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Design and Implementation of an ESP32-Controlled Valve System

Board of Examiners:

Mse. MEZIANE Assia	Président
Mr. DJOUGHRAB Ala Eddine	Examinateur
Dr. MANSOURI Khaled	Encadreur

Presented by:

- ZINE Mohammed Elbachir
- TOUIL Youssef
- MANSOURI Abderrahmane
- LEGREIB Abdel Moumen

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Acknowledgment

We start our modest scientific research with the grace of God, the maximum amount of praise and thanks to him before and after that we have succeeded in reaching this degree of learning and development. Then, we thank our supervisor "Mr. MANSOURI KHALED" for the support and guidance he provided us on the topic of research and outside it, and all the professors who taught and supported us throughout our academic career and who were the reason for what we have reached today.

Dedication

We dedicate this work to whom do we prefer them over ourselves and who were and still a reason to facilitate the paths of life

To our parents

We dedicate it to our brothers and sisters, and we thank them for their encouragement and assistance, as well as to our family members. To all our friends from near and far.

Moreover, all those who stood beside us and helped us with everything they had.

We offer you this research

Table of contents

Lists of figures

General Introduction

In the era of smart technology, the automation of everyday tasks is becoming increasingly prevalent, leading to enhanced efficiency and control in various applications. One such application is the management of water distribution systems. Traditional methods of controlling water flow often involve manual intervention or rudimentary automated systems, which can be inefficient, prone to error, and difficult to integrate with modern smart infrastructure. This dissertation presents a solution that leverages contemporary advancements in microcontroller technology to automate the control of water distribution valves, specifically using the ESP32 microcontroller.

The ESP32, known for its robust performance, low power consumption, and integrated Wi-Fi and Bluetooth capabilities, is an ideal candidate for developing a sophisticated valve control system. This project aims to design and implement an ESP32-controlled valve system that can efficiently manage the opening and closing of a water distribution valve. The proposed system not only ensures precise control over water flow but also offers remote monitoring and control capabilities, which are critical for modern smart city applications.

The motivation behind this project is to address the inefficiencies and limitations of current water distribution control systems. By integrating IoT (Internet of Things) technology, the proposed solution seeks to provide a reliable, scalable, and user-friendly system that can be deployed in various settings, from residential to industrial environments. The ability to control the valve remotely and automate its operation based on real-time data and predefined schedules represents a significant advancement in water management systems.

This dissertation is structured to provide a comprehensive overview of the design and implementation process of the ESP32-controlled valve system. It begins with a detailed review of the current state of water distribution systems and the limitations of existing technologies. Following this, the hardware and software components of the proposed system are discussed, including the selection of sensors, actuators, and communication protocols. The implementation chapter provides insights into the integration of these components and the development of the control algorithms.

Furthermore, the system's performance is evaluated through a series of experiments and simulations, demonstrating its effectiveness and reliability. The results section highlights the benefits of the ESP32-controlled valve system, including improved efficiency, ease of use, and scalability. Finally, the dissertation concludes with a discussion on the potential applications of this technology and future directions for research and development.

In summary, the design and implementation of an ESP32-controlled valve system represent a significant step towards modernizing water distribution management. This project not only addresses the current challenges but also sets the stage for further innovations in the field of smart water management systems.

Chapter I: Literature Review

I.1 Introduction

In this section, provides a thorough examination of existing research, theories, and applications relevant to electromechanical systems, microcontroller integration, and valve control mechanisms. By analyzing past studies and identifying gaps in current knowledge, this review sets the foundation for the subsequent stages of system design, implementation, and evaluation.

I.2 Review existing research on automated valve control systems

The expansion in the interest for water notwithstanding the restriction of the assets due to the development of the populace as well as the modern improvement brings about an emergency of water in a few nations. To lessen this issue, the utilization and the interest the executives issues are expected to be planned in the frameworks of water circulation. A potential arrangement that has been introduced is the use of a particular sorts of valves to decrease water utilization .

Most enterprises have water driven transmission frameworks, one of the key parts, to control and convey the stream, is the stream control valve. The stream control valves are broadly used in a few different sorts relying upon the application. In any case, the regular sort has an initial which could be changed to diminish or expanding the pace of the stream. The stream control valve could be fabricated from different materials, for example, zinc, treated steel, carbon steel and metal. It gives a few decisions to a total and basic framework that can change the temperature, pressure and other stream factors. Figure 1-1 addresses[1].

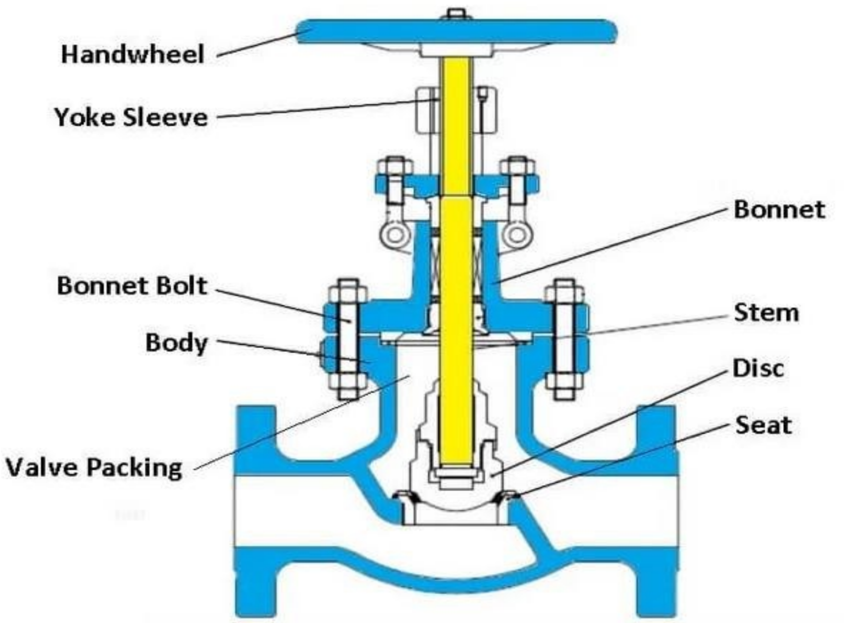

Figure I.1- A schematic diagram for the typical flow control valve.

The parts of the stream control valve are addressed as follow ;

- Body

The body is the significant piece of the valve, as it holds any remaining parts. Accomplishing the funneling in the body of the valve with the assistance of welded joints and bolts is conceivable. Typically, this part is fabricated from cast iron.

- Bonnet

This part is a cover which is used for the body opening and it incorporates two primary parts that are fixed together. The hoods are utilized as a cover just in certain valves nonetheless, involving them as valve inside extras in different types is likewise conceivable.

- Trim

Typically, this part is introduced on the valve inside and it incorporates the plate, sleeve, seat and stem. Recognizing the presentation of the valve by the connection point of the plate and seat is conceivable.

- Disc and seat

The fundamental capability of the plate is to permit and limit the progression of the liquid, thusly, it is a roundabout piece of the stream control valve. In the event that the discis shut, the complete strain of the framework is carried out to the deck and it is applied towards the power source.

- Stem

This part is answerable for the circle association with the actuator, which fixed the plate in its place. Welded joints notwithstanding strings are used to play out the association. There are two principal sorts of this part which are rising stem and non-rising stem.

- Actuator

The actuator is one of the significant pieces of the valve, and it is driven by the gathering of the plate and stem. It is feasible to work the actuators of the control valve physically or by utilizing an electrical engine.

- Handwheel

he handwheel is utilized to control the end and opening of the stream control valve physically.

- Valve packing

This standard is answerable for forestalling the spillage between the cap and stem.

I.3 Valve Types

A valve is a part in a channeling framework that is utilized to control the progression of the media through the framework. This control is accomplished by the control of an obstructer inside the valve of some sort. Impelled valves utilize mechanical gadgets called "actuators" to work the valve utilizing a power source like packed air or power. Most impelled valves are likewise accessible in a physically worked rendition, or as an incited valve with a manual supersede.

Every one of the most well-known sorts of computerized valves can be categorized as one of three principal classes. They are direct, rotating, and self-activated. There are an assortment of valve types inside every one of these classifications each having its own advantages. This instructional class is centered around rotating and straight impelled valves[2], [3].

I.3.1 Rotary Valves

These kinds of valves depend on the revolving movement of the stream obstructer Generally speaking this revolution is restricted to 90 degrees (one quarter-turn), in any case, there are valves that work utilizing a bigger level of pivot and have multiple places that are utilized in standard activity. Valves that are really quarter-turn are totally shut down at 0˚ and totally open at 90˚. Instances of quarter-turn valves are ball valves, plug valves, and butterfly valves.

Figure I.2- Rotary Valves Presentation[4].

Since quarter-turn valves consider an extensive variety of movement with the turn of a handle, these valve types are ordinarily utilized in applications that focus on fast and simple opening/shutting over accuracy.

I.3.1.1 Ball Valves

Ball valves can be utilized in many applications where a liquid stream should be turned down. They are the most broadly utilized process control valve, as a matter of fact. These revolving valves utilize ported circles that turn in the line stream, attempting to begin or stop stream.

Since the valve's port can be fitted exactly to match the line's measurement, ball valves offer low head misfortune. Ball valves might be more costly than other turning valve choices, yet they offer preferable fixing over types like butterfly valves.

I.3.1.2 Butterfly Valves

Butterfly valves work using a center-mounted, disc-shaped obstructer that sways in and out of the piping system's flow. These quarter-turn valves are frequently used with larger pipe sizes and in wastewater plants, power plants and other process plants where shut-off, regulation, and isolation are called for.

Advantages of using butterfly valves include lower cost and smaller size. However, these common valve types are more vulnerable to leaks and head losses than ball valves and may not work as well against high-pressure flows.

I.3.1.3 Plug Valves

Plug valves are basically the same as ball valves in their development and capability. In any case, rather than utilizing a ball-formed obstructer, plug valves deter or permit stream by means of a tightened chamber that swings into or out of the stream. There are two fundamental sorts of attachment valves: greased up and unlubricated.

This kind of turning valve is regularly utilized for turned down and as a control valve for compound handling businesses, handling plants and wastewater treatment offices. Plug valves might be inclined toward for their absence of voids and holes, and their capacity to be adapted to releases that foster over the long haul. Accordingly, these valves are much of the time utilized in outrageous help situations — think destructive conditions like petroleum treatment facilities and substance plants.

I.3.2 Linear Valves

There are 2 unmistakable kinds of direct valves: rising stem (multi-turn) and pivotal. While both valve types depend on the direct movement of the stream obstructer, they are totally different in development and activity.

