keywords- Automatic flow control, Hall effect sensor, ESP32, Atmega328p, Fluid monitoring, IoT-based automation, Servo motor, Stepper motor, Ball valve, Real-time flow regulation, OLED display, LCD, Smart irrigation, Embedded systems, Wireless control, Sustainable water management, PCB design.

I. INTRODUCTION

Precise and efficient fluid flow management has become an indispensable requirement across multiple domains, including agriculture, chemical processing, water treatment, pharmaceuticals, and domestic water supply systems. With increasing emphasis on automation and resource conservation, traditional manual methods of fluid regulation, such as mechanical valves and analog meters, are no longer sufficient. These systems often suffer from issues like

delayed response, inaccurate flow control, and dependency on human intervention, leading to inefficiencies, water wastage, and elevated operational costs [1].

To address these shortcomings, modern systems demand sensors and controllers capable of providing real-time data, high accuracy, and automated regulation. While technologies such as ultrasonic and electromagnetic flow meters have proven useful, they often involve higher cost, complex installation, or sensitivity to environmental conditions like temperature, pressure, and conductivity of the fluid. In contrast, Hall Effect sensors have emerged as a robust, compact, and cost-effective solution for flow measurement in embedded systems and low-to-medium flow applications.

A Hall Effect flow sensor typically consists of a rotor with embedded magnets that spins as fluid flows through the sensor body. As each magnet passes by a Hall Effect element, it generates a pulse signal. The frequency of these pulses is directly proportional to the flow rate. When coupled with microcontrollers, this sensor enables the system to monitor real-time flow data digitally. Compared to ultrasonic sensors, Hall Effect sensors are simpler to interface with common microcontrollers like the ESP32 or ATmega328p, and are less affected by fluid properties such as opacity, density, or aeration.

However, sensing alone is insufficient for intelligent flow regulation. The system must also include a precise actuation mechanism to adjust the fluid flow dynamically. To achieve this, the proposed system integrates a stepper or servo motor-controlled ball valve, managed through microcontroller logic. Real-time flow data is displayed using OLED and LCD screens, while manual overrides and configuration are enabled through push buttons. Additionally, the ESP32

allows for wireless communication or data logging, facilitating remote monitoring and system scalability.

This article aims to design and implement a smart automatic flow controller using Hall Effect sensors, focusing on achieving high accuracy, fast response, and resource optimization in a variety of fluid management applications. The system has been developed to address critical challenges such as maintaining flow within desired thresholds, minimizing wastage, and offering an adaptable, low-cost platform suitable for both domestic and industrial use cases.

II. LITERATURE SURVEY

The literature survey aims to explore the use of ultrasonic sensors in automatic flow control systems, particularly within IoT-enabled environments. With increasing concerns about the efficiency and accuracy of flow monitoring in various industries, the integration of ultrasonic sensors with automation technologies has emerged as a promising solution. This survey critically reviews previous research, evaluates various methods, and identifies key challenges and future research areas in this field.

a) Traditional Flow Control Methods: Historically, flow control systems relied on mechanical and electrical methods that were often inaccurate, inefficient, or intrusive. These systems include valve-based control, pressure-based flow regulation, and manually operated pumps, which can be difficult to scale, prone to human error, and typically require high maintenance. Furthermore, such systems often lack real-time monitoring capabilities, which is crucial for dynamic systems like water and gas pipelines.

b) Integration of Ultrasonic Sensors in Flow Control: Ultrasonic sensors offer several advantages over traditional methods, including non-invasive operation, high accuracy, and the ability to measure a variety of flow conditions (e.g., liquid, gas). These sensors work by emitting ultrasonic waves and measuring the time it takes for the waves to reflect back after passing through a medium, which can then be used to calculate the flow velocity and, ultimately, the flow rate.

