**College of Engineering
and Computer Science**
UNIVERSITY OF CENTRAL FLORIDA

**SENIOR DESIGN II
Water Saver**

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Table of Contents

1.0   Executive Summary

From the dawn of time, water scarcity has been a critical issue, affecting billions, especially in developing countries. In the year 2030, the situation has worsened due to a global virus and the resultant collapse of governmental water management systems in the United States. Amid this crisis, WaterSaver emerges as a beacon of hope, introducing a groundbreaking approach to water management that transforms the accessibility and utilization of rainwater.

WaterSaver aims to enhance sustainability by providing a reliable and environmentally friendly water supply for communities worldwide. This project, conceived to tackle global water scarcity, capitalizes on the abundant yet underutilized rainwater to empower resource-limited settings, including farmers and homeowners. Our mission is multifaceted: to collect, purify, and efficiently use rainwater, ensuring a sustainable water source for all.

Our state-of-the-art system features advanced rainwater sensors and solar power for sustainable operation. WaterSaver includes a high-efficiency filtration system, ensuring water purity for diverse uses such as gardening, household tasks, groundwater replenishment, and outdoor cleaning. Its user-friendly interface, coupled with a sophisticated web application, enables seamless operation and real-time water management monitoring.

WaterSaver not only addresses water shortages but also promotes environmental stewardship. By reducing dependence on traditional water sources and minimizing waste, the system aligns with global conservation efforts and contributes to combating climate change. Additionally, it manages flood risks and repurposes excess water, promoting environmentally friendly practices and sustainable community development. This prototype represents our dedication to focusing on the features and technology aspects of the project to meet our senior design goals, applying what we have learned in electrical and computer engineering to produce this business.

WaterSaver signifies a shift towards sustainable water management, aiming to redefine how individuals and communities think about and interact with water. Affordable resources and technologies make it accessible for wide adoption, ensuring that communities, regardless of economic status, can benefit from this innovation. By encouraging global dialogue and action, WaterSaver aspires to ignite a worldwide movement towards a more sustainable and equitable future for our planet, transforming this vision into a growing reality.

2.0   Project Description

Introduction

In an era where the sanctity of water is increasingly threatened by the dual forces of climate change and global population expansion, our team, drawn together by a shared history of water scarcity in our diverse homelands, embarked on a mission. Our collective experience has not only imbued us with a profound respect for this precious resource but has also propelled us toward the pursuit of a novel solution aimed at ameliorating the pervasive challenge of water distribution on a worldwide scale. This endeavor, rooted in a deep-seated appreciation for the value of water, seeks to galvanize a global movement towards more equitable and efficient water usage through the innovative harnessing of rainwater.

The essence of our project lies in the untapped potential of rainwater, a resource that is plentiful yet vastly underappreciated. With a vision to redefine the paradigms of water consumption, our project is predicated on the belief that rainwater can be transformed from a transient meteorological phenomenon into a cornerstone of sustainable water management. Our initiative envisions rainwater as a keystone in mitigating the pressures on conventional water sources, offering a pragmatic yet revolutionary approach to ensuring the availability of high-quality water for critical applications.

At the heart of our venture is the aspiration to tackle the global crisis of water scarcity head-on. The genesis of this project was inspired by the personal experiences of our team members, who have witnessed firsthand the struggles and ingenuity of communities striving to manage limited water resources in various corners of the world. This intimate understanding of the value of water has fueled our commitment to devise a system that not only captures and manages rainwater but also exemplifies our dedication to promoting sustainable practices that are economically viable and environmentally sound.

Our methodology embodies the principles of practicality and stewardship, drawing inspiration from the bountiful rains of Florida to illustrate the potential of rainwater harvesting. By prioritizing the allocation of water to essential needs, we aim to not only curtail the financial burden associated with water procurement but also to foster a culture of conservation and sustainability. This initiative represents a proactive stance against the environmental dilemmas of our time, advocating for a paradigm shift in water management that prioritizes efficiency, resilience, and responsibility.

Through this project, we aim to demonstrate the practicality of repurposing rainwater, challenging current perceptions and practices of water conservation, and inspiring a global shift in how water is perceived, valued, and conserved, towards a more sustainable and secure future for all.
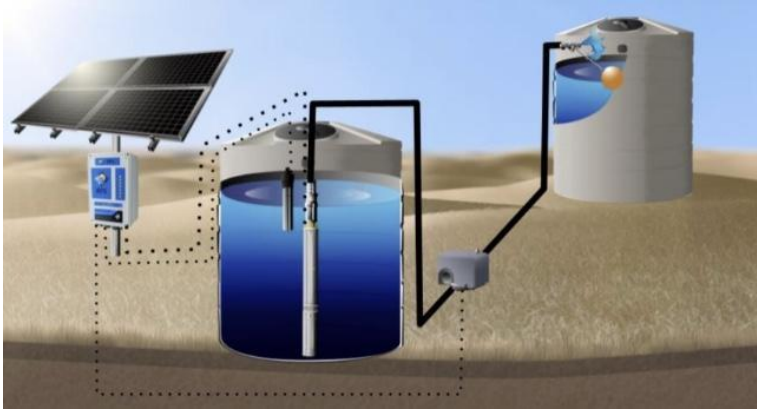
Figure 2.0 - Denotes Pump and Tank 1 and 2 flowing to Basin

2.1 Project Background and Motivation

Introduction
The inspiration behind this project is that most of our team members came from different countries where the importance of water storage is a daily necessity. This collective understanding and commitment to water conservation became the driving force behind our venture. The goal is to extend our impact globally, we aimed to develop a solution that could address water distribution challenges communities worldwide face.
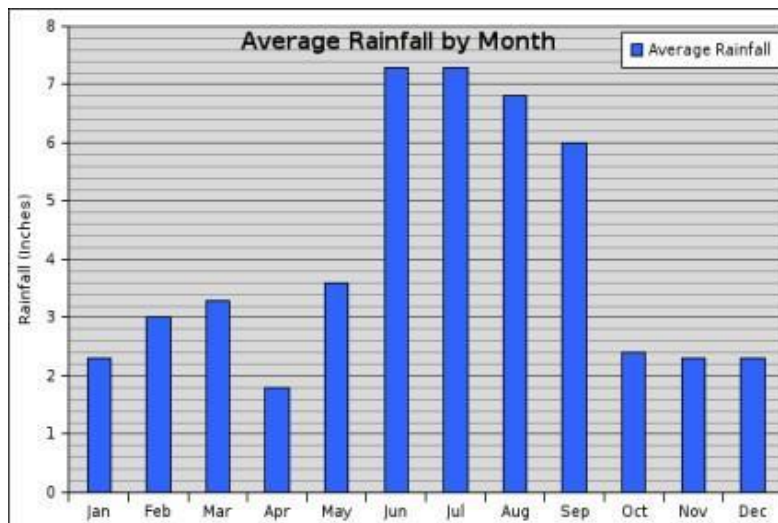
Figure 1.1 – Denotes Average Rainfall by Month in 2023
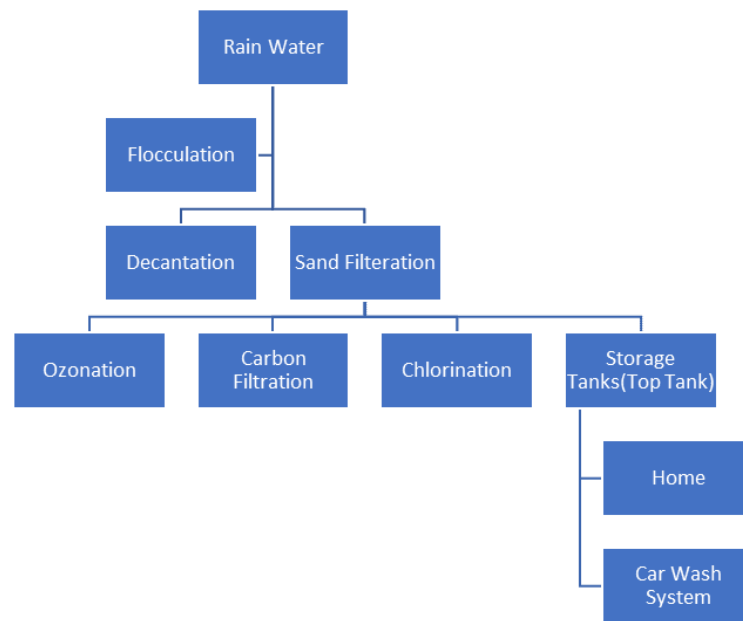
Figure 1.2 – Denotes Process of Filtration and USA

The focus of our project revolves around rainwater. The intention is clear: harness this copious and often underutilized resource to revolutionize water distribution practices. We see rainwater not merely as drops from the sky but as a potential solution to reduce overall water consumption and strategically allocate high-quality water to critical needs.