Multi-turn rising stem valves move the obstructer by the revolution of a strung bar (stem) which is joined to the obstructer Instances of multi-turn valves are door valves, globe valves, squeeze valves, stomach valves, and needle valves. These valve types are normally utilized for stream control applications.

Pivotal valves utilize pneumatic or electro-attractive power to slide the obstructer along a hub. A few instances of these are coaxial valves, and point seat valves. These valves are normally effective and just utilized for on/off process applications [5], [6].

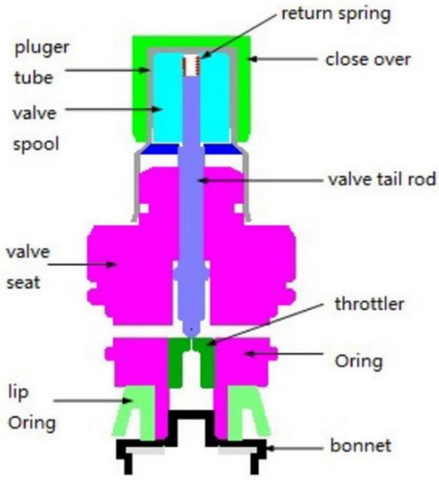

Figure I.3- Linear Valves Presentation[7].

Ordinarily utilized in stream control applications, multi-turn valves work by wrenching a handle to move an obstructer component into the stream way. This confines stream inside the funneling framework. A few kinds of multi-turn valves empower the stream to be delivered or impeded at variable velocities. These kinds of valves are generally alluded to as control valves.

I.3.2.1 Globe Valves

These are named for the globular hole around their valve seat. Globe valves are a fantastic decision for situations requiring stream obstruction and significant tension drops.

I.3.2.2 Gate Valves

The level confronted vertical circle or entryway of this valve slides down to hinder the stream, making it ideal for full open or close activities.

I.3.2.3 Diaphragm Valves

These valves utilize a twisting adaptable surface or stomach for conclusion. They track down significant use in shut-off administrations of slurries or destructive liquids.

I.3.2.4 Pinch Valves

These work like stomach valves yet offer an extremely low tension drop because of no inner hindrances.

I.3.3 Types of Fast-acting On/Off Valves with Built-in Actuators

Much as the name recommends, on/off valves are effective gadgets that either empower unlimited stream or block stream altogether. However these sorts of valves don't consider exact stream change, they are valuable in different applications where speed is fundamental, for instance when utilized for circumstances that require crisis shut-off[8], [9].

I.3.3.1 Solenoid Valves

Solenoid valves control fluid flow with a movable plunger that opens, closes, or diverts the flow. Different types of plungers exist, like poppet, spool, and diaphragm. An electromagnet coil, when energized, pulls the plunger in one direction. A spring pushes the plunger back when the coil is off. Two-position (on/off) valves are most common, but there are also three-position valves with two coils and proportional valves for flow control based on voltage. Solenoid valves are relatively small, limited by the coil strength and the need for small flow paths to create pressure drop[10].

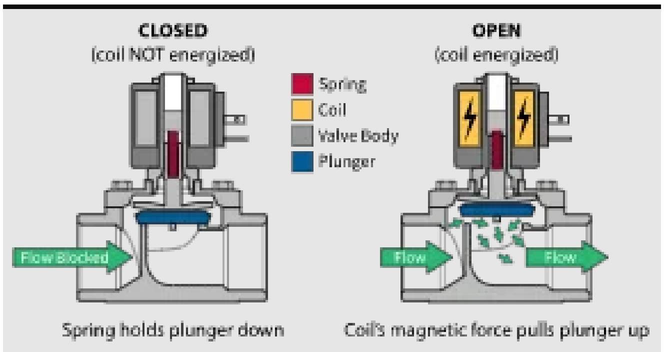

Figure I.4-Solenoid Valve.

I.3.3.2 Coaxial Valves

Coaxial valves are 2-position valves that can be pneumatically or electrically activated. The electric variants utilize an electromagnetic loop versus a spring, like solenoid valves. The pneumatic adaptations use gaseous tension versus a spring (spring return), or pneumatic force in the two bearings (twofold acting).

Coaxial valves utilize a bus type obstructer that the media goes through when open. This bus moves to one position or the other to carry out its role, either on/off or redirecting stream to the appropriate outlet. Coaxial valves have a lot bigger stream way contrasted with solenoid valves, yet at the same time don't come near a full port valve. That being valid, there is again a breaking point on stream and an expansion in pressure drop[11].

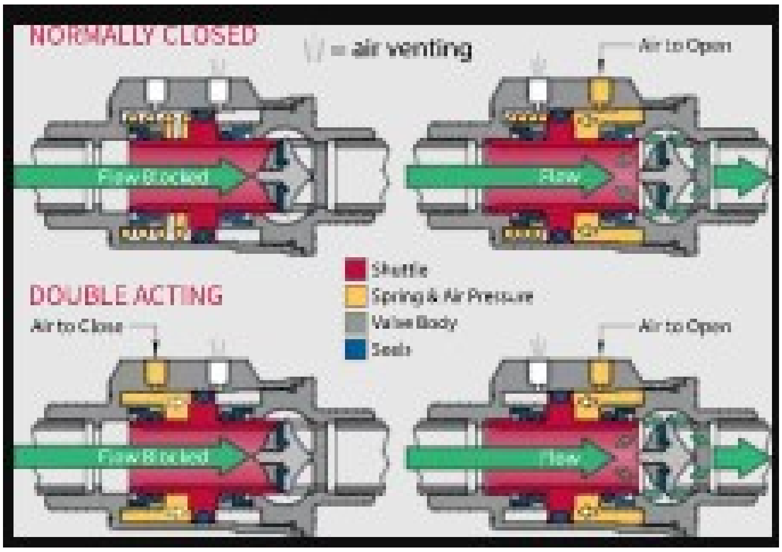

Figure I.5-Coxial Valve.

I.4 Valve Actuator

A valve actuator is the instrument for opening and shutting a valve. Physically worked valves require somebody in participation to change them utilizing an immediate or outfitted system joined to the valve stem. Power-worked actuators, utilizing gas pressure, water driven strain or power, permit a valve to be changed from a distance, or permit quick activity of huge valves. Power-worked valve actuators might be the last components of a programmed control circle which naturally directs some stream, level or other cycle. Actuators might be just to open and close the valve, or may permit transitional situating; some valve actuators incorporate switches or alternate approaches to demonstrate the place of the valve from a distance[12].

I.4.1 Types of Valve Actuators

I.4.2 Manual

A manual actuator utilizes switches, cog wheels, or wheels to move the valve stem with a specific activity. Manual actuators are controlled the hard way. Manual actuators are economical, ordinarily independent, and simple to work by people. In any case, a few huge valves are difficult to work physically and a few valves might be situated in remote, poisonous, or unfriendly conditions that forestall manual tasks in certain circumstances. As a wellbeing highlight, particular kinds of circumstances might require faster activity than manual actuators can give to close the valve.

I.4.3 Pneumatic

Air (or different gas) pressure is the power hotspot for pneumatic valve actuators.They are utilized on direct or quarter-turn valves. Pneumatic stress follows up on a cylinder or howls stomach making straight power on a valve stem. On the other hand, a quarter-turn vane-type actuator produces force to give rotating movement to work a quarter-turn valve. A pneumatic actuator might be set up to spring shut or spring-opened, with gaseous tension conquering the spring to give development. A "twofold acting" actuator use air applied to various gulfs to move the valve in the opening or shutting bearing. A focal packed air framework can give the perfect, dry, compacted air required for pneumatic actuators. In certain sorts, for instance, controllers for compacted gas, the stockpile pressure is given from the cycle gas stream and waste gas either vented to air or unloaded into lower-pressure process channeling.

I.4.3.1 Hydraulic

Water driven actuators convert liquid strain into movement. Like pneumatic actuators, they are utilized on straight or quarter-turn valves. Liquid tension following up on a cylinder gives direct push to door or globe valves. A quarter-turn actuator produces force to give rotating movement to work a quarter-turn valve. Most kinds of pressure driven actuators can be provided with safeguard elements to close or open a valve under crisis conditions. Water powered strain can be provided by an independent pressure driven pressure siphon. In certain applications, for example, water siphoning stations, the cycle liquid can give pressure driven pressure, albeit the actuators should utilize materials viable with the liquid.

I.4.3.2 Electric

The electric actuator utilizes an electric engine to give force to work a valve. They hush up, non-harmful and energy productive. Nonetheless, power should be accessible, which isn't generally the situation, they can likewise work on batteries.

I.5 Analyze different control techniques and technologies employed

I.5.1 PID Control Technique:

- Control Technique Analysis: PID control is a classical control technique widely employed due to its simplicity, reliability, and effectiveness in regulating valve positions based on error feedback[13].
- Technologies Employed:

- Actuators: PID controllers interface with actuators (pneumatic, electric, or hydraulic) to modulate valve positions based on control signals.
- Sensors: Feedback from sensors (e.g., position sensors, pressure transmitters) provides real-time process variable information necessary for PID controllers to compute error signals.
- Control Systems: PID controllers process error signals and generate control outputs, adjusting valve positions to minimize deviations from setpoints.
- Communication Protocols: PID controllers communicate with actuators and sensors using various protocols such as Modbus, Profibus, or Ethernet/IP, ensuring seamless data exchange.

I.5.2 Model Predictive Control (MPC):

- Control Technique Analysis: MPC is an advanced control technique that utilizes dynamic models of the process to predict future behavior and optimize control actions over a finite time horizon, offering superior performance, especially in complex systems.
- Technologies Employed:
- Control Systems: MPC algorithms leverage computational models of the process dynamics to predict future states and optimize control inputs accordingly.
- Sensors: High-fidelity sensors provide real-time process data used for model identification, state estimation, and predictive control.
- Communication Protocols: MPC controllers communicate with sensors and actuators to gather real-time data and implement predictive control strategies.
- Computing Systems: MPC requires robust computing infrastructure to solve optimization problems and execute control algorithms in real-time, often involving high-performance computing (HPC) systems or distributed control architectures.

I.5.3 Fuzzy Logic Control:

- Control Technique Analysis: Fuzzy logic control offers a rule-based approach to control, capable of handling nonlinearities and uncertainties in the system through linguistic rules and fuzzy sets, making it suitable for systems with imprecise models.
- Technologies Employed:
- Control Systems: Fuzzy logic controllers employ linguistic rules and fuzzy inference mechanisms to map input variables to output control actions.