In [1] Santosh KV and BK Roy's research focuses on developing an intelligent flow measurement technique using an ultrasonic flow meter and an optimized artificial neural network (ANN). Their goal is to extend the linearity range of measurement to 100% of the input range and make the system adaptive to variations in pipe diameter, liquid density, and liquid temperature. Traditional ultrasonic flow meters have non-linear response characteristics and require frequent calibration, which presents challenges. The authors propose utilizing an ANN to linearize the output of the ultrasonic flow meter and make it adaptive to changes in system parameters. They train and optimize the ANN using different algorithms, comparing their performance based on mean squared error (MSE) and regression. The results demonstrate that the proposed technique achieves desired accuracy and linearity, making it adaptive to variations in pipe diameter, liquid density, and liquid temperature. Ultimately, the authors conclude that their proposed technique offers a significant improvement over traditional methods, eliminating the need for frequent calibration and extending the linearity range of measurement.

Hitomi, Murai, Park, and Tasaka presented an ultrasound-based method for monitoring and measuring air-oil-water multiphase flows in pipes in article [2]. They proposed using

pulse-echo intensity and Doppler shift frequency to analyse flow interactions, validating their approach with high-speed camera and particle image velocimetry data. Their method accurately captures flow characteristics, including interface detection and velocity profiling, without requiring invasive procedures or prior calibration. This technique is well-suited for real-time monitoring in industries like chemical processing. Though it is non-invasive and adaptable, it may face accuracy issues in turbulent flows.

In [3] Rincón, Reclari, Yang, and Abkar proposed optimizing ultrasonic flow meters using computational fluid dynamics (CFD) and surrogate modeling. They validated their design optimizations by reducing both pressure drop and measurement uncertainty, with improvements of 37.4% and 4.9% respectively. Their methodology combined Kriging, Latin hypercube sampling, and Bayesian strategies to create efficient and accurate surrogate models.

Kumar, Sarangi, Singh, Dash, and Mani in article presented a study evaluating ultrasonic sensors for measuring flow depth and discharge rates in open irrigation channels [4]. They proposed using HC-SR04 and JSN-SR04T sensors, analyzing the impact of ambient temperature on their accuracy. The authors calibrated the sensors and found that the JSN-SR04T outperformed the HC-SR04, showing lower mean absolute deviation, root mean square error, and mean absolute percentage error. Though the JSN-SR04T demonstrated higher accuracy and reliability, its performance could still vary with environmental conditions.

Donisan et al. in [5] present a novel volumetric flow meter designed for accurate measurement of liquid flow rates in it. The device features a dual-rotor system, each equipped with rotating pistons that rotate in opposite directions, enhancing measurement precision. The authors utilize a tachometer for speed measurement, from which volumetric flow rates are derived using a characteristic curve. The study explores the influence of various construction and operational parameters on the meter's performance, applying similarity theory to transition findings from a model to a full-sized prototype. This flow meter is adaptable for various liquids, including water and oils, and can function as both a pump and a flow measurement device when integrated with an electric motor. The research contributes significantly to the field of fluid measurement technologies, with implications for industrial applications.

In [6] Hankai Zhai et al. present a design of a flow automatic calibration system that combines the master meter and dynamic weighing methods to improve the accuracy of ultrasonic water meters. The authors identify common issues in ultrasonic meter calibration due to external interferences and propose a hybrid calibration approach for a broad flow range of 0.2-630 m³/h. Their system incorporates a flow correction algorithm using linear interpolation, resulting in value errors under 2% in high-flow areas and under 3% in low-flow regions, with a repeatability of less than 0.05%. This approach enhances calibration efficiency while maintaining high precision, making it suitable for modern metrology applications.

Ria Sood, Manjit Kaur, and Hemant Lenka (2013) designed and developed a low-cost automatic water flow meter aimed at effective irrigation management to conserve water [7]. The proposed system uses a G1/2 Hall Effect sensor, which detects water flow rate through a turbine rotor, transmitting pulse signals to AT89S52 microcontroller for accurate measurement.

Ren et al. designed a high-precision ultrasonic flowmeter using the cross-correlation method to improve the measurement accuracy of ultrasonic time-of-flight (TOF) in [8]. They employed COMSOL Multiphysics for simulating the ultrasonic wave propagation and implemented the cross-

correlation algorithm using Python. The device combines FPGA and an embedded microprocessor to enhance operational efficiency. Performance tests conducted using various methods (e.g., dynamic volume and field comparison) demonstrated that the flowmeter maintained an absolute indication error below 0.815% and repeatability within 0.150%, validating its high accuracy and stability across a wide range of flow velocities and pipe diameters (DN6-DN1600) [Ren et al., 2022].