The global significance of mitigating water scarcity issues became evident to us as a team. This project stands as a testament to our commitment to contribute technologically innovative solutions deeply rooted in the practical experiences of those who intimately understand the pressing need for effective water management. In developing this rainwater harvesting and management system, we strive to provide more than just a technological fix; we aspire to champion economic sensibility and environmental responsibility in tandem.

Our approach is one of practicality and responsibility, resonating with the efficient use of Florida's rainfall. Prioritizing the preservation of water for essential needs, we seek not only to reduce overall water costs but also to advocate for the adoption of sustainable water management practices.

This initiative is our proactive response to the pressing environmental challenges of our era. Beyond economic advantages, our project champions environmental conservation and responsible water management. By showcasing the viability of rainwater for practical purposes, our goal is to set a positive example, promoting water efficiency and resilience in the face of changing environmental conditions. Our project is more than just a system; it's a commitment to instigating a shift in how we perceive, use, and conserve water resources, a commitment that begins locally and extends globally to regions grappling with similar challenges

2.2 Goals and Objectives

Our project outlines specific goals and objectives, categorized into basic, advanced, and stretch goals. These include efficient rainwater collection and distribution as basic goals, integration of advanced filtration technologies, solar power, and IoT monitoring as advanced goals, and, finally, stretch goals involving implementing a user-friendly interface and ensuring adherence to diverse regulatory requirements.

The core focus revolves around rainwater – an abundant yet often underutilized resource. Our intention is straightforward: to harness the potential of rainwater and revolutionize water distribution practices. Rainwater, to us, is more than drops from the sky; it signifies a solution to reduce overall water consumption and strategically allocate high-quality water to critical needs. Recognizing the global significance of mitigating water scarcity, this project stands as a testament to our commitment to providing technologically innovative solutions rooted in the practical experiences of those who understand the urgent need for effective water management. Our aim in developing this rainwater harvesting and management system goes beyond a technological fix; we aspire to champion economic sensibility and environmental responsibility hand in hand.

Our approach is one of practicality and responsibility, aligning with the efficient use of Florida's rainfall. By prioritizing the preservation of water for essential needs, we aim not only to reduce overall water costs but also to advocate for the adoption of sustainable water management practices. This initiative is our proactive response to the pressing environmental challenges of our era, championing environmental conservation and responsible water management. By showcasing the viability of rainwater for practical purposes, our goal is to set a positive example, promoting water efficiency and resilience in the face of changing environmental conditions. Our project transcends being merely a system; it's a commitment to instigate a shift in how we perceive, use, and conserve water resources – a commitment that begins locally and extends globally to regions grappling with similar challenges.

2.3 Design Requirements

This project addresses water scarcity in impoverished regions by introducing a sophisticated rainwater harvesting and management system, efficiently collecting and purifying rainwater for various applications. The system integrates IoT devices, automating the water transfer process and utilizing renewable resources to mitigate water scarcity challenges. Through strategically placed pipes and advanced filtration mechanisms, the project harnesses rainwater from residential roofs and roadside structures, maximizing collection efficiency. State-of-the-art sensors monitor tank levels, triggering automated water transfers without the need for manual intervention. The user-friendly interface allows remote configuration, providing real-time data and reports on tank levels, temperature, and battery status. This integrated approach facilitates seamless connection to existing gutter systems, ensuring adaptability to diverse residential setups in developing countries. The project aims to enhance water management infrastructure,

promoting sustainable water usage and technological advancements in regions with unreliable electricity access.

2.4 To build this project

We did need a comprehensive water collection system comprising several components. Firstly, we'll install gutters along the roof to efficiently collect rainwater. These gutters will direct the water toward downspouts, ensuring a smooth flow toward the storage tanks. Additionally, we'll incorporate a First Flush Diverter, a crucial device that diverts the initial, potentially contaminated rainwater away from the storage tanks, guaranteeing that cleaner water enters the system.

Moving on to the storage tanks, we'll select dedicated water tanks that are suitable based on the anticipated water demand. These tanks must meet specific criteria, including durability, non-toxicity, and corrosion resistance.

For the filtration system, we'll implement both pre-filtration and a more advanced filtration unit. Pre-filtration will involve the use of mesh screens or filters to remove large debris from the collected rainwater before it enters the storage tanks. The advanced filtration system may include sand filters, cartridge filters, or other technologies to ensure the water is safe and suitable for various applications.

In terms of the pump system, we'll install a water pump sized appropriately for the system's water flow requirements. This pump will be responsible for distributing rainwater to different applications effectively. The distribution system will consist of pipes to transport rainwater to various areas, such as irrigation systems, kitchens, bathrooms, and car wash systems. Control valves will also be incorporated to regulate the flow of water to different applications, ensuring efficient usage. To integrate solar power into the system, we'll install solar panels to generate electricity for powering the pump and other components. Additionally, a charge controller will be utilized to regulate the power generated by the solar panels and prevent overcharging of batteries.

For monitoring and control, we'll implement sensors to monitor water levels in the storage tanks, enabling efficient use of available rainwater. A control unit, such as a microcontroller or programmable logic controller (PLC), will automate the system and optimize water distribution based on sensor data.
Regarding overflow and drainage, we'll include overflow pipes to divert excess rainwater away when storage tanks are full. Proper drainage systems will also be established to prevent waterlogging in the surrounding area. Maintenance and access points are crucial aspects, and we'll provide access hatches for maintenance and inspection of the storage tanks. A mechanism for periodic cleaning of the filtration system will also be considered to ensure its optimal performance. Finally, regulatory compliance is essential, and we'll thoroughly check local regulations and obtain necessary permits for rainwater harvesting systems to ensure the project meets all legal requirements and standards.

Our rainwater harvesting system prioritizes both efficient water use and responsible management. To monitor water levels in the storage tanks, we'll integrate sensors that provide real-time data. This information will be relayed to a central control unit, like a microcontroller or PLC, which will automate the system and optimize water distribution based on current needs. Overflow prevention is key: when tanks reach capacity, excess rainwater will be diverted through designated overflow pipes to prevent damage. Additionally, a well-designed drainage system will be established to avoid waterlogging in the surrounding areas. Maintaining the system's functionality is equally important. Access hatches will be incorporated into the storage tanks to facilitate cleaning and inspections.

SPECIFICATION	MEASURE
Tank Capacity	500 gallons to 10,000 gallons
Filtration Efficiency	95% removal of debris and contaminants
Pump Flow Rate	10 gallons per minute to 100
System Integration	Compatibility with standard plumbing systems
Monitoring Accuracy	+/-5% deviation from actual water usage.
Modular Scalability	Addition of extra tanks without system overhaul
Energy Efficiency	Power consumption below 100 watts during operation.