- Sensors: Sensor data provides inputs for fuzzy logic controllers to make control decisions based on predefined rules.
- Actuators: Control outputs from fuzzy logic controllers drive actuators to adjust valve positions as per fuzzy logic rules.
- Computing Systems: Fuzzy logic controllers necessitate computational resources to perform fuzzy inference and decision-making, typically implemented on embedded systems or programmable logic controllers (PLCs).

I.5.4 Cascade Control:

- Control Technique Analysis: Cascade control involves nested control loops, where the inner loop controls a fast process variable (e.g., valve position), and the outer loop adjusts a slower process variable (e.g., flow rate), improving overall system performance and stability.
- Technologies Employed:
- Control Systems: Cascade control systems integrate multiple control loops, with the outer loop providing setpoints to the inner loop, enabling coordinated control of interconnected processes.
- Sensors: Feedback from sensors is utilized in both inner and outer loops to regulate process variables and valve positions accurately.
- Actuators: Actuators receive control signals from primary and secondary controllers, adjusting valve positions to maintain desired process conditions.
- Communication Protocols: Cascade control systems require communication protocols for data exchange between controllers, actuators, and sensors, ensuring synchronization and coordination between loops.

I.5.5 Advanced Sensing and Actuation:

- Control Technique Analysis: Employing advanced sensing and actuation technologies enhances control accuracy, responsiveness, and reliability, facilitating improved process control and optimization.
- Technologies Employed:
  - Sensor Technologies: Advanced sensors (e.g., ultrasonic flow meters, Coriolis flow meters) provide precise measurements for controlling process variables, enhancing control performance.

- Actuator Technologies: Advanced actuators with integrated control features (e.g., servo-electric actuators, proportional solenoid valves) offer precise and responsive control of valve positions, contributing to tighter control loops and improved system efficiency.
- Wireless Sensor Networks: Wireless sensor networks enable distributed sensing and control, allowing for flexible and scalable deployment in remote or hazardous environments, expanding the scope of automated valve control applications.

In summary, automated valve control systems leverage a variety of control techniques and technologies, each offering distinct advantages in terms of performance, robustness, and suitability for different applications and operational environments. The selection of the most appropriate control technique and technology depends on factors such as system requirements, complexity, reliability, and cost considerations.

I.6 Identify potential advancements and address limitations of current solutions

Automated valve control systems have come a long way, but there's still room for improvement and innovation. Here are some potential advancements and ways to address current limitations[14]:

I.6.1 Advancement: Artificial Intelligence Integration:

Incorporating AI algorithms can enhance the predictive capabilities of valve control systems. AI can analyze historical data, predict potential failures or inefficiencies, and optimize valve operations in real-time. Machine learning algorithms can adaptively adjust control parameters based on changing system dynamics, improving efficiency and reliability.

I.6.2 Limitation: Dependency on Sensor Accuracy:

Current automated valve systems heavily rely on sensor data for control and feedback. However, sensor inaccuracies or failures can compromise system performance. Addressing this limitation involves developing redundancy mechanisms, where multiple sensors cross-validate each other's readings, or implementing advanced calibration algorithms to mitigate sensor errors.

I.6.3 Advancement: IoT Connectivity:

Leveraging the Internet of Things (IoT) enables remote monitoring and control of valve systems. Real-time data transmission from sensors to centralized control hubs facilitates proactive maintenance and troubleshooting. Additionally, IoT connectivity allows for seamless integration with other smart systems, enabling interoperability and holistic control of industrial processes.

I.6.4 Limitation: Vulnerability to Cyberattacks:

With increased connectivity comes the risk of cyber threats. Automated valve control systems are susceptible to hacking, which can lead to unauthorized access, sabotage, or data breaches. Addressing this limitation involves implementing robust cybersecurity measures, such as encryption, authentication protocols, and intrusion detection systems, to safeguard against cyberattacks and ensure the integrity and confidentiality of system data.

I.6.5 Advancement: Self-Diagnosis and Healing:

Future valve control systems could possess self-diagnostic capabilities to detect anomalies and malfunctions autonomously. By continuously monitoring system health parameters and analyzing performance metrics, these systems can proactively identify issues and initiate corrective actions, such as self-calibration or rerouting operations to redundant components, before failures occur.

I.6.6 Limitation: Energy Consumption:

Some automated valve control systems consume significant energy, especially in continuous operation scenarios. This limitation can be addressed by optimizing control algorithms to minimize unnecessary valve adjustments, implementing energy-efficient actuators, and integrating renewable energy sources or energy storage systems to offset power consumption.

I.6.7 Advancement: Adaptive Control Strategies:

Introducing adaptive control strategies can enhance the responsiveness and robustness of valve control systems in dynamic environments. By dynamically adjusting control parameters based on real-time feedback and environmental conditions, these systems can optimize performance under varying operating conditions, such as changes in flow rates, pressure levels, or fluid properties.

I.6.8 Limitation: Cost and Complexity:

The initial investment and complexity associated with implementing automated valve control systems can be prohibitive for some organizations. To address this limitation, advancements in manufacturing technologies, such as 3D printing and modular design, can reduce production costs and lead times. Additionally, user-friendly interface designs and standardized communication protocols can simplify installation, configuration, and maintenance processes, lowering overall system complexity.

By embracing these advancements and addressing current limitations, automated valve control systems can continue to evolve, delivering greater efficiency, reliability, and safety across various industrial applications.

I.7 Conclusion

In this section, we have studied current research on automatic valve control systems, explained valves, and mentioned their types. We have also analyzed the various control techniques for controlling valves, and the techniques used, identifying potential developments, and addressing the limitations imposed on existing solutions. Mentioning the problems that occur in these cases to control automatic valves. After studying this case, we developed a new solution to avoid some of these problems. We introduced automatic control of valves using ESP32 by controlling it remotely via the Internet.

Chapter II: System Design

II.1 Hardware Selection:

Detailing the rationale behind the selection of components, including the ESP32 microcontroller and associated peripherals, this subsection elucidates the crucial decisions driving the system's architecture.

II.1.1 Overview of the proposed ESP32-controlled valve system architecture

The ESP32-controlled valve system architecture integrates the ESP32 microcontroller, a versatile and powerful platform known for its Wi-Fi and Bluetooth capabilities, with a valve control mechanism to create a flexible and IoT-enabled solution. Here's an overview of the proposed architecture (Figure II.1)[15]:

a) Features of ESP-Wroom-32

- ESP-Wroom-32 contains a low-power Tensilica Xtensa® Dual-Core 32-bit LX6 microprocessor at 240 MHz: 994.26 CoreMark; 4.14 CoreMark/MHz
- 448 KB of ROM for booting and core functions.
- 520 KB of on-chip SRAM for data and instructions.
- 4MB of Flash Memory
- 16 KB SRAM in RTC
- Wi-Fi 802.11b/g/n
- Bluetooth v4.2 BR/EDR and Bluetooth LE specifications

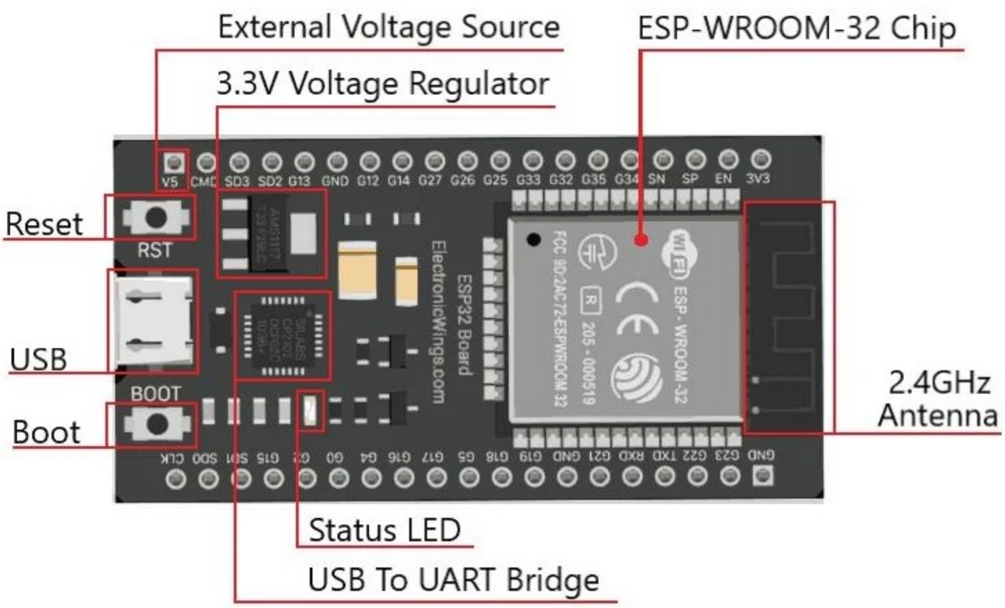

Figure II.1 ESP32 Board Highlight[15].

- ESP-WROOM-32

- ESP-WROOM-32 advancement load up containing Tensilica Xtensa® Double Center 32-digit LX6 chip works at 80 to 240 MHz flexible clock recurrence.
- It accompanies 448 KB of ROM, 520 KB of on-chip SRAM, and 4MB of Glimmer Memory.

  - Remote Network

- On-chip Wi-Fi upholds 802.11b/g/n standard
- Works at 2.4 GHz band, up to 150 Mbps
- It likewise upholds Bluetooth v4.2 BR/EDR and Bluetooth LE particulars this double method of Bluetooth makes it considerably more adaptable.

  - Reset/Boot buttons

- In ESP32 board accompanies two principal press buttons one is the Reset (RST/EN) button another is the BOOT button.
- The reset button is utilized to reset the ESP32 Chip.
- The utilization of the boot button is to enter in boot mode to transfer the new sketch or program.

  - Power

- ESP32 advancement barricade power from two sources one is from an outside 5 Volt source and one more from the USB power source.
- The ESP32 Board works at a 2.3 Volt to 3.6 Volt voltage source and its suggested yield current is 600 Mama or more.
- The greater part of the ESP32 improvement board has an inbuilt 1117 voltage controller which changes over the 5-volt contribution to 3.3 volts at the result.

  - Status Pointer

- In ESP32 improvement board has one red drove status marker, which shows status while program transferring and sequential correspondence.

b) ESP32 Improvement Board Pinout

The ESP32 improvement board has a sum of 38 pinouts, the pin planning that are as followsms.