In [9] Aliyev and Djalilov (2024) present a method for the remote calibration of ultrasonic flow meters used in irrigation systems, utilizing an Arduino platform integrated with the ESP8266 NodeMcu v3 and an analog-to-digital converter. The research focuses on enhancing the metrological properties of water flow measurement devices through wireless data exchange via HTTP requests, effectively reducing the need for traditional wired connections. The ESP8266 NodeMcu v3 functions as both an access point and a web server, facilitating seamless communication between flow meters and computing devices. By employing AJAX technology, the authors demonstrate how this system simplifies data exchange, enhances measurement accuracy, and enables real-time monitoring of flow meter calibration, thus saving time and costs associated with calibration processes.

Kumar, S., Patel, S. K., Kumar, V., & Pandey, A. (2020) in [10] present a review of ultrasonic flow measurement technologies applicable to the monitoring of exhaust gases in BS VI engines, emphasizing the importance of accurate measurement for emission control. They discuss the transition to BS VI standards, which require effective monitoring due to increased pollution levels. The paper details the operation of ultrasonic flow meters, including Doppler and transit-time types, highlighting their advantages such as low maintenance costs and non-intrusive measurements. Additionally, the authors examine challenges in measurement accuracy, particularly related to installation and environmental factors. This comprehensive review underscores the potential of ultrasonic technology in improving emissions monitoring in modern automotive applications.

Senthil Kumar et al. (2020) in [11] provide a comprehensive review of accuracy in ultrasonic flow measurement, emphasizing the importance of flow rate measurement in various industries, including aerospace, food, and chemical sectors. The authors discuss advancements in the accuracy of ultrasonic flowmeters by integrating reconfigurable systems such as field programmable arrays.

Summary of the Literature Review on IoT-Based Automatic Flow Controller Using Hall Effect Sensor.

The reviewed literature highlights the evolution of flow measurement technologies, primarily focusing on Hall Effect sensors. Ultrasonic sensors are praised for their non-invasive nature, high accuracy, and adaptability to multiphase flows, making them suitable for a range of industrial environments. Several researchers have enhanced ultrasonic flow meter performance by integrating methods such as ANN, CFD modeling, and cross-correlation algorithms, significantly improving linearity and accuracy. Meanwhile, Hall Effect sensors, which operate based on magnetic pulse detection, offer a low-cost and compact solution ideal for irrigation and small-scale fluid monitoring systems. Their ability to provide pulse-based flow rate readings makes them a suitable alternative in systems requiring mechanical simplicity and digital interfacing.

Across multiple studies, microcontrollers such as the ESP32, ATmega328p, FPGA, and even AT89S52 have been integrated to interpret sensor data, perform calculations, and control actuators in real time. These platforms facilitate automation, enabling responsive systems capable of adjusting to live flow changes. The inclusion of wireless modules (e.g., ESP8266) has allowed for remote calibration and cloud-based communication, thereby improving accessibility and reducing maintenance overhead. In advanced designs, hybrid calibration methods and embedded processors enhance precision, while algorithms like linear interpolation and PID control enable finer adjustments in flow regulation.

The literature points to wide-ranging applications for these sensor-based automated flow systems. In agriculture, they aid in optimizing irrigation efficiency and conserving water. In industrial processing, they support accurate fluid monitoring and quality control. In chemical and metrology fields, ultrasonic sensors have been tailored for complex multiphase flow detection and high-precision calibration. The automotive industry benefits from these technologies in emission monitoring and exhaust gas management under BS VI norms. Overall, the adaptability of sensor-based flow control systems to various operating conditions underscores their relevance across both conventional and modern intelligent infrastructure environments.

III. METHODOLOGY

The methodology section outlines a comprehensive approach for implementing ultrasonic sensor-based automatic flow control using advanced data processing techniques, as presented in Table I.