Selection\Feature	Space Requirement	Control and Flexibility	Reason for Selection
Float Switch	Requires more physical space	Limited (on/off only)	Initial option considered
5V Relay	Compact	Greater control (PWM, logic control)	Selected for compact size, control, and current handling

SD2 motor control table selection

2.5 Description of Features/Functionalities

The rainwater harvesting and management system we propose embodies a holistic approach to tackling water scarcity challenges. At its core, the system integrates various features aimed at maximizing the utilization of rainwater resources while promoting sustainable water management practices. Through strategically placed gutters and downspouts, the system ensures efficient rainwater collection from rooftops and other surfaces. Advanced filtration technologies, including sand filters and cartridge filters, guarantee that the harvested water meets stringent quality standards and is suitable for a wide range of applications from domestic use to agricultural irrigation. Our system features meticulously designed pump and distribution mechanisms to optimize water usage across different applications. By calibrating these components, we minimize water wastage while maximizing efficiency, contributing to both economic viability and environmental sustainability. Integrated solar power technology further enhances the system's resilience and sustainability, reducing reliance on conventional energy sources and powering essential components such as the pump and monitoring devices. With a comprehensive monitoring and control system leveraging IoT-enabled sensors and user-friendly interfaces, users can remotely monitor and configure the system in real time, ensuring optimal operation tailored to specific needs and preferences.

Figure 2.5 Sensor water reserve tank flow chart

2.6 Reference and Analysis

Our project draws inspiration from the practical experiences of the team members and comprehensive market analyses. Comparable projects have informed the design requirements, ensuring our system meets the specific needs of regions facing water distribution challenges.

2.7 Existing Product/Past Project/Prior Related Work

In our plan of rainwater harvesting systems, our project emerges as a standout due to its holistic and comprehensive approach. While several systems exist in the market, our endeavor distinguishes itself by incorporating cutting-edge features such as IoT integration and user-friendly interfaces, positioning our solution at the forefront of efficient and sustainable water management practices. By amalgamating these advanced functionalities, our system not only addresses the immediate challenges posed by water scarcity but also sets a new standard for innovation and effectiveness in the field.

Our commitment to excellence is further underscored by a meticulous consideration of key engineering specifications, encapsulated in the Table of Key Engineering Specifications. These specifications serve as benchmarks for our project's performance and efficacy, ensuring that each aspect of our rainwater harvesting system meets or exceeds industry standards. With parameters ranging from collection efficiency to sensor accuracy and user interface satisfaction, our project embodies a dedication to precision and reliability unparalleled in the realm of water management solutions.

Moreover, our project aspires not merely to meet existing expectations but to redefine them entirely. By aiming to achieve a collection efficiency of over 90% and filtration effectiveness of over 70%, we set ambitious yet attainable goals that underscore our commitment to maximizing the utility of rainwater resources. Additionally, our emphasis on minimizing energy consumption and dependency on solar power further exemplifies our dedication to environmental sustainability and resource optimization.

In essence, our project endeavors to set a new benchmark in rainwater harvesting, not only by addressing immediate water scarcity challenges but also by pioneering a paradigm shift towards more innovative, sustainable, and user-centric water management solutions. Through our relentless pursuit of excellence and our unwavering commitment to pushing the boundaries of what is possible, we aspire to leave a lasting impact on the field of water management and contribute significantly to global efforts towards a more sustainable future.
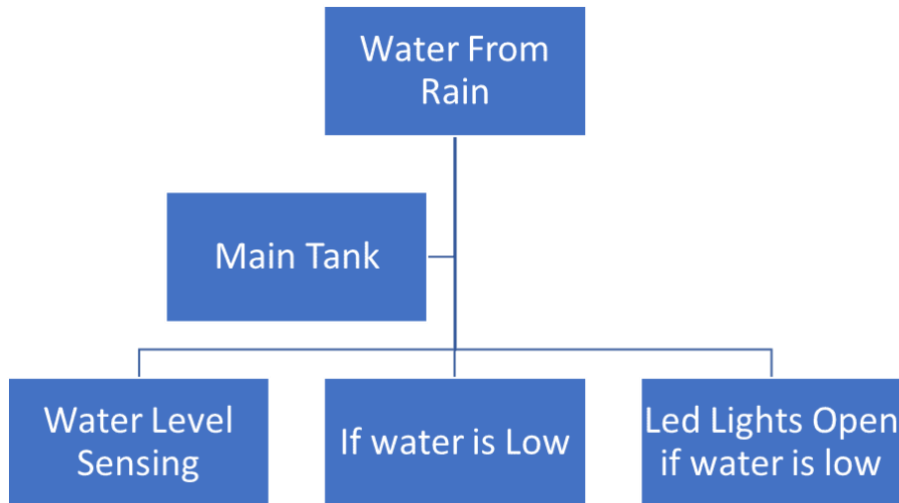
Figure 2.7 Water from rain water sensor flow of the level indicator

The above diagram can show you the water saver working process in the imaginary world. You can easily see the working method of the project and this project needs to be done in any part of the world.

2.8 Key Engineering Specifications

The rainwater harvesting and management system represents a sophisticated integration of various components, seamlessly combining rainwater collection, advanced filtration, solar power integration, and IoT-enabled monitoring. This comprehensive approach ensures a holistic solution to water management, addressing both economic and environmental concerns. At the heart of the system lies its efficient pump and distribution mechanism, which optimizes the utilization of harvested rainwater across various applications. By ensuring optimal usage, the system contributes not only to economic viability but also to environmental sustainability, as it minimizes waste and promotes resource efficiency.

Key to the system's effectiveness are its engineering specifications, meticulously designed to ensure optimal performance and reliability. Rainwater collection efficiency, exceeding 90%, stands as a testament to the system's ability to maximize the utilization of available rainwater resources. This high efficiency ensures that rainwater is effectively harnessed for various applications, ranging from domestic use to agricultural irrigation.

Similarly, the pump efficiency, surpassing 85%, underscores the system's commitment to minimizing energy consumption while facilitating the distribution of rainwater. By maximizing pump efficiency, the system reduces operational costs and enhances economic viability, making rainwater harvesting a financially attractive option for users.

Crucial to the functionality and effectiveness of the WaterSaver system is its advanced filtration capability, meticulously engineered to meet and exceed rigorous quality standards. Targeting a filtration efficacy of over 70%, the system is designed to ensure that the harvested rainwater is not only safe but also suitable for a wide array of uses, ranging from domestic chores to watering gardens, and even extending to certain industrial processes. This ambitious benchmark for filtration efficiency is set to guarantee that the water, once filtered, adheres to health and safety norms that are on par with, if not superior to, conventional water sources.

In parallel with its focus on water quality, WaterSaver places a significant emphasis on sustainable and eco-friendly operations, particularly in terms of energy consumption. The system is meticulously engineered to operate beneath a specific energy usage threshold, thereby underscoring its commitment to environmental stewardship and promoting a greener, more sustainable approach to resource management. This conscientious reduction in energy reliance, coupled with the seamless integration of solar power capabilities, not only bolsters the system's operational resilience but also markedly diminishes its carbon footprint. Through these measures, WaterSaver contributes to the broader objective of long-term environmental preservation, aligning with global efforts to combat climate change and foster a sustainable future.

At the heart of WaterSaver's operational excellence is the unparalleled accuracy of its IoT-enabled sensors, which play a pivotal role in ensuring the system's efficiency and precision in water management. By setting a goal for sensor accuracy at an impressive ±80%, the system is poised to provide dependable, real-time data crucial for the automated management of water transfers. This high level of accuracy is indispensable for optimizing the utilization of collected rainwater, effectively minimizing any potential for wastage and ensuring the sustainable use of every collected drop. The system's advanced sensor technology is adept at monitoring various critical parameters, including water levels, quality, and flow rates, with remarkable precision.