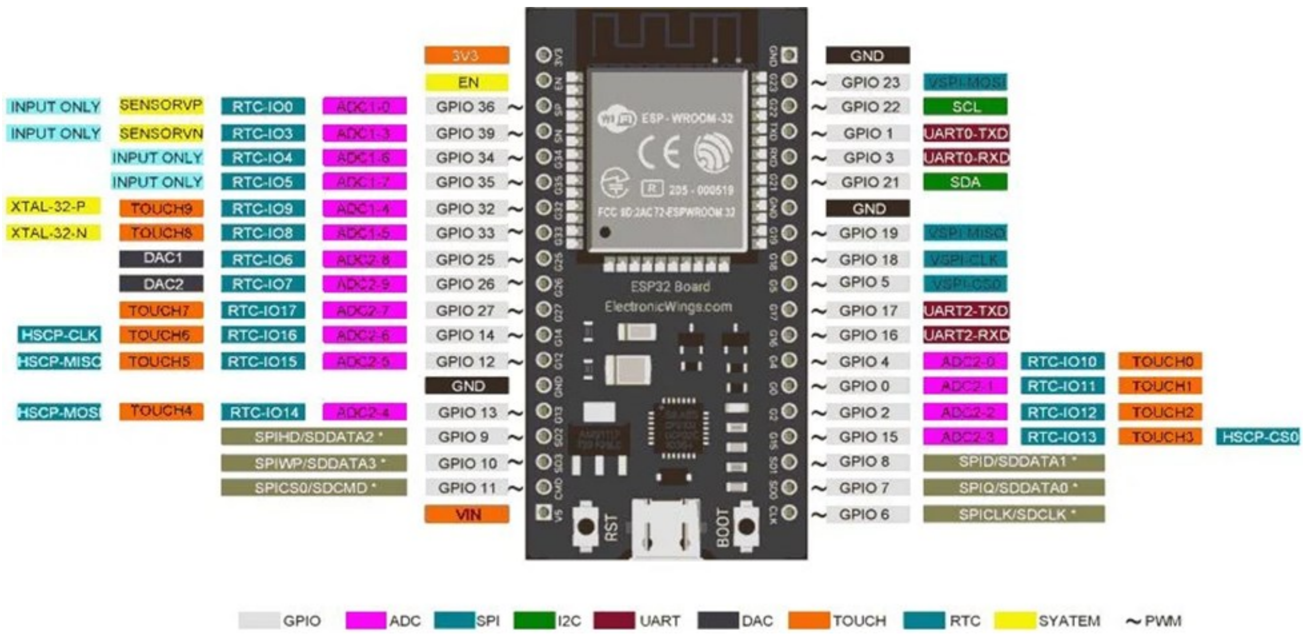

Figure II.2 ESP32 Pinout Diagram[15]-.

c) High level Fringe Points of interaction

- GPIO: Absolute 32 Multifunctional GPIOs are accessible on the ESP-Wroom-32 improvement board which can be utilized for input/yield gadgets. Each GPIO pin can be designed as an inside pull-up, pull-down, or set to high impedance. The information can likewise be set to edge-trigger or level-trigger to create computer processor interferes.
- Note: GPIO34, GPIO35, GPIO36, and GPIO39 are the main info pins
- ADC: On-chip 12-bit SAR (Progressive Guess Registers) ADCs (Simple to Advanced Converter) which upholds estimations on 16 channels of ESP32.
- DAC: On-chip two 8-bit DAC (Advanced to Simple) channels to deliver computerized signals into simple voltage signal results. Both DAC channels can likewise uphold free transformations.
- PWM: ESP32 advancement board has support 8-bit 32 channels PWM. The pins with the image '~' address that it has PWM support. It tends to be utilized for diminishing LEDs or controlling engines and so on.
- Contact Cushion: ESP32 has 10 capacitive detecting GPIOs, that recognize actual touch by the human body. This strategy can supplant mechanical fastens and changes to dispose of mechanical mileage.

- I2C: The ESP32 advancement board has just a single I2C transport interface (Upheld in Arduino IDE). which can act as an I2C expert or slave, contingent upon the client's setup.
- The I2C interfaces support:
    - Standard mode Backing (100 Kbit/s)
    - Quick mode Backing (400 Kbit/s)
    - Support both 7-piece and 10-digit tending to modes
    - Double tending to mode
- SPI: ESP32 has three SPIs which are SPI, HSPI, and VSPI. These SPIs additionally support the accompanying universally useful SPI highlights.
- Four methods of SPI move design (rely upon the extremity and the period of the SPI clock)
    - Accelerate to 80 MHz
    - up to 64-byte FIFO
- UART: ESP32 advancement board has two UART interfaces UART0 and UART1. Both give nonconcurrent correspondence and backing to RS232, RS485, and IrDA as well.

II.1.2 Selection and justification of ESP32 microcontroller

II.1.2.1 ESP32 Microcontroller:

The heart of the system is the ESP32 microcontroller, which serves as the central processing unit. The ESP32 offers dual-core processing power, ample memory, and built-in Wi-Fi and Bluetooth connectivity, making it ideal for IoT applications[16].

II.1.2.2 Valve Control Module:

The valve control module interfaces with the ESP32 to manage the opening, closing, and modulation of valves in the system. This module typically consists of actuators, such as electric motors or solenoids, that physically manipulate the valves based on commands received from the ESP32.

II.1.2.3 Sensor Interface:

Sensors are integrated into the architecture to provide feedback on various parameters, such as fluid flow, pressure, temperature, and valve position. These sensors interface with the ESP32, enabling real-time monitoring and control of the valve system.

II.1.2.4 Communication Interfaces:

The ESP32 facilitates communication between the valve system and external devices or networks. It can establish Wi-Fi connections to communicate with local networks or cloud services, enabling remote monitoring and control. Additionally, Bluetooth connectivity allows for direct communication with nearby devices, such as smartphones or tablets[17].

II.1.2.5 User Interface:

A user interface is implemented to interact with the valve system. This can take the form of a web-based dashboard accessible via a web browser or a dedicated mobile application. The user interface enables operators to monitor system status, adjust valve settings, and receive alerts or notifications.

II.1.2.6 Cloud Integration:

The architecture may include integration with cloud services for data storage, analytics, and remote management. The ESP32 can communicate with cloud platforms, such as AWS IoT or Google Cloud IoT Core, to securely transfer sensor data, receive firmware updates, and enable advanced analytics or machine learning algorithms.

II.1.2.7 Security Features:

Robust security measures are implemented to protect the valve system from unauthorized access, data breaches, and cyber threats. This includes encryption protocols, secure authentication mechanisms, and regular firmware updates to patch vulnerabilities.

II.1.2.8 Power Management:

Efficient power management is essential to optimize energy consumption and prolong battery life in battery-operated applications. The architecture may include power-saving features, such as sleep modes, dynamic voltage scaling, and low-power sensor configurations.

II.1.2.9 Scalability and Modularity:

The architecture is designed to be scalable and modular, allowing for easy expansion and customization. Additional valves, sensors, or functionalities can be integrated into the system as needed, without requiring major redesigns.

Overall, the ESP32-controlled valve system architecture offers a versatile and IoT-enabled solution for monitoring, controlling, and automating valve operations in various applications, including industrial process control, irrigation systems, and smart home automation.

II.1.3 NEMA 23 stepper motors

NEMA 23 is a stepper engine with a 2.3×2.3 inch (58.4×58.5 mm) faceplate and 1.8° step point (200 stages/unrest). Each stage draws 2.8 An at 3.2 V, considering a holding force of 19 kg-cm. NEMA 23 Stepper engine is for the most part utilized in Printers, CNC machine, Straight actuators and hard drives.

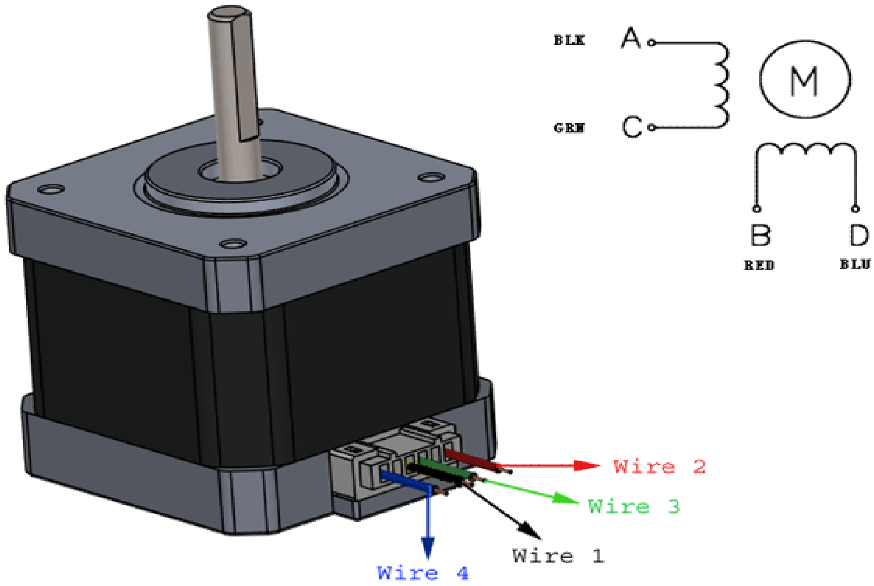

Figure II.3 NEMA 23 Stepper Motor Pinout[18]**-.**

NEMA 23 stepper motors are a popular choice for various applications requiring precise motion control. They are characterized by their standard dimensions defined by the National Electrical Manufacturers Association (NEMA). These motors have a faceplate size of 2.3 inches square (hence the name "NEMA 23") and are widely used in CNC machines, 3D printers, robotics, and other automation systems[18].

a) Some key features and specifications of NEMA 23 stepper motors include:

Step Size: NEMA 23 motors typically have a step angle of 1.8 degrees per step, which means there are 200 steps per revolution (360 degrees / 1.8 degrees per step).

b) Torque:

They are available in various torque ratings, ranging from a few dozen ounce-inches to several hundred ounce-inches, depending on the specific model and manufacturer. Higher torque motors are capable of handling more substantial loads and maintaining position more effectively.

c) Voltage and Current:

- The voltage and current ratings vary depending on the specific motor and its intended application. Typically, NEMA 23 motors operate at voltages ranging from 12V to 48V, with current ratings typically falling between 1A to 4A per phase.

d) Holding Torque:

This is the amount of torque a motor can produce when stationary and energized. It's an essential factor in determining the motor's ability to maintain position against external forces.

e) Shaft Size and Configuration:

NEMA 23 motors usually have a 0.25-inch diameter shaft, although this can vary. The shaft may be single or double-ended, with different configurations (such as single shaft or dual shaft) available for different applications.

f) Construction:

These motors are typically constructed with a stator and a rotor, with windings on the stator and permanent magnets or toothed rotor on the rotor. The number of phases (usually 2 or 4) determines the number of wires required for operation.

g) Driver Compatibility:

NEMA 23 motors require compatible stepper motor drivers to operate. These drivers control the current and timing of the electrical pulses sent to the motor windings, allowing precise control of position and speed.