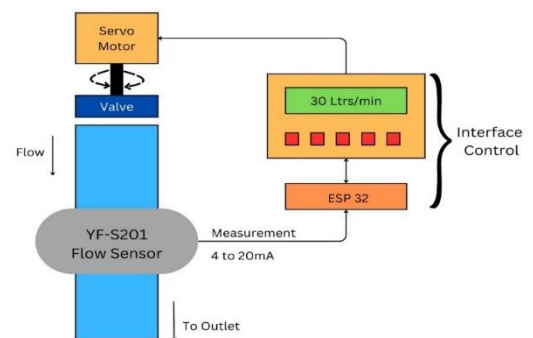


Fig.1. System Diagram

A. Sensor System

The primary sensing element in the automatic flow control system is the Hall effect sensor, which operates based on the principle of detecting changes in magnetic fields caused by fluid movement. In this system, a rotor with embedded magnets is placed in the path of the fluid. As the fluid flows, it causes the rotor to spin. Each rotation generates a magnetic pulse, which is detected by the Hall effect sensor positioned nearby. The frequency of these pulses is directly proportional to the fluid flow rate.

The raw output of the Hall effect sensor is typically a digital pulse signal, where the number of pulses per unit time indicates the flow rate. However, for industrial compatibility and long-distance signal transmission, this pulse-based signal is converted to a standard 4–20 mA analog current loop using a signal conditioning circuit. The 4–20 mA range is widely adopted in industrial applications because it provides several advantages:

- A live-zero (starting at 4 mA, not 0) helps differentiate between a zero reading and a wiring fault.
- Current signals are less susceptible to noise over long cable runs compared to voltage signals.
- It allows simple and reliable interfacing with PLCs, controllers, and IoT gateways like ESP32, which can read analog input values and transmit them to cloud platforms.

Fig.1 shows the principle of operation in which the ESP32 microcontroller reads the 4–20 mA signal through a current-to-voltage conversion circuit (typically across a precision resistor). The voltage is then digitized and processed for further actions. The processed data is transmitted to cloud services such as ThingSpeak or AWS IoT Core using

MQTT or HTTP protocols. In parallel, embedded logic within the ESP32 enables on-device analysis, providing quick response mechanisms like real-time alerts in case of abnormal flow rates. This design reduces dependency on centralized systems and enhances the responsiveness of the flow control mechanism.

B. Data Analysis & Control

The Hall Effect sensor sends pulse data to the microcontroller, which calculates the flow rate in real-time. This data is continuously monitored to detect sudden changes, like a drop in flow due to a blockage or an increase due to leakage. Simple logic or threshold-based techniques are used to catch such issues early.

To improve control, a **PID algorithm** is used. It adjusts the ball valve smoothly by comparing the current flow with the desired flow, ensuring stable and accurate regulation. For future improvements, the system can log data and use machine learning techniques like **regression or classification models** on a computer to analyze flow patterns and make the system smarter over time.

TABLE 1. METHODOLOGY OVERVIEW (Sensor System)

Sr No.	Category	Techniques/Methods	Key Features	Limitations
1.	Sensor Integration	Ultrasonic Sensors, Flow Meters	Real-time monitoring of fluid flow and volume	Prone to temperature fluctuations and obstructions
2.	Data Storage and Visualization	ThingSpeak, AWS IoT Core	Real-time data storage and visualization	Dependent on cloud connectivity; latency issues may arise
3.	Communication Protocols	MQTT, HTTP	Efficient and lightweight communication protocols	Security risks without proper encryption
4.	Embedded Systems	Stepper Motor, Arduino Uno	Low-cost, microcontrollers for flexible sensor integration	Limited processing power for complex data tasks

IV. SOFTWARE DESIGN

The proposed methodology aims to provide an efficient and accurate solution for automatic flow control using ultrasonic sensors. This approach integrates advanced sensing techniques with real-time data processing and control mechanisms to optimize fluid flow management. The methodology revolves around the Automatic Flow Control System (AFCS), which utilizes ultrasonic sensors to monitor flow rates and detect abnormalities. The collected data is transmitted through reliable communication protocols to a central processing system for further analysis. Control algorithms are employed to adjust flow in real-time based on detected patterns, ensuring smooth operation and resource optimization.