These state-of-the-art sensors are the backbone of WaterSaver, facilitating the automatic initiation of water collection during rainfall and governing the judicious distribution of stored water according to specific needs and conditions. The integration of cutting-edge IoT technology into the system allows for a fluid and continuous exchange of data between the sensors and the control unit, ensuring that each component operates in perfect harmony. This technological synergy not only enhances the system's responsiveness to environmental changes but also enables users to customize and control water management processes with unparalleled ease and efficiency. Through the use of sophisticated algorithms and data analytics, WaterSaver is capable of predicting water usage patterns, identifying potential savings, and even recommending adjustments to improve overall water management strategies.

WaterSaver represents a paradigm shift in water conservation and management, marrying advanced technological innovation with a steadfast commitment to sustainability. Through its rigorous filtration standards, prudent energy use, and the deployment of highly accurate IoT sensors, WaterSaver sets a new benchmark in the

efficient, sustainable management of water resources. This system is not merely a tool for water conservation; it is a comprehensive solution designed to enhance the quality of life, protect the environment, and pave the way for a sustainable, water secure future.

To ensure the filtration system performs optimally over time, a mechanism for periodic cleaning will also be implemented. Finally, we understand the importance of adhering to regulations. We'll conduct a thorough review of local rainwater harvesting guidelines and obtain the necessary permits to guarantee our project meets all legal requirements and environmental standards.

The rainwater harvesting and management system, WaterSaver, represents a sophisticated integration of various components, seamlessly combining rainwater collection, advanced filtration, solar power integration, and IoT-enabled monitoring. This comprehensive approach ensures a holistic solution to water management, addressing both economic and environmental concerns. At the heart of the system lies its efficient pump and distribution mechanism, which optimizes the utilization of harvested rainwater across various applications. By ensuring optimal usage, the system contributes not only to economic viability but also to environmental sustainability, as it minimizes waste and promotes resource efficiency.

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Components	Input	Output	Status	Working Process
Rainwater Collection System	Rainwater from gutters/downspouts	Filtered Rainwater to storage tanks	Acquired	Good
Filtration System	Rainwater from the collection system	Filter rainwater to storage tanks	Completed	accurate
Storage Tanks	Filtered rainwater	Rainwater energy	Acquired	accurate
Solar Panels	Solar Energy	Electrical Energy	Acquired	accurate
Charge Controller	Solar Energy	Regulated charging for batteries	Completed	accurate
Batteries	Electrical energy from Solar panels	Stored Electrical Energy	Acquired	good
Pump System	Electrical energy from batteries	Distributed Rainwater	Designing	good
IoT Sensors	Water level, Temperature data	Data for monitoring and control	Prototyping	good
Microcontroller	Sensor Data	Control Signals	Completed	Accurate
User Interface	User commands	System status information	Designing	good

This chart can show you the difference between the different sensors, you can easily pick the sensor for the project.

2.9 Detailed Software Diagram/Flowchart

Creating a flowchart with group member names highlighted in different colors is smart way to visually represent collaborative progress in a project. By assigning specific colors to each member, it becomes easier to track individual contributions and see the overall distribution of work. This approach fosters transparency and accountability within the group, as members can quickly identify who is responsible for each part of the project. Additionally, it promotes teamwork by encouraging communication and coordination among team members, ensuring that tasks are effectively delegated and completed in a timely manner. Overall, utilizing colored flowcharts enhances both the organization and efficiency of the collaborative process, leading to smoother project execution and successful outcomes.
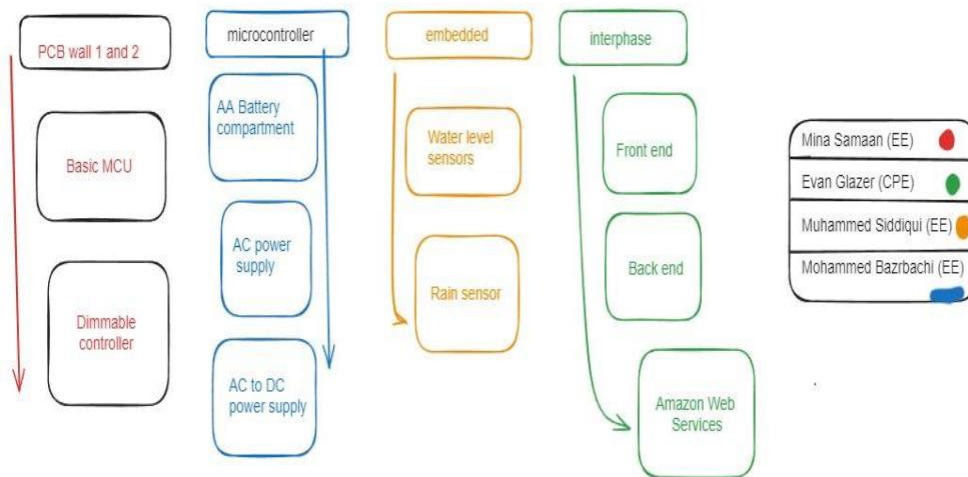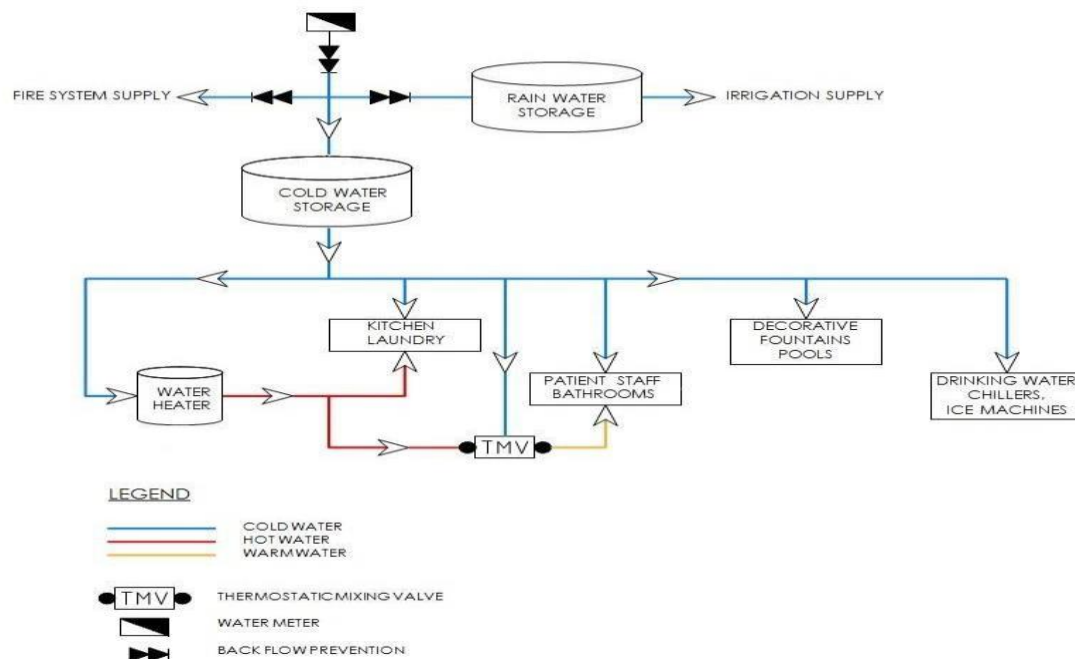
2.10 Prototype illustration

Prototype illustrations serve as crucial visual representations of early-stage designs, offering stakeholders a tangible preview of the final product's appearance and functionality. These illustrations typically embody the core features and interactions envisioned for the prototype, providing a roadmap for development and gathering valuable feedback from users and stakeholders. By depicting key elements such as layout, navigation, and user interface components, prototype illustrations facilitate clear communication and alignment among team members, guiding the iterative design process towards achieving the desired user experience. With their ability to bridge the gap between concept and reality, prototype illustrations play a pivotal role in refining ideas, validating assumptions, and ultimately shaping the direction of the project towards its intended goals.