II.1.4 DRV8825

II.1.4.1 Introduction

The DRV8825 provides an integrated motor driver solution for printers, scanners, and other automated equipment applications. The device has two H-bridge drivers and a microstepping indexer, and is intended to drive a bipolar stepper motor. The output driver block consists of N-channel power MOSFET's configured as full H-bridges to drive the motor windings. The DRV8825 is capable of driving up to 2.5 A of current from each output (with proper heat sinking, at 24 V and 25°C).

A simple STEP/DIR interface allows easy interfacing to controller circuits. Mode pins allow for configuration of the motor in full-step up to 1/32-step modes. Decay mode is configurable so that slow decay, fast decay, or mixed decay can be used. A low-power sleep mode is provided which shuts down internal circuitry to achieve very low quiescent current draw. This sleep mode can be set using a dedicated nSLEEP pin[19].

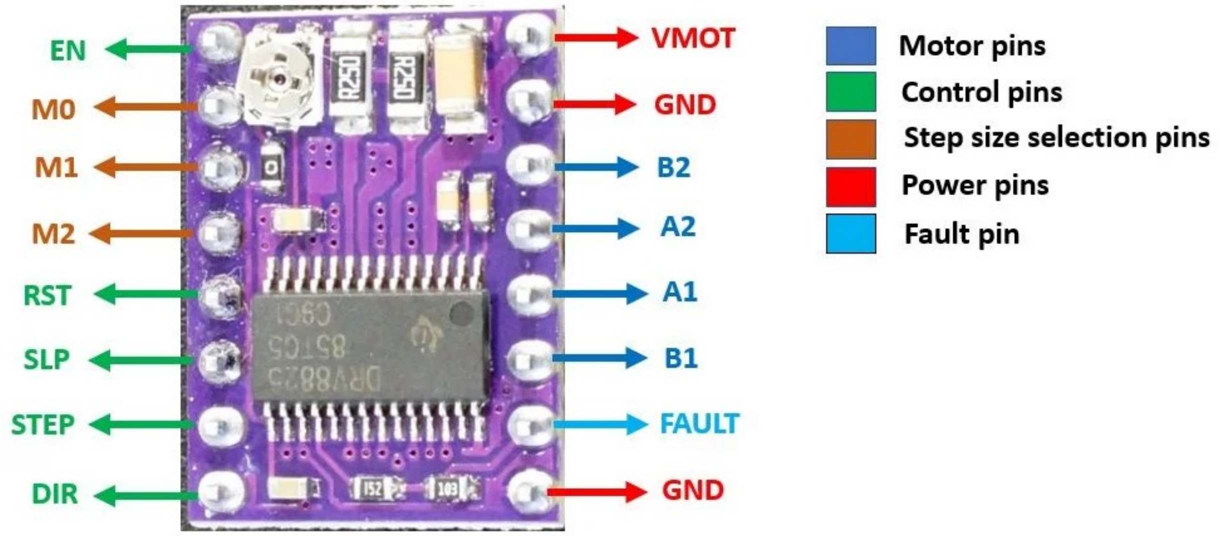

Figure II.4 diagrame of DRV8825-[20].

II.1.4.2 Parameters

- **Power connections:**

The driver requires a motor supply voltage of 8.2 – 45 V to be connected across VMOT and GND. This supply should have appropriate decoupling capacitors close to the board, and it should be capable of delivering the expected stepper motor current.

- **Current limiting:**

To achieve high step rates, the motor supply is typically much higher than would be permissible without active current limiting. For instance, a typical stepper motor might have a maximum current rating of 1 A with a 5Ω coil resistance, which would indicate a maximum motor supply of 5 V. Using such a motor with 12 V would allow higher step rates, but the current must actively be limited to under 1 A to prevent damage to the motor. The DRV8825 supports such active current limiting, and the trimmer potentiometer on the board can be used to set the current limit. You will typically want to set the driver's current limit to be at or below the current rating of your stepper motor. One way to set the current limit is to put the driver into full-step mode and to measure the current running through a single motor coil without clocking the STEP input. The measured current will be 0.7 times the current limit (since both coils are always on and limited to approximately 70% of the current limit setting in full-step mode). Another way to set the current limit is to measure the voltage on the "ref" pin and to calculate the resulting current limit (the current sense resistors are 0.100Ω). The ref pin voltage is accessible on a via that is circled on the bottom silkscreen of the circuit board. The current limit relates to the reference voltage as follows:

Current Limit = VREF × 2

- **Microstepping Indexer:**

Built-in indexer logic in the DRV8825 allows a number of different stepping configurations. The MODE0 through MODE2 pins are used to configure the stepping format as shown in Table 1.

MODE0	MODE1	MODE2	Microstep Resolution
Low	Low	Low	Full step
High	Low	Low	Half step
Low	High	Low	1/4 step
High	High	Low	1/8 step
Low	Low	High	1/16 step
High	Low	High	1/32 step
Low	High	High	1/32 step
High	High	High	1/32 step

Figure II.5 Table for Stepping Format -.

II.1.5 Stepper motor driver expansion board

The stepper motor driver expansion board uses on-board DIP switch and you can easily adjust the drive segments, which is so convenient for you to operate. It is a terminal power connector and you can easily connect the drive power supply, which provides convenience for you largely.

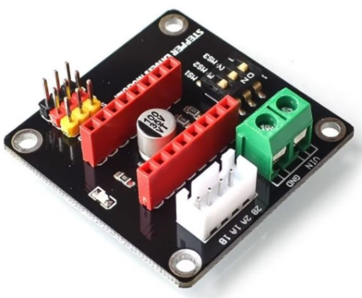

Figure II.6 Stepper motor driver expansion board-.

II.1.5.1 Features:

On-Board DIP Switch: Customize your drive segments on-the-go!

- Achieve the desired torque or microstepping level.
- Easily adjust and fine-tune settings without additional tools or software.

Effortless Power Connection:

- Integrated terminal power connector streamlines your setup.
- Eliminate the hassles of intricate wiring or soldering tasks.
- Ensure a stable and secure power connection every time.

Unrivalled Versatility & Compatibility:

- Dual compatibility with 12V and 24V drive schemes.
- Tailored specifically for 42 stepper motors.
- Ideal for a diverse range of applications including 3D printers, CNC machinery, robotics, and DIY projects.

Technical Specifications of 42 Stepper Motor Driver:

- Mounting Hole Diameter: 3mm
- Layout Pitch: 1400 x 1400mil (35.56 x 35.56mm)
- Logic Voltage: 5V
- Operational Voltage Range: 12-30V
- Available Ports: Digital
- Control Interface: Provides Direction, Enable, and Speed inputs.
- Compatible Modules: A4988 and DRV8825
- Physical Dimensions: 42 x 42 x 15mm

II.2 Mechanical Design Presentation

The mechanical design aspect of the ESP32-controlled valve system involves creating the physical structure and components necessary to facilitate the controlled opening and closing of the water distribution valve. This section will delve into the selection of materials, design of components, and the assembly process to ensure robust, reliable, and efficient operation.

II.2.1 Design Objectives

- Durability: The system should withstand environmental factors and regular operational stresses.

- Precision: Ensure accurate control of the valve position to regulate water flow effectively.
- Compatibility: Components must be compatible with the ESP32 microcontroller and other electronic parts.
- Ease of Maintenance: Design should allow for easy access and replacement of parts.

II.2.2 Component Selection

- Valve Body: Typically made of durable materials like cast iron or stainless steel to resist corrosion and wear.
- Actuator: NEMA 23 stepper motors are selected for their precision and reliability in controlling the valve position.
- Support Structures: Frames and mounts are designed using robust materials to securely hold the actuator and valve in place.

II.2.3 Detailed Design

- Motor Mounting: Design brackets to secure the stepper motor to the valve assembly, ensuring alignment and stability.
- Coupling Mechanism: Use a coupling to connect the motor shaft to the valve stem, allowing the motor to rotate the valve.
- Housing: Design a protective housing for the actuator to shield it from environmental damage and physical impacts.

II.2.4 CAD Modeling

- Software: Utilize SolidWorks for creating detailed 3D models of the components and the overall assembly.
- Assembly Drawings: Produce detailed assembly drawings that illustrate the connections and interactions between components.

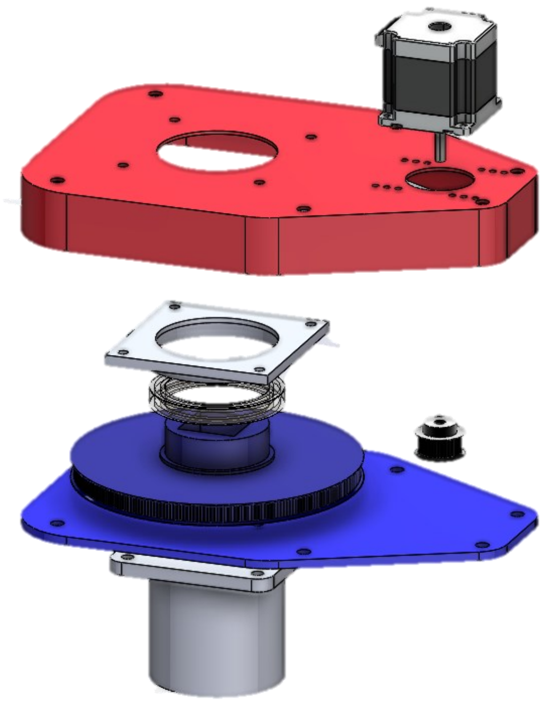

Figure II.7 Exploded view in Solidworks

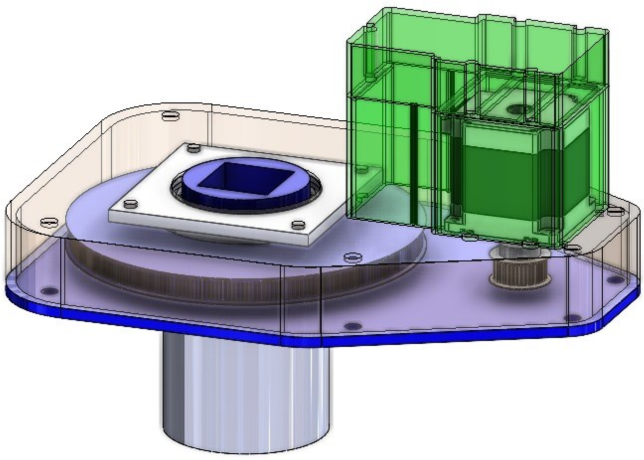

Figure II.8 System Assembly in SolidWorks

II.2.5 Fabrication

- Material Selection: Choose materials based on durability, cost, and compatibility with other components.
- Manufacturing Techniques: Utilize CNC machining, welding, and 3D printing as appropriate for creating precise and durable parts.