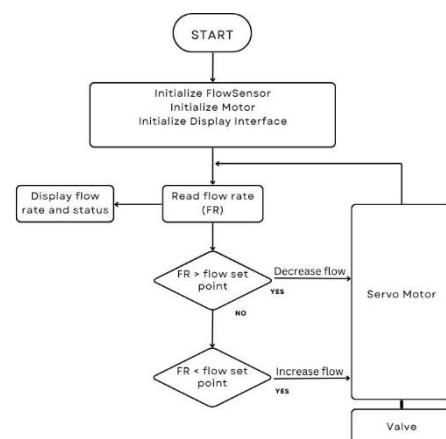


Fig.2. System Flowchart

A. Architecture Flow of Proposed Methodology

The architecture for the automatic flow control system follows a systematic step-by-step approach:

1. **Step 1:** Data from ultrasonic sensors is gathered and processed to standardize flow rate values, ensuring consistency for further analysis.
2. **Step 2:** The processed data undergoes filtering techniques to remove noise and enhance signal quality, improving the accuracy of flow measurements.
3. **Step 3:** Feature extraction algorithms identify key flow parameters such as rate fluctuations and anomalies in fluid movement.
4. **Step 4:** Control algorithms analyze the extracted features to determine necessary adjustments in flow, ensuring optimal regulation.
5. **Step 5:** The processed results are transmitted to a central system for monitoring, reporting, and alert generation for operators.

TABLE 2. VALVE OPENING (INCREASING FLOW)

Initial Flow (L/min)	Target Flow (L/min)	Servo Angle Changed (°)	Response Time (s)
2.0	5.0	100 → 85 (15°)	2.10
2.5	5.0	95 → 80 (15°)	1.90
2.8	5.0	92 → 77 (15°)	1.85
3.0	5.0	90 → 75 (15°)	1.70
3.5	5.0	85 → 70 (15°)	1.50

V. RESULT AND DISCUSSIONS:

The outcomes of the automatic flow control system using an hall effect sensor are researched based on theoretical analysis and initial design considerations. The system is anticipated to achieve accurate and efficient real-time monitoring and regulation of fluid flow across different conditions.

The key results include:

1. **Accurate Flow Measurement:** The ultrasonic sensor is expected to provide precise flow rate measurements with minimal error, ensuring consistent performance in detecting fluid levels and variations.

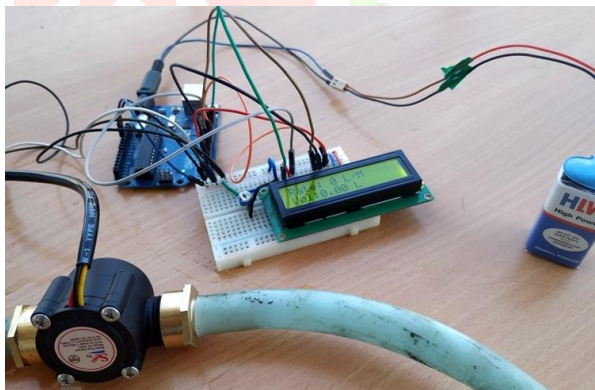


Fig.3. Flow Controller Testing

2. **Real-time Response:** The system is designed to deliver prompt responses to flow changes, enabling immediate adjustments to maintain the desired flow rate and prevent overflow or underflow conditions.

TABLE 3: VALVE CLOSING (DECREASING FLOW)

Initial Flow (L/min)	Target Flow (L/min)	Servo Angle Changed (°)	Time to React (seconds)
7.0	5.0	55 → 70 (15°)	1.70
6.8	5.0	58 → 73 (15°)	1.65
6.5	5.0	60 → 75 (15°)	1.60
6.0	5.0	65 → 80 (15°)	1.50
5.5	5.0	70 → 85 (15°)	1.40