Figure 2.10 Prototype concept of Water Saver v1

House of Quality

The House of Quality (HOQ) is a vital tool in quality management and product development, converting customer needs into engineering characteristics. It organizes customer requirements, competitive benchmarks, and technical specifications in a matrix format, with rows for customer needs and columns for engineering features. This systematic approach helps cross-functional teams prioritize design decisions, identify trade-offs, and align resources to meet customer expectations. By fostering a customer-centric mindset, the HOQ ensures the final product exceeds customer satisfaction while maintaining technical feasibility and competitive advantage. Ultimately, it drives continuous improvement and innovation, enabling organizations to deliver superior products and services.

The above picture is the 10-gallon tank and there is a water filter on it.

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

Column #	1	2	3	4	5	6	7	8	10	11	12
Direction of Improvement	▲	◇	▲	▲	▼	◇	▲	◇	◇	▲	▼
Functional Requirements → / Row # · Relative Weight · Customer Importance · actual price · Customer Requirements (Explicit and Implicit)	Water Pump	Cost (must be within budget)	Structural integrity	Filtration System	Solar Power	Weight	Monitoring and Control System	storage	show tank state	universal adaptability	battery
1 · N/A · 1 · N/A · Cost effective	●	○	●	▽	▽	▽	○	▽	○	●	●
2 · N/A · 4 · N/A · Light weight	○		●		▽	●		●		●	▽
3 · N/A · 1 · N/A · Adaptablity	○	○		○	○		●	●	○	●	●
4 · N/A · 1 · N/A · Commercially Avaliable Components	●	●	●					●		●	●
5 · N/A · 1 · N/A · Portability	▽	▽	▽	▽	▽	▽				●	●
6 · N/A · 7 · N/A · Low Power Consumption	▽	○	○	○	○		●	●	○		○
7 · N/A · 5 · N/A · data accuracy	●		▽	●	●	▽	▽	○	●		○
8 · N/A · 7 · N/A · Scalable	●	●		○	▽	▽					
9 · N/A · 3 · N/A · Easly Implemented	●	○		●	▽	▽	●	▽	●	●	○
10 · N/A · 2 · N/A · Safe Utalization	●			●		●	●		○		
11 · N/A · 5 · N/A · Reusability	●	●	●	●	▽		●	●	●	●	▽

	1	2	3	4	5	6	7	8	10	11	12
Organizational Difficulty (5=difficult, 1=easy)	2	1	3	4	1	3	5	2		1	3
Our Company	$18	$549	$60	$17	$30	N/A	$40	N/A		Yes	$20
Company A	N/A	$308	N/A	N/A	N/A	N/A	N/A	N/A		Yes	Cheap

3.0 Research and Investigation

In the face of growing global water scarcity, waterSaver introduces an innovative and sustainable approach to water management, aiming to transform the way communities across the world, especially in third-world countries, access and utilize one of life's most essential resources: water. This project, driven by a deep understanding of the challenges posed by limited access to clean water, proposes a novel solution—utilizing the untapped potential of rainwater to mitigate these challenges, promote environmental sustainability, and improve quality of life.

In the pursuit of developing a project that is not only innovative but also highly efficient and reliable, our project navigates the intricate landscape of microcontroller selection, sensor integration, motor and battery choices, and the implementation of H-bridge circuits. Central to our design are considerations of power efficiency, especially vital in a system expected to operate autonomously in remote or resource limited settings. Our objective is to create a device that can be controlled remotely, perhaps via Wi-Fi, ensuring ease of use alongside robust performance in various environmental conditions.

The heart of our system lies in the adept selection of a microcontroller, which must strike a balance between processing power and energy consumption. Given the need for precise sensor data acquisition and processing, a microcontroller with an integrated ADC (Analog to Digital Converter) is paramount. This facilitates accurate monitoring of

environmental parameters through sensors, crucial for the adaptive responses of our water management system. Furthermore, the choice of motor and its control via an H-bridge circuit is pivotal, as it directly influences the system's ability to regulate water flow efficiently. Here, the selection leans towards a brushless motor for its longevity and minimal maintenance, particularly suitable for remote operations where reliability is key.

Battery selection underscores our commitment to sustainability and operational longevity. A lithium-ion battery is favored for its high energy density and rechargeability, ensuring that the system can function for extended periods without intervention. The integration of solar charging capabilities further enhances this, aligning with our goal of a self-sustaining system that minimizes environmental impact.

The design intricacies extend to the selection of sensors, where accuracy, reliability, and power consumption are weighed carefully. Capacitive sensors are chosen for their non-invasive measurement capabilities, ideal for monitoring water levels without contaminating the supply. This choice reflects our system's adaptability to various water

management applications, from irrigation to quality monitoring, without compromising efficiency or safety.

3.1 Technology Comparison for Microcontrollers

Microcontrollers serve as the compact and efficient computing cores within numerous modern electronic devices. These integral components range widely in capability, power consumption, and application, making them indispensable in the technological landscape. This section delves into the characteristics and applications of microcontrollers based on their data bus sizes—8-bit, 16-bit, and 32-bit—as well as specialized forms like Low-Power Microcontrollers, Digital Signal Controllers (DSCs), and FPGA (Field-Programmable Gate Array) Microcontrollers.

3.2 Classification by Data Bus Size

When we have to decide on microcontrollers we also have to consider that based on their data bus sizes offer insight into their capabilities and ideal applications, starting with the 8-bit microcontrollers. These devices stand as the entry-level option, perfectly suited for straightforward tasks that demand minimal processing power. With the ability to manage numerical values from 0 to 255 and possessing a limited addressing range, 8-bit microcontrollers present a cost-effective solution for powering simple sensors, toys, and remote controls. Their appeal lies in the balance between slower processing speeds and lower power consumption, rendering them ideal for a wide array of basic, low-demand applications.

16-bit Microcontrollers: offer enhanced capabilities over their 8-bit counterparts. Capable of processing larger numbers and executing more complex operations at a faster pace, 16-bit microcontrollers are suited for intermediate applications requiring greater computational power. Common uses include motor control systems, data logging, and advanced sensing technologies. While these microcontrollers come at a higher cost than 8-bit versions, their increased speed and data-handling capabilities justify the investment for more complex projects.

32-bit Microcontrollers: stand at the pinnacle of microcontroller technology, providing significant advancements in data efficiency and processing speed. The expanded data bus size allows these microcontrollers to efficiently manage and process large volumes of information, catering to high-demand applications that necessitate rapid computational capabilities. Despite their higher power consumption, 32-bit microcontrollers are preferred for intricate tasks such as sophisticated control systems and extensive data processing. However, for simpler applications, the more modest 8-bit and 16-bit microcontrollers might be more appropriate and cost-effective. By implementing these measures, we can create a sustainable and responsible rainwater harvesting system that effectively manages this valuable resource.

3.3 Specialized Microcontroller Types

The categorization by data bus size demonstrates the broad range of microcontroller capabilities. However, for tailored applications or specific project requirements, specialized microcontrollers such as Low-Power Microcontrollers, Digital Signal Controllers (DSCs), and FPGA Microcontrollers offer distinct advantages.

3.4 Low-Power Microcontrollers

Can be used as we engineer to minimize energy consumption, extending the battery life of portable and remotely operated devices. These microcontrollers often incorporate power-saving modes, such as sleep or idle states, to reduce power usage when not actively performing tasks. They are ideal for applications where energy efficiency is paramount, such as in wearable technology, smoke detectors, and other battery-dependent devices.

Optimal Use Cases: These microcontrollers are exceptionally suited for devices that operate on battery power for extended periods without access to constant recharging—making them perfect for field research equipment, environmental monitoring devices, and personal health trackers. In wearable technology, where size and battery life directly influence user experience, low-power microcontrollers can make the difference between a day and several weeks of usage on a single charge. Similarly, in-home safety devices like smoke detectors, which require long-term reliability and minimal maintenance, these microcontrollers ensure functionality is preserved over extended periods, even with minimal power availability.