- Quality Control: Implement stringent quality control measures during fabrication to ensure all parts meet design specifications.

II.2.6 Assembly and Testing

- Pre-Assembly Checks: Inspect all components for defects and ensure they meet design specifications before assembly.
- Assembly Process: Follow a step-by-step process to assemble the valve system, ensuring all connections are secure and aligned.
- Testing: Conduct thorough testing of the assembled system to verify operational functionality, including leak tests, flow tests, and durability tests under various conditions.

The mechanical design of the ESP32-controlled valve system is crucial for ensuring the reliability and efficiency of the overall system. By focusing on durability, precision, and ease of maintenance, the design aims to provide a robust solution for automated water distribution control. The use of advanced CAD tools and meticulous fabrication processes ensures that the system meets the necessary performance standards and can be effectively integrated into smart infrastructure setups.

II.3 Software development:

II.3.1 Choice of programming language for control logic implementation

II.3.1.1 Arduino ide

The Arduino IDE is an open-source software, which is used to write and upload code to the Arduino boards. The IDE application is suitable for different operating systems such as Windows, Mac OS X, and Linux. It supports the programming languages C and C++. Here, IDE stands for Integrated Development Environment.

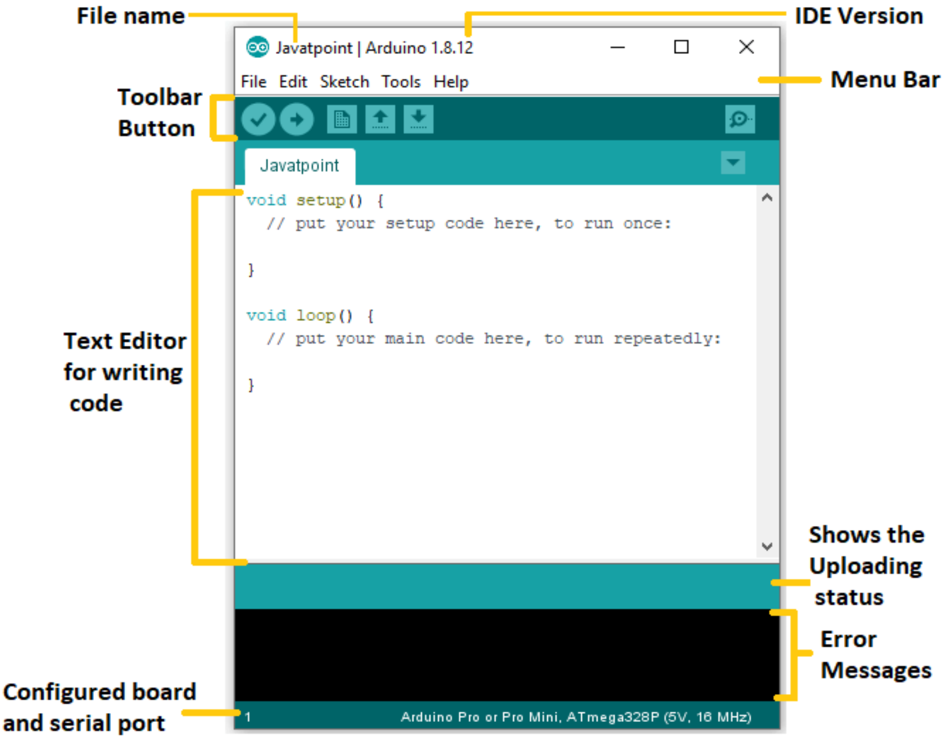

Figure II.9 Arduino ide-.

II.3.1.2 SOLIDWORKS

The SOLIDWORKS CAD software is a mechanical design automation application that lets designers quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawings.

Figure II.10 Simple photo of SolidWorks -.

II.3.1.3 MIT App Inventor

is an intuitive, visual programming environment that allows everyone – even children – to build fully functional apps for Android phones, iPhones, and Android/iOS tablets. Those new to MIT App Inventor can have a simple first app up and running in less than 30 minutes. And what's more, our blocks-based tool facilitates the creation of complex, high-impact apps in significantly less time than traditional programming environments. The MIT App Inventor project seeks to democratize software development by empowering all people, especially young people, to move from technology consumption to technology creation.

Figure II.11 Simple picture explain an application mit app inverter -.

Chapter III: System Implementation And Evaluation

III.1 Introduction

In developing an advanced control system, meticulous attention to both hardware and software components is essential to achieve optimal performance. This chapter outlines the comprehensive process of system implementation, starting with the selection of hardware components, followed by detailed schematics, and concluding with an in-depth explanation of the software's functionalities. Subsequently, the system evaluation covers testing methodologies, performance metrics, and a detailed analysis of the results to validate the system's effectiveness.

III.2 System Implementation

The selection of hardware components is pivotal to the system's success. Each component is chosen based on criteria such as performance requirements, compatibility, cost-effectiveness, and scalability.

III.2.1 Selection process and chosen hardware components

The success of the system heavily relies on the careful selection of hardware components. Each component is chosen based on specific criteria such as performance requirements, compatibility with other components, cost-effectiveness, and scalability for future enhancements.

III.2.1.1 Measuring Torque of the Valve

To measure the torque required to operate a valve using a digital force gauge, you can follow these steps:

- ***Prepare the Equipment:***
  - Ensure you have a digital force gauge, a wrench or lever arm, and a setup that can securely hold the valve in place.
  - Attach the digital force gauge to the end of the wrench or lever arm. This setup will allow you to measure the force applied at a known distance from the pivot point (the center of the valve stem).
- ***Measure the Lever Arm Length:***
  - Measure the distance from the center of the valve stem (pivot point) to the point where the force gauge is attached. This distance is your lever arm length (L).
- ***Position the Setup:***
  - Secure the valve so it does not move during the measurement.
  - Attach the wrench or lever arm to the valve stem, ensuring it is perpendicular to the valve stem.

- ***Calibrate the Force Gauge:***

Turn on the digital force gauge and calibrate it according to the manufacturer's instructions. Ensure it reads zero when no force is applied.

- ***Apply Force:***
  - Gradually apply force to the wrench or lever arm using the digital force gauge.
  - Ensure that you apply the force smoothly and perpendicularly to the lever arm to get an accurate reading.
- ***Record the Force:***

Read the force measurement (F) from the digital force gauge display once the valve begins to turn or reaches the desired position.

- ***Calculate the Torque:***

Use the torque formula:

$$\text{Torque (N.m)} = \text{Force (kg)} \times \text{Length of handle (m)} \times g \qquad \text{(III-1)}$$

Ensure that the force (F) is in Newtons (N) and the lever arm length (L) is in meters (m) to get the torque (T) in Newton-meters (Nm).

Given a force of 2.1 kg and a handle length of 30 cm, the torque is calculated as:

$$\text{Torque} = 2.1\text{kg} \times 0.3\text{m} \times 9.81 = 6.17\,\text{N.m} \qquad \text{(III-2)}$$

Figure III.1 Measuring Torque with a Digital Force Gauge

III.2.2 Measure diameter of the pulley

A pulley system consists of two pulleys of different diameters connected by a belt, which is highlighted in red. The driver pulley receives the transmitting power, causing it to rotate, while the driven pulley rotates due to the force transmitted through the belt. The key parameters for each pulley are its diameter and angular velocity, measured in revolutions per minute (RPM).

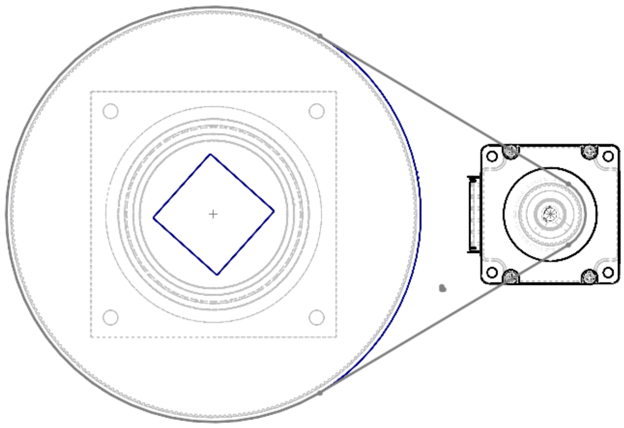

Figure III.2 pulley system

Pulley Parameters:

- Driver Pulley (Pulley 1):
  - Diameter: d_1
  - Angular velocity: n_1 (RPM)
- Driven Pulley (Pulley 2):
  - Diameter: d_2
  - Angular velocity: n_2 (RPM)
- Holding Torque of Stepper motor Nema 23: $\boldsymbol{T = 10.1\ \mathrm{kgf.cm}}$:
- RPM motor: $\boldsymbol{n_1 = 30\ rpm}$
- $\boldsymbol{D}$: distance between their centers

a. Calcule The power *P*:

$$P = T \times w \tag{III-3}$$

$$w = \frac{2 \times \pi \times n_1}{60} \tag{III-4}$$

b. Calcule the torque of the pulley 1:

The last values that you can find with this pulley calculator are the drive torque (torque of the driver pulley) and the driven torque (of the driven pulley). Use the following equation:

$$T_{1}=\frac{P \times 60}{2 \times \pi \times n_1} \tag{III-5}$$

where the angular velocity **n** of each pulley is expressed in revolutions per minute.

c. Calcule the RPM of the pulley 2:

$$T_{1}=\frac{P \times 60}{2 \times \pi \times n_2} \tag{III-6}$$

$$n_{2}=\frac{P \times 60}{2 \times \pi \times \mathrm{T1}} \tag{III-7}$$

d. Calcule the torque of the pulley 2:

$$T_{2}=\frac{P \times 60}{2 \times \pi \times n_2} \tag{III-8}$$

e. Calcule the diameter of the pulley 2:

For a pulley system like this, the product of pulley diameter d and RPM n is the same for both driver and driven pulley. It means that:

$$d_1 \times n_1 = d_2 \times n_2 \tag{III-9}$$

You can use this formula to find any of these four values: driver pulley diameter d_1, its angular velocity n_1, the driven pulley diameter d_2, or its angular velocity n_2.