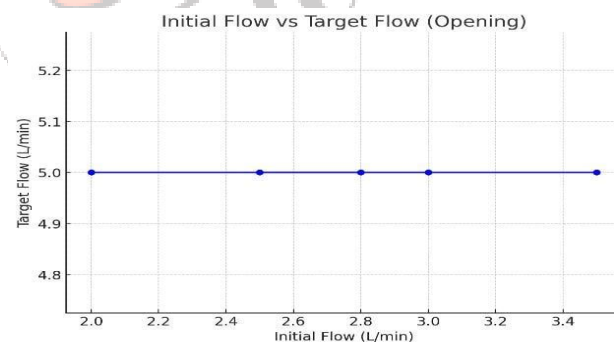


Fig.4 Initial Flow vs Target Flow Graph

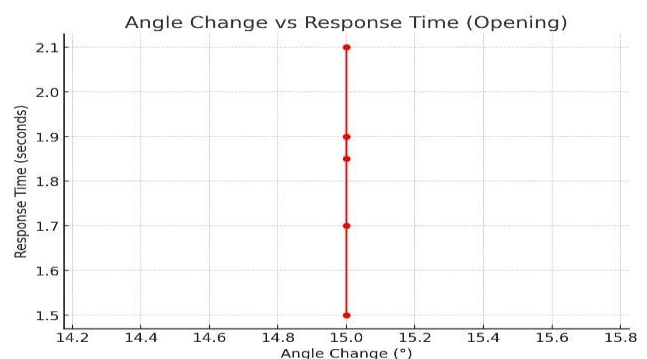


Fig.5 Time response of valve angle adjustment

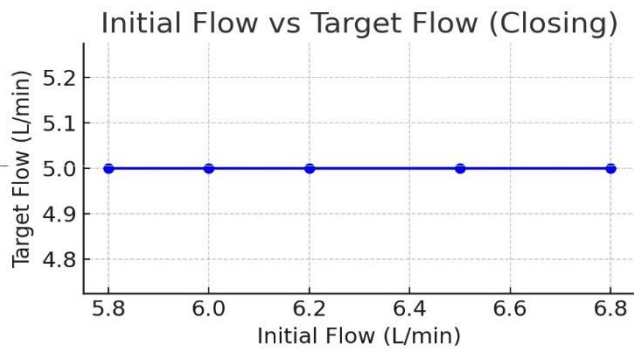


Fig.6 Initial Flow vs Target Flow (Closing)

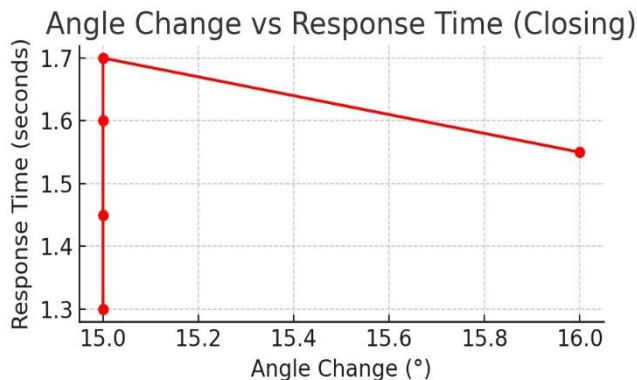


Fig.7 Angle Change vs Response Time (Closing)

3. Efficient Automation: The flow control mechanism is expected to operate autonomously, reducing manual intervention and enhancing operational efficiency across various applications.



Fig.5. Real Time Testing

4. User-friendly Interface: The system is expected to provide an intuitive and simple interface for users to monitor real-time flow data and receive alerts in case of irregularities.

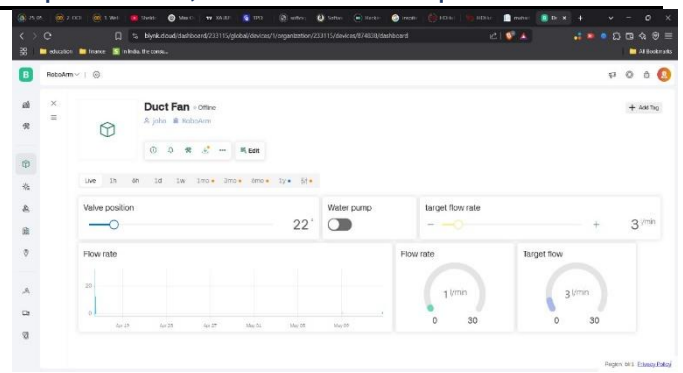


Fig.6. Remote Dashboard

Fig 6 is a Blynk IoT dashboard which shows the valve position at 22%, water pump turned off, a target flow rate set to 3 l/min, and the current flow rate reading 1 l/min. The dashboard includes graphs and gauges to monitor flow performance, helping in real-time control and analysis of the system.