3.5 Digital Signal Controllers (DSCs)

Digital Signal Controllers (DSCs) are sophisticated devices that marry the computational abilities of microcontrollers with the signal processing prowess of digital signal processors. This hybrid design enables DSCs to handle complex algorithms and processes involved in managing digital signals, making them particularly suitable for applications that demand both control and high-speed signal processing capabilities. Now, looking at the optimal applications for DSCs, they shine in scenarios requiring the efficient handling of digital signals. Their architecture allows for rapid interrupt responses and access to specialized control peripherals, making them slightly more expensive yet highly cost-effective for specific real-time processing tasks. These include audio signal processing, where precise manipulation of digital sound is crucial, and advanced motor control systems that require intricate speed and position adjustments.

Imagine the complex requirements of audio processing equipment, where every millisecond and sound wave must be precisely managed to deliver clarity and implement effects; here, DSCs step in with their robust computational abilities. Similarly, the realm of robotics and industrial machinery demands meticulous timing and speed control for smooth operation. DSCs excel in these applications, providing the precise control needed to ensure efficiency and effectiveness, demonstrating their indispensable role in advancing technology where precision is key.

3.6 FPGA Microcontrollers

Field-Programmable Gate Arrays (FPGAs) are a marvel of modern electronics, representing a class of microcontrollers known for their unmatched flexibility and adaptability. Unlike traditional microcontrollers, which are hardwired to perform specific tasks, FPGAs can be reprogrammed by the user after manufacturing, enabling a wide range of functionalities to be implemented or modified without altering the physical hardware. This unique attribute allows FPGAs to be custom tailored to meet the exact requirements of virtually any application, making them a powerful tool for developers seeking to create highly specialized and optimized systems.

FPGAs achieve this versatility through an array of programmable logic blocks and a configurable interconnect, allowing them to perform complex combinational functions or simulate the architectures of other specialized processors. This reconfigurability not only offers the ability to prototype designs rapidly but also provides the capability to update the device's functionality in response to evolving technological standards or project requirements, all without the need for physical modifications.

The implications of FPGA technology are profound, particularly in fields requiring high levels of customization and performance optimization. From digital signal processing and cryptographic systems to sophisticated control systems and beyond, FPGAs offer the power and flexibility to innovate and adapt hardware solutions in previously inconceivable ways, firmly establishing them as a cornerstone of modern electronic design and application development.

Optimal Use Cases: FPGAs are ideal for research and development projects where requirements can change rapidly, allowing teams to iterate on designs without the need for new hardware. They're also invaluable in prototyping, enabling developers to test various configurations and functionalities with the same hardware setup. For specialized applications requiring unique logic operations not supported by standard microcontrollers—such as custom encryption for secure communications, or complex parallel processing tasks in scientific computations—FPGAs provide a flexible and powerful solution.

3.7 Part Comparison for Microcontrollers

Microcontrollers are the brains behind countless modern devices and vary widely in their capabilities, power consumption, and intended applications. From simple gadgets to complex industrial machinery, the choice of an MCU hinges on understanding the specific requirements of the project at hand. Factors such as power efficiency, processing power, available peripherals, and cost all play critical roles in this decision-making process. This intricate landscape of options demands a thorough exploration to identify the microcontroller that best aligns with the project's goals, ensuring optimal performance and scalability.

Building on this foundation, let's delve into some notable microcontrollers that stand out for their distinct characteristics and suitability for various applications.

Texas Instruments MSP430, for example, is celebrated for its ultra-low power consumption and an array of power-saving modes, positioning it as a prime candidate for battery-operated devices. It boasts a comprehensive suite of integrated peripherals and a versatile clocking system, making it adaptable to a broad range of application needs. With its diverse packaging and memory configurations, the MSP430 caters to projects requiring efficient power management without compromising functionality.

Transitioning to the Arduino UNO (ATmega328P), this platform shines with its user-friendly environment, ideal for beginners and hobby enthusiasts. Operating at 5V and a 16 MHz clock speed, it provides ample digital and analog I/O pins for a multitude of projects. The Arduino's vast community support enriches users with extensive resources, tutorials, and libraries, encouraging a collaborative and innovative project development process.

The Microchip PIC32MX steps up the performance with its operation frequency reaching up to 80 MHz. It stands out with high-speed USB 2.0, Ethernet, and CAN connectivity options, alongside a generous provision of I/O pins and timers for complex peripheral integration. Supported by the MPLAB X IDE and a comprehensive software library, it caters to developers looking for high computational performance and development support.

Adding to this lineup is the Raspberry Pi, a single-board computer that transcends the traditional microcontroller capabilities. Unlike the typical microcontroller, the Raspberry Pi offers a full computing experience with a Linux-based operating system, capable of running high-level programming languages and supporting complex computational tasks. It features multiple USB ports, HDMI, Ethernet, and GPIO pins for extensive peripheral and display options. With models boasting clock speeds up to 1.5 GHz and various RAM options, the Raspberry Pi is adept at handling tasks ranging from educational purposes to sophisticated DIY projects, home automation, and even as a low-cost desktop replacement. Its ability to serve as a server, especially when combined with an Ethernet shield, adds a new dimension to project possibilities, blending the lines between microcontrollers and full-fledged computers.

Microcontrollers are the brains behind countless modern devices, varying widely in capabilities, power consumption, and intended applications. From simple gadgets to complex industrial machinery, choosing the right microcontroller (MCU) depends on understanding the specific project requirements. Factors like power efficiency, processing power, available peripherals, and cost are critical in this decision-making process. This complex landscape demands a thorough exploration to identify the MCU that best aligns with the project's goals, ensuring optimal performance and scalability.

Feature/Spec	Texas Instruments MSP430	Arduino UNO (ATmega328P)	Microchip PIC32MX	Raspberry Pi (General Specs)
Power Consumption	Ultra-low, with power saving modes	Operates at 5V	Higher frequency operations (up to 80 MHz)	Low power, varies by model
Integrated Peripherals	Timers, UART, SPI, I2C interfaces, ADCS	14 digital 1/0 pins (6 PWM outputs), 6 analog input pins	High-speed USB 2.0, Ethernet, CAN, multiple timers, ADCS, DACS	Multiple USB ports, HDMI, Ethernet, GPIO pins
Clocking System	Flexible, optimizes power consumption	16 MHz clock speed	High computational performance	Up to 1.5 GHz (varies by model
Package & Memory Options	Numerous, for a broad range of applications	Simple IDE, great for beginners	Comprehensive peripheral integration	Various models with different RAM and storage options
Development Environment		Easy to use, with large community support	MPLAB X IDE, with a comprehensive set of software libraries	Linux-based OS with support for multiple programming

Together, the Texas Instruments MSP430, Arduino UNO, Microchip PIC32MX, and Raspberry Pi offer a spectrum of options from simple, low-power device control to complex, computer-like functionalities. This array ensures that regardless of the project's complexity or power requirements, developers can find a suitable platform that best fits the specific needs and constraints of their work.

After careful consideration of various options, including the Texas Instruments MSP430, Arduino UNO, and Microchip PIC32MX, I have decided to proceed with the Raspberry Pi for my project. The choice was influenced by the Raspberry Pi's exceptional versatility and computing power, which stand out among the alternatives. Unlike traditional microcontrollers, the Raspberry Pi offers a comprehensive computing experience with a full-fledged Linux-based operating system, capable of running sophisticated software and handling complex computational tasks. This single-board computer brings the flexibility of high-level programming languages and extensive connectivity options, including USB, HDMI, Ethernet, and GPIO pins, making it an ideal platform for a wide range of applications.

The Raspberry Pi's capacity to function as both a development platform and a standalone computer offers unparalleled opportunities for innovation and project development. Its support for various programming environments and languages, coupled with a robust community and wealth of educational resources, provides a solid foundation for learning and creating. Whether for educational purposes, DIY projects, home automation, or even as a server, the Raspberry Pi presents a cost effective yet powerful solution. Its ability to seamlessly integrate with various peripherals and sensors further enhances its applicability across numerous domains, making it the most suitable option for my project's requirements.

Choosing the Raspberry Pi also aligns with the project's long-term goals of scalability and adaptability. The platform's continuous updates and wide-ranging model variations ensure that it can evolve alongside the project, accommodating future expansions and increasing demands. By leveraging Raspberry Pi's comprehensive feature set and active development community, I am confident in its ability to meet and exceed the project's objectives, providing a robust and flexible foundation for innovation.

3.8 ADC Technology Comparison

In digital electronics, Analog-to-Digital Converters (ADCs) and Digital-to-Analog Converters (DACs) serve as critical bridges between the analog world we live in and the digital systems that form the backbone of modern technology. Understanding when to use ADCs or DACs, their differences, and the outcomes of their application is essential for anyone involved in electronics design, signal processing, or similar fields.

3.9 Analog-to-digital converters (ADCs)

An ADC is a device that converts continuous physical quantities into a digital number that represents the quantity's amplitude. The process of conversion involves sampling the signal at discrete intervals and quantizing the signal's magnitude into a series of numbers or digital values. This functionality is crucial in applications where analog signals from the environment, such as temperature, sound, or light intensity, need to be processed by digital systems, such as microcontrollers, digital signal processors, or computers. we did use ADC in scenarios where there is a need to accurately monitor or measure analog signals using digital equipment. For instance, in environmental monitoring systems,

ADCs are used to convert temperature, humidity, or pressure readings into digital data for analysis and storage. In audio equipment, ADCs transform analog sound waves from microphones into digital signals for processing, recording, or transmission.

Outcome of Using ADCs: The primary outcome of using ADCs is the ability to integrate analog signals into digital systems, allowing for more precise control, analysis, and manipulation of the data. This integration enables the development of sophisticated digital control systems, digital audio and video equipment, medical monitoring devices, and various sensor-based applications.

3.10 Digital-to-Analog Converters (DACs)

The best way we can say the primary use for DAC is that it performs the opposite function of an ADC. It converts digital data into a continuous analog signal. This process involves taking numerical values and converting them into signals with precise voltage or current levels that correspond to the digital values. DACs find their application in situations where digital systems need to control analog devices or need to produce real-world signals. A common application is in multimedia systems, where DACs convert digital audio or video files back into analog signals that can be played on speakers or displayed on screens. In industrial and consumer electronics, DACs are used to control motors, adjust volumes, or modulate frequencies based on digital inputs.
Outcome of Using DACs: The use of DACs enables digital systems to interact with and control the analog world effectively. This interaction is fundamental in creating a seamless user experience in consumer electronics, producing high-quality audio and video playback, and enabling precise control in automation and robotics.

3.11 Technology Comparison: ADC vs DAC

The key difference between ADCs and DACs lies in their direction of conversion Analog-to-Digital Converters (ADCs) and Digital-to-Analog Converters (DACs). These components serve as the critical pathways for the flow of information between the digital domain, where data is represented in binary form, and the analog world, characterized by continuous signals. Understanding the key distinctions and applications of ADCs and DACs is fundamental for anyone navigating the fields of electronics and digital systems design.

ADCs are essentially the interpreters of the physical world for digital systems. They convert analog signals, which vary smoothly over a range of values, into digital signals, which are represented as sequences of bits. This conversion is crucial for digital systems, such as computers and microcontrollers, to process and store information originating from analog sources like temperature sensors, microphones, or light sensors. For instance, in a digital thermometer, an ADC is used to convert the analog temperature signal into a digital form that can be processed and displayed by the device. Without ADCs, capturing and digitizing real-world phenomena for analysis, monitoring, or processing by digital systems would be impossible.

On the flip side, DACs perform the reverse operation. They take digital instructions—often resulting from computational processes within a digital system—and translate them into analog signals that can interact with the physical world. This capability is vital in applications requiring a digital system to produce real-world effects, such as generating sound in a digital audio player, controlling motor speeds in robotic systems, or adjusting brightness levels in LED displays.

DACs act as the voice of digital systems, enabling them to communicate and exert control over their analog surroundings.

The necessity for either an ADC or a DAC hinges on the specific demands of an application. For projects focused on data acquisition or monitoring systems, where it's essential to accurately capture and digitize analog signals from the environment, ADCs are indispensable tools. They enable digital systems to perceive and understand the nuances of the analog world, facilitating sophisticated data analysis, predictive maintenance, and automated decision-making processes.

Conversely, DACs find their significance in applications where digital systems are required to influence the physical environment. Whether it's through producing sound, light, motion, or any other form of analog output, DACs provide the means for digital decisions and computations to manifest tangibly. Their role is especially pronounced in the realm of multimedia systems, automated control systems, and anywhere else the digital domain seeks to make its mark on the physical world.

As we continue to advance technologically, the importance of both ADCs and DACs only grows. These components are the linchpins in the ongoing convergence of digital and analog systems, facilitating not only the current wave of smart devices and IoT applications but also paving the way for future innovations. The seamless integration of digital functionalities into everyday devices and systems underscores the transformative role that ADCs and DACs play in modern technology, embodying the essence of converting and conveying information across the digital-analog divide.

The key difference between Analog-to-Digital Converters (ADCs) and Digital-to-Analog Converters (DACs) lies in their direction of conversion. ADCs convert analog signals, which are continuous and vary smoothly over a range of values, into digital signals, which are represented as sequences of bits. This conversion is crucial for digital systems, such as computers and microcontrollers, to process and store information from analog sources like temperature sensors, microphones, or light sensors.

Feature	Analog-to-digital converters (ADCs)	Digital-to-Analog Converters (DACs)
Function	Convert continuous analog signals into discrete digital numbers.	Convert digital numbers into continuous analog signals.
Usage Scenario	Necessary when analog signals (e.g., temperature, sound) need to be processed by digital systems.	Required when digital systems need to produce or control real-world signals (e.g., audio output, motor control).
Applications	Environmental monitoring systems, digital audio recording, and sensor data processing.	Multimedia systems (audio players, video displays), motor controls, volume modulation.
Outcome	Enables digital systems to accurately monitor, measure, and analyze analog signals.	Allows digital systems to effectively interact with and control the analog world.
Key Difference	Brings analog signals into the digital domain for processing and analysis.	Translates digital instructions into tangible analog outputs for various uses.
Ideal For	Monitoring or data acquisition systems need to capture real-world phenomena.	Systems requiring tangible outputs like sound, light, or motion based on digital inputs.

3.12 Part comparison ADC

The Texas Instruments ADS1115: represents a family of high-precision, low-power, 16-bit analog-to-digital converters (ADCs) that stand out due to their compact size and versatility. These devices are housed in an ultra-small X2QFN-10 package, measuring just 2 mm × 1.5 mm × 0.4 mm, making them an ideal choice for space constrained applications. They support a wide operating voltage range from 2.0 V to 5.5 V and are designed to be power-efficient, with a low current consumption of 150 µA in continuous-conversion mode. The ADS1115 features a programmable data rate ranging from 8 samples per second (SPS) to 860 SPS, allowing for adaptable measurement speed to match application requirements. Additionally, it includes a built-in low-drift voltage reference, an internal oscillator, and an I2C interface with four pin-selectable addresses for flexible connectivity options.

Designed to cater to a broad spectrum of applications, the ADS1115 is particularly well-suited for portable instrumentation, battery voltage and current monitoring, temperature measurement systems, consumer electronics, and factory automation and process control. It boasts a programmable gain amplifier (PGA) for precise measurements across a wide input range and a digital comparator for under- and overvoltage detection, enhancing its utility in various sensor measurement scenarios. Whether deployed in continuous-conversion mode for real-time monitoring or in single-shot mode to conserve power during idle periods, the ADS1115's combination of precision, low power consumption, and small form factor make it a highly efficient power solution- and space-constrained environments.

The Analog Devices AD converter AD7991: stands out in the field of analog-to digital conversion with its exceptional performance and versatility. These devices are engineered to offer precision conversion from analog signals to digital form, boasting a fast conversion time of just 1 µs. This rapid processing capability is essential for applications requiring timely data analysis and decision-making. Operating within a voltage supply range of 2.7 V to 5.5 V, these converters are designed for efficiency, featuring remarkably low power consumption. A distinctive shutdown mode reduces power usage to a mere 1 µA maximum, making these ADCs particularly well-suited for energy-conscious projects where power efficiency is paramount.

Each model in the series is equipped with an I2C-compatible serial interface, accommodating a variety of communication speeds including standard, fast, and high-speed modes. This flexibility ensures that the converters can be easily integrated into a wide range of system designs. Furthermore, the AD7991 models are available in two versions, each with a unique I2C address, allowing for the use of two identical devices on the same bus. This feature, coupled with their ability to handle input frequencies up to 14 MHz and the option for sequencer operation across multiple analog input channels, positions these ADCs as highly adaptable solutions for diverse applications, from system monitoring and data acquisition to medical instruments and automotive applications.

The Microchip MCP3008: is a highly versatile and efficient 10-bit Analog-to-Digital (A/D) converter, part of Microchip Technology Inc.'s series of A/D converters which also includes the MCP3004. These devices are designed with precision in mind, featuring a

maximum Differential Nonlinearity (DNL) and Integral Nonlinearity (INL) of ±1 LSB, ensuring accurate readings for a variety of applications. The MCP3008, in particular, offers flexibility with its 8 input channels, which can be programmed as either four pseudo-differential input pairs or eight single-ended inputs, making it an ideal choice for complex data acquisition needs. Its on-chip sample and hold circuit ensure stable input signal sampling, critical for accurate conversions. Communication is streamlined through an SPI serial interface, supporting modes 0,0, and 1,1, allowing for easy integration into existing digital systems. Designed for efficiency, these converters operate on a single supply voltage ranging from 2.7V to 5.5V and offer impressive conversion rates—up to 200 ksps at 5V and 75 ksps at 2.7V.

The MCP3008, engineered using advanced low-power CMOS technology, epitomizes efficiency in energy consumption, thereby setting a benchmark for analog-to-digital converters. Its design prioritizes minimal energy usage, with an impressively low standby power draw of only 5 nA and maximum active consumption of 500 µA at 5V. This exceptional energy efficiency renders the MCP3008 an ideal component for battery-operated systems, where power conservation is paramount to prolong battery lifespan and ensure sustained operation.

Further enhancing its utility across a broad spectrum of applications, the MCP3008 is engineered to withstand the rigors of industrial environments, reliably functioning within a wide temperature range from -40°C to +85°C. This robustness, coupled with the availability of various package formats such as PDIP, SOIC, and TSSOP, offers unparalleled flexibility, accommodating diverse deployment needs in sensor interfaces, process controls, data acquisition systems, and any application necessitating precise and dependable analog-to-digital conversion.

Its prowess is not merely confined to its low power consumption and operational resilience. The MCP3008 also shines in its technical capabilities, boasting high resolution and programmable inputs that enable users to customize the device for specific monitoring and control tasks. These features make it a standout choice for professionals and enthusiasts alike who require top-tier performance from their digital monitoring and control systems. The MCP3008's blend of energy efficiency, operational durability, and versatile functionality positions it as a premier solution in the realm of analog-to-digital conversion, promising to enhance the efficacy and reliability of a wide array of technological applications.

The Texas Instruments ADS1115 is a versatile 16-bit analog-to-digital converter (ADC) known for its high precision and low power consumption. Encased in a tiny X2QFN-10 package (2 mm × 1.5 mm × 0.4 mm), it is perfect for space-constrained applications. Operating over a voltage range of 2.0 V to 5.5 V, it consumes only 150 µA in continuous-conversion mode.

Specification	Texas Instruments ADS1115	Analog Devices AD7991	Microchip MCP3008
Resolution	16-bit	12-/10-/8-bit	10-bit
Max DNL (Differential Nonlinearity)	±1LSB	±1LSB	±1LSB
Max INL (Integral Nonlinearity)	±1LSB	±1LSB	±1LSB
Input Channels	4 Single-Ended or 2 Differential	4/3 Channels with Reference Input	8 Input Channels
Sampling Rate (at max VDD)	860 SPS	200 ksps	200 ksps
Voltage Supply Range	2.0 V to 5.5 V	2.7 V to 5.5 V	2.7 V to 5.5 V
Power Consumption (Active)	150*10^-6 A	1*10^-6 A Shutdown Mode	500*10^-6 A
Interface	I2C	I2C	SPI
Temperature Range	-40°C to +125°C	-40°C to +125°C	-40°C to +85°C
Package Options	X2QFN-10	PDIP, SOIC, TSSOP	PDIP, SOIC, TSSOP.

We have decided to proceed with the Texas Instruments ADS1115. This decision is anchored in the ADS1115's outstanding combination of high precision, low power consumption, and compact form factor, making it superior for my specific application needs compared to other devices. The ADS1115 offers a 16-bit resolution, which is crucial for projects demanding high accuracy and fine detail in measurements. This level of resolution ensures that even the smallest changes in the analog input are captured and

converted accurately into digital form, a necessity for my project that relies on precise data to drive decision-making processes.

Furthermore, the ADS1115's ultra-low power consumption of just 150 µA in continuous-conversion mode is a significant advantage, especially in applications where power efficiency is paramount. This feature aligns perfectly to create a battery-powered device that can operate for extended periods without requiring frequent recharging. Additionally, the ADS1115's versatile voltage supply ranges from 2.0 V to 5.5 V, and its programmable data rate ranging from 8 SPS to 860 SPS offers flexibility in tuning the power usage and conversion speed according to the project's requirements. Coupled with its I2C interface for easy communication and small X2QFN-10 package that suits space-constrained applications, the ADS1115 stands out as the most suitable option for delivering the precision, efficiency, and compactness needed for my project's success.

3.13 Capacitive Liquid Level Sensors Technology Comparison:

Capacitive liquid level sensors operate on the principle of detecting changes in capacitance that occur as the proximity of a liquid alters the dielectric constant in their vicinity. This change is then accurately translated into liquid-level measurements by the sensor.

The beauty of capacitive sensors lies in their ability to perform non-invasive level measurements through tank walls, making them perfectly suited for handling highly viscous liquids or in situations where direct contact with the liquid is either undesirable or impractical. This feature, along with their non-contact nature, makes them exceptionally well-suited for use in the food and beverage, pharmaceutical, and chemical processing industries. In these sectors, the avoidance of contamination is critical, and the materials being measured can often be corrosive or otherwise harmful to direct-contact sensors. The capacitive liquid level sensor, therefore, offers an elegant solution, providing reliable measurements without the risk associated with exposure to the liquid being measured. The water level liquid sensor has different kinds of ways to prove that it is the main product of our project.

We could use expensive sensors in our project, but we can't use anything very expensive because of the cost standards and constraints. To make the project operate we have to take care of the cost and price. There are so many similar projects present in the market so we have to make something way cheaper and more beneficial than those products. This sensor requires some difficult work but in the end, you have to make something difficult from the products which have less work and less efficiency. The more you find products the more you will learn about the particular stuff.

3.14 Ultrasonic Liquid Level Sensors

Ultrasonic liquid level sensors represent a sophisticated technological solution for measuring the level of liquids in a vast array of applications, harnessing the power of sound waves to deliver precise and reliable data. These sensors function by emitting high-frequency ultrasonic pulses that travel through the air until they encounter the surface of

the liquid. Upon hitting this