f. Calcule the Belt length:

The length of the belt is dependent on the diameters of both pulleys and the distance between their centers **D**:

$$\boldsymbol{L = \left(d_1 \times \frac{\pi}{2}\right) + \left(d_2 \times \frac{\pi}{2}\right) + 2 \times D + \frac{d_1 - d_2}{4 \times \mathrm{D}}} \tag{III-10}$$

You can also reverse this formula to calculate the distance between the pulleys for a known belt length.

g. Belt velocity

We can calculate the speed of the belt according to the formula:

$$\boldsymbol{v = \pi \times d_1 \times \frac{n_1}{60}} \tag{III-11}$$

where the angular frequency is expressed in RPM and the belt velocity in meters per second.

h. Belt tension

The tension in the belt is dependent on the belt velocity and the transmitting power **P**:

$$\boldsymbol{F = \frac{P}{V}} \tag{III-12}$$

Table III.1. Pulley System Parameters

	Parameter	**Value**
Pulley Parameters	**Driver Pulley**	
	$n_1\ (rpm)$	30
	$d_1\ (m)$	0.0254
	Torque (N.m)	3.358
	Driven Pulley	
	$n_2\ (rpm)$	4.615
	$d_2\ (m)$	0.167
	Torque (N.m)	21.83
	Distance between their centers	
	$\boldsymbol{D\ (m)}$	0.137
Motor Characteristic	**Type**	Stepper motor Nema 23
	Holding Torque	10.1 kgf. cm
	Max Current	2 A
	VOLTAGE	2.3 V
	RESITANCE	0.83 ±10% Ω
	INDUTANCE	2.2 ±20% mH
Belt Characteristic	**Belt length (m)**	0.610
	Belt velocity (m/s)	0.04
	Belt tension (N)	263.76

III.2.3 Explanation of software development

III.2.3.1 Software implementation

This flowchart illustrates the overall process of setting up and operating a motor control system using an ESP32 microcontroller and Firebase. The chart is divided into three main sections: Setup, Firebase Configuration, and Motor Control.

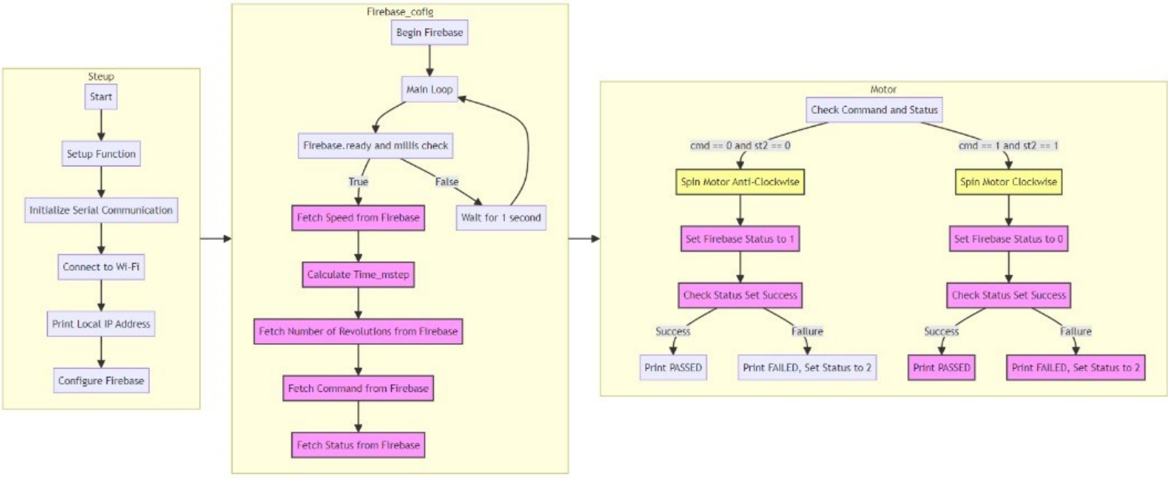

Figure III.3 Flowchart for ESP32 and Firebase-Based Motor Control System

III.2.3.2 Cloud integration

This image illustrates a motor control system that uses an ESP32 microcontroller, Firebase, and a mobile application interface. The system communicates in real-time to control the motor's operation based on user inputs.

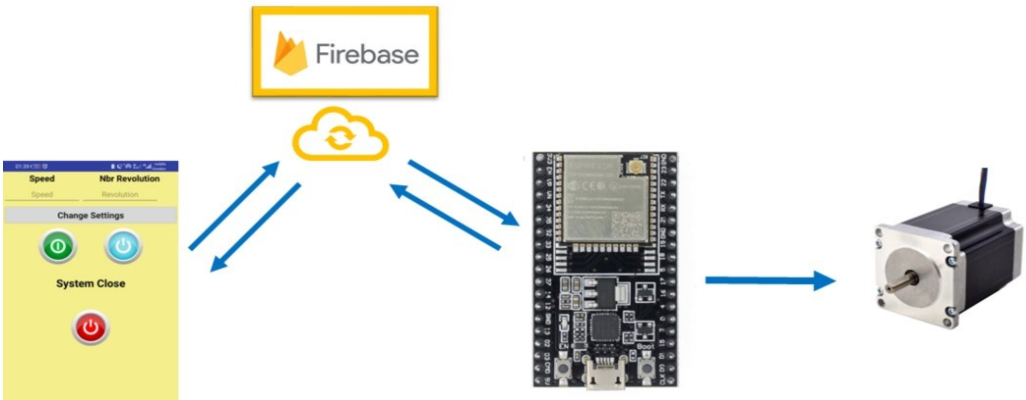

Figure III.4 ESP32-Based Motor Control System with Firebase Integration

III.2.4 Step-by-step explanation of software implementation and functionalities

The software implementation is a critical aspect, encompassing the development of control algorithms, user interfaces, and communication protocols.

1. Include Required Libraries

First, we include the libraries necessary for Wi-Fi and Firebase functionalities:

```
#include <WiFi.h>
#include <Firebase_ESP_Client.h>
```

- WiFi.h: Provides functions to connect to Wi-Fi networks.
- Firebase_ESP_Client.h: Allows communication with Firebase services.

2. Define Wi-Fi Credentials

We define the Wi-Fi SSID (network name) and password to connect the ESP32 to a Wi-Fi network:

```
/* 1. Define the WiFi credentials */
#define WIFI_SSID "WIFI_SSID"
#define WIFI_PASSWORD "USER_PASSWORD"
```

- API_KEY: The API key used to authenticate requests to Firebase.
- DATABASE_URL: The URL of your Firebase Realtime Database.

3. Define Firebase API Key and Database URL

We set up the API key and Firebase Real-time Database URL:

```
/* 2. Define the API Key */
#define API_KEY "AIzaSyBLTt_44RawA4A-IwZ9RA8mppCA3_6TgVA"

/* 3. Define the RTDB URL */
#define DATABASE_URL "https://USER_EMAIL.firebaseio.com/"
```

- API_KEY: The API key used to authenticate requests to Firebase.
- DATABASE_URL: The URL of your Firebase Realtime Database.

4. Define User Credentials

We specify the email and password for the Firebase user:

```
/* 4. Define the user Email and password that alreadey registerd or added in your project */
#define USER_EMAIL ""
#define USER_PASSWORD ""
```

- USER_EMAIL: The email address of the user registered in Firebase.
- USER_PASSWORD: The password for this user.

5. Initialize Firebase Data Object and Configuration

We create objects and configurations for Firebase operations:

```
// Define Firebase Data object
FirebaseData fbdo;
FirebaseAuth auth;
FirebaseConfig config;
```

- fbdo: An object to handle Firebase data operations.
- auth: An object to handle Firebase authentication.
- config: An object to configure Firebase settings.

6. Define Timing Variables

We set up a variable to track the time for periodic data sending:

```
unsigned long sendDataPrevMillis = 0;
```

7. Configure Stepper Motor Pins and Constants

We define the GPIO pins used for the stepper motor and other related constants:

```
// Stepper Motor Settings
#define DIR_PIN 12
#define STEP_PIN 14
#define EN_PIN 26
const int stepsPerRev = 6400;
float microstepDelay = 500;
int numRevolutions = 3;
```

- DIR_PIN: The GPIO pin for the motor's direction control.
- STEP_PIN: The GPIO pin for the motor's step control.
- EN_PIN: The GPIO pin for enabling/disabling the motor.
- stepsPerRev: The number of steps required for one full revolution of the motor.
- microstepDelay: The delay between steps to control the motor's speed.
- numRevolutions: The number of revolutions the motor should complete

8. Setup Function

The setup function initializes the hardware, Wi-Fi connection, and Firebase setup:

```
void setup() {
  pinMode(STEP_PIN, OUTPUT);
  pinMode(DIR_PIN, OUTPUT);
  pinMode(EN_PIN, OUTPUT);

  Serial.begin(115200);
  WiFi.begin(WIFI_SSID, WIFI_PASSWORD);

  Serial.print("Connecting to Wi-Fi");
  while (WiFi.status() != WL_CONNECTED) {
    Serial.print(".");
    delay(300);
  }
  Serial.println();
  Serial.print("Connected with IP: ");
  Serial.println(WiFi.localIP());
  Serial.println();

  // Firebase setup
  config.api_key = API_KEY;
  auth.user.email = USER_EMAIL;
  auth.user.password = USER_PASSWORD;
  config.database_url = DATABASE_URL;
  Firebase.reconnectNetwork(true);

  fbdo.setBSSLBufferSize(4096, 1024);
  fbdo.setResponseSize(2048);
  Firebase.begin(&config, &auth);
  Firebase.setDoubleDigits(5);
  config.timeout.serverResponse = 10 * 1000;
```

- Pin Configuration: Sets the pin modes for the stepper motor.
- Wi-Fi Setup: Connects to the Wi-Fi network and prints the local IP address once connected.
- Firebase Setup: Initializes Firebase with the API key, user credentials, and database URL.

9. Loop Function

The loop function continuously checks for commands from Firebase and controls the stepper motor accordingly:

```
void loop() {
  if (Firebase.ready() && (millis() - sendDataPrevMillis > 1000 || sendDataPrevMillis == 0)) {
    sendDataPrevMillis = millis();

    String rpmStr, numRevStr, cmd, status;
    if (Firebase.RTDB.getString(&fbdo, "/Vanne/Speed")) {
      rpmStr = fbdo.stringData();
      microstepDelay = round((30 * 1000000) / (stepsPerRev * rpmStr.toInt()));
      Serial.println(microstepDelay);
    } else {
      Serial.println(fbdo.errorReason().c_str());
    }

    if (Firebase.RTDB.getString(&fbdo, "/Vanne/rev")) {
      numRevStr = fbdo.stringData();
      numRevolutions = numRevStr.toInt();
    } else {
      Serial.println(fbdo.errorReason().c_str());
    }

    if (Firebase.RTDB.getString(&fbdo, "/Vanne/Cmd")) {
      cmd = fbdo.stringData();
      if (Firebase.RTDB.getString(&fbdo, "/Vanne/Stat")) {
        status = fbdo.stringData();
        handleCommand(cmd, status);
      } else {
        Serial.println(fbdo.errorReason().c_str());
      }
    } else {
      Serial.println(fbdo.errorReason().c_str());
    }
```

- Firebase Ready Check: Ensures Firebase is ready for operations.
- Command Retrieval: Retrieves the speed, number of revolutions, command, and current state from Firebase.
- Motor Control: Based on the command and state, controls the stepper motor and updates the state in Firebase.

10. Command Handling Function

The handle Command function executes the appropriate motor action based on the command and status:

```
void handleCommand(String cmd, String status) {
  if (cmd == "0" && status == "0") {
    antiClockwise(numRevolutions, microstepDelay);
    updateStatus("1");
  } else if (cmd == "1" && status == "1") {
    clockwise(numRevolutions, microstepDelay);
    updateStatus("0");
  }
}
```

- Command Execution: Executes the motor control functions based on the command and current status.
- Status Update: Updates the status in Firebase after the command is executed.

11. Update Status Function

The update Status function updates the motor's status in Firebase:

```
void updateStatus(String newStatus) {
  if (Firebase.RTDB.setString(&fbdo, "/Vanne/Stat", newStatus)) {
    Serial.println("Status update PASSED");
  } else {
    Serial.println("Status update FAILED");
    Serial.println(fbdo.errorReason().c_str());
  }
}
```

Status Update: Sends the new status to Firebase and prints the result.

12. Motor Control Functions

We define functions to control the stepper motor in both directions:

```
void clockwise(int nRev, int delayMicrosec) {
  digitalWrite(EN_PIN, LOW);
  digitalWrite(DIR_PIN, HIGH);
  Serial.println("Spinning Clockwise...");

  for (int i = 0; i < nRev * stepsPerRev; i++) {
    digitalWrite(STEP_PIN, HIGH);
    delayMicroseconds(delayMicrosec);
    digitalWrite(STEP_PIN, LOW);
    delayMicroseconds(delayMicrosec);
  }
  digitalWrite(EN_PIN, HIGH);
}

void antiClockwise(int nRev, int delayMicrosec) {
  digitalWrite(EN_PIN, LOW);
  digitalWrite(DIR_PIN, LOW);
  Serial.println("Spinning Anti-Clockwise...");

  for (int i = 0; i < nRev * stepsPerRev; i++) {
    digitalWrite(STEP_PIN, HIGH);
    delayMicroseconds(delayMicrosec);
    digitalWrite(STEP_PIN, LOW);
    delayMicroseconds(delayMicrosec);
  }
  digitalWrite(EN_PIN, HIGH);
}
```

- Clockwise Function: Spins the motor clockwise by setting the DIR pin high and toggling the STEP pin.
- Anti-Clockwise Function: Spins the motor counterclockwise by setting the DIR pin low and toggling the STEP pin.
- Enable/Disable Motor: The motor is enabled at the start and disabled at the end of the function.

III.3 System Evaluation

The system evaluation involves rigorous testing and analysis to ensure that the control system operates as intended. Key performance metrics include responsiveness, accuracy, reliability, and scalability.

III.3.1 Testing Methodologies

Various testing methodologies are employed to assess the system's performance:

1. Functional Testing: Verifies that each function of the software operates according to specifications.
2. Integration Testing: Ensures that all hardware and software components work seamlessly together.
3. Performance Testing: Measures the system's responsiveness and speed under different loads and conditions.
4. Stress Testing: Determines the system's stability and reliability under extreme conditions.

III.3.2 Performance Metrics

Performance metrics are used to quantify the system's effectiveness:

- Response Time: The system's response time to a command.
- Accuracy: The precision of the motor's movements and the correctness of data transactions.
- Reliability: The system's ability to function consistently over time.
- Scalability: The ease with which the system can be expanded to handle additional loads or functionalities.

III.3.3 Analysis of Results

The results of the testing methodologies are analyzed to identify areas of improvement and to validate the system's overall performance. Specific findings include:

- Response Time Analysis: The system's response time meets the required specifications, ensuring timely execution of commands.
- Accuracy Evaluation: The motor control functions accurately perform the intended actions, with minimal deviations.
- Reliability Assessment: The system operates reliably over extended periods, with no significant failures or malfunctions.
- Scalability Analysis: The system demonstrates the potential for easy scalability, accommodating additional hardware and increased data loads with minimal modifications.

Conclusion

The "Design and Implementation of an ESP32-Controlled Valve System" document presents a comprehensive and innovative approach to modernizing water distribution systems through advanced automation and IoT integration. By utilizing the ESP32 microcontroller, the system offers enhanced operational efficiency, reliability, and real-time monitoring capabilities, making it a significant improvement over traditional valve control mechanism.

The thorough analysis of existing technologies and the identification of gaps in current systems provide a solid foundation for the proposed solution. The document meticulously details the selection and integration of hardware components, such as NEMA 23 stepper motors and DRV8825 drivers, along with the development of software using the Arduino IDE and MIT App Inventor. This level of detail ensures a clear understanding of the system's architecture and functionality, making it accessible for replication and further development.

One of the standout features of this system is its use of the ESP32 microcontroller, which brings inherent advantages like built-in Wi-Fi and Bluetooth connectivity. These features enable remote monitoring and control, which are crucial for efficient and responsive water management. The integration of these capabilities positions the system as a leading solution in the field of IoT-enabled water distribution systems.

The practical evaluation of the system through rigorous testing and simulations validates its effectiveness and reliability. The document presents detailed experimental results that demonstrate the system's performance under various conditions, highlighting its robustness and potential for real-world application. These evaluations provide confidence in the system's ability to deliver consistent and reliable operation.

Despite the promising results, the document acknowledges certain limitations, such as the initial investment required and the reliance on sensor accuracy. However, it also suggests that advancements in sensor technology and manufacturing processes could mitigate these challenges in the future. This forward-looking perspective is essential for the continuous improvement and adoption of such systems.

Future research directions proposed in the document include the integration of artificial intelligence for enhanced decision-making, improvements in energy efficiency, and strengthening security features. These advancements will be crucial in addressing current limitations and further enhancing the system's capabilities. The document’s emphasis on future development ensures that the proposed system remains relevant and adaptable to evolving technological landscapes.

In conclusion, the ESP32-controlled valve system represents a significant step forward in the automation of water distribution networks. It addresses critical challenges faced by traditional systems and offers a scalable, efficient, and sustainable solution. The document’s comprehensive approach and detailed analysis provide a valuable resource for researchers and practitioners in the field. With continued research and technological advancements, the potential of such systems can be fully realized, leading to smarter and more efficient water management practices.

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Abstract

This work details the design and implementation of an automated valve control system using the ESP32 microcontroller to enhance water distribution management. Leveraging the ESP32's Wi-Fi and Bluetooth capabilities, the system offers improved efficiency, reliability, and remote monitoring. Key components include NEMA 23 stepper motors, DRV8825 stepper motor drivers, and various sensors, integrated with the ESP32. The design process encompasses hardware selection, CAD modeling, and software development with Arduino IDE and MIT App Inventor. Performance evaluations through testing and simulations confirm the system's robustness and practical applicability. While initial investment and sensor accuracy are challenges, the long-term benefits in operational cost savings and water conservation are significant. Future research suggestions include integrating artificial intelligence, improving energy efficiency, and enhancing security features. This study provides a foundation for further advancements in automated water distribution systems.

Keywords: Automated valve, control system, ESP32, water conservation

Résumé

Ce document détaille la conception et la mise en œuvre d'un système de contrôle de valve automatisé utilisant le microcontrôleur ESP32 pour améliorer la gestion de la distribution d'eau. En tirant parti des capacités Wi-Fi et Bluetooth de l'ESP32, le système offre une efficacité, une fiabilité et une surveillance à distance accrues. Les composants clés incluent des moteurs pas à pas NEMA 23, des pilotes de moteur pas à pas DRV8825 et divers capteurs, intégrés avec l'ESP32. Le processus de conception comprend la sélection du matériel, la modélisation CAO et le développement de logiciels avec Arduino IDE et MIT App Inventor. Les évaluations des performances par des tests et des simulations confirment la robustesse et l'applicabilité pratique du système. Bien que l'investissement initial et la précision des capteurs posent des défis, les avantages à long terme en termes d'économies opérationnelles et de conservation de l'eau sont significatifs. Les suggestions de recherches futures incluent l'intégration de l'intelligence artificielle, l'amélioration de l'efficacité énergétique et le renforcement des fonctionnalités de sécurité. Cette étude fournit une base pour des avancées ultérieures dans les systèmes de distribution d'eau automatisés.

Mots-clés : Valve automatisé, Système de contrôle, ESP32, Conservation de l'eau

ملخص:

هذا العمل يوضح تصميم وتنفيذ نظام تحكم تلقائي لصمامات باستخدام متحكم ESP32 لتعزيز إدارة توزيع المياه. بالاستفادة من قدرات الواي فاي والبلوتوث فيESP32 ، يوفر النظام كفاءة محسنة وموثوقية أعلى ورصد عن بعد. تشمل المكونات الرئيسية محركات الخطوة NEMA 23 ومشغلات محركات الخطوة DRV8825 ومستشعرات مختلفة، متكاملة مع .ESP32 يشمل عملية التصميم اختيار الأجهزة ونمذجة CAD وتطوير البرمجيات باستخدام Arduino IDE و .MIT App Inventorتؤكد التقييمات الأدائية من خلال الاختبارات والمحاكاة على صلابة النظام وتطبيقه العملي. على الرغم من التحديات المتمثلة في الاستثمار الأولي ودقة المستشعرات، إلا أن الفوائد على المدى الطويل في توفير تكاليف التشغيل والحفاظ على المياه تكون ملحوظة. تشمل اقتراحات البحث المستقبلية دمج الذكاء الاصطناعي، وتحسين كفاءة الطاقة، وتعزيز ميزات الأمان. يوفر هذا الدراسة أساسًا للتطورات الأخرى في أنظمة توزيع المياه التلقائية.

كلمات مفتاحية: صمام تلقائي، نظام تحكم، ESP32، توفير المياه