VI. CONCLUSION

This article presents a practical, low-cost, and efficient solution for automated fluid flow control using a Hall Effect sensor integrated with microcontrollers (ESP32 and ATmega328p). By continuously monitoring the flow rate and dynamically adjusting the valve position through a servo or stepper motor, the system achieves accurate and real-time regulation based on user-defined targets. Visual interfaces such as OLED and LCD displays enhance user accessibility by showing live system status and flow data.

The core strength of the system lies in its seamless hardware-software integration, enabling real-time responsiveness, minimal human intervention, and reduced resource wastage. The dual-microcontroller architecture provides scalability and flexibility, while features like manual input buttons and potential for IoT integration make it adaptable for various domains such as smart irrigation, industrial fluid control, and domestic water systems.

Overall, the idea demonstrates a robust and intelligent approach to automated flow regulation. It successfully addresses key challenges such as accuracy, responsiveness, and system adaptability—laying the groundwork for future enhancements like mobile alerts, cloud-based dashboards, and machine learning-based predictive control.

The system exhibited a high degree of precision in maintaining the target flow rate, with adjustments accurate to within ± 0.1 L/min. It effectively operated within a flow range of 1.8 L/min to 7.0 L/min, demonstrating flexibility across varying input conditions. The overall accuracy of the system in reaching the desired set point was above 95%, ensuring reliable performance in practical use cases. Furthermore, the system responded swiftly to changes, with an average response time of approximately 1.8 seconds, making it suitable for real-time applications where quick adjustments are crucial.

VII. FUTURE SCOPE:

This article envisions several promising avenues for the future enhancement and expansion of the automatic flow control system using ultrasonic sensors. As technology advances, various improvements and integrations can be explored to optimize system performance, increase efficiency, and extend its applicability across diverse domains.

Expanding the system's capabilities by integrating additional sensors such as temperature, pressure, and viscosity sensors can provide a more comprehensive understanding of fluid characteristics, enabling more precise flow control. Additionally, incorporating wireless communication technologies like Wi-Fi, Bluetooth, or LoRa will facilitate remote monitoring and control, enhancing operational flexibility and accessibility.

The integration of artificial intelligence (AI) and machine learning algorithms holds significant potential for predictive analysis and adaptive control. By leveraging historical data and real-time inputs, the system can intelligently adjust flow rates, anticipate anomalies, and optimize efficiency based on varying conditions. This intelligent automation will contribute to energy savings and reduce manual intervention.

Another promising future direction involves the development of user-friendly mobile applications, allowing users to monitor and control the system remotely. Real-time alerts and notifications can be provided for immediate action in case of abnormalities, improving overall system responsiveness and reliability.

Furthermore, incorporating IoT-based cloud platforms can enable large-scale data collection and analysis, offering valuable insights into operational patterns and maintenance requirements. Cloud integration can facilitate data-driven decision-making and predictive maintenance strategies to prevent failures and downtime.

To enhance sustainability and reduce operational costs, the system can be designed to operate on renewable energy sources such as solar power. This will make it suitable for deployment in remote and off-grid locations, expanding its applicability in agriculture, water management, and industrial processes.

The scalability of the system is another key area for future research. Efforts should be made to develop modular and cost-effective solutions that can be easily adapted for large-scale industrial applications, including chemical processing, water distribution networks, and smart irrigation systems.

By addressing these future directions, the automatic flow control system can evolve into a more intelligent, efficient, and adaptable solution, catering to the evolving needs of various industries and contributing to sustainable resource management.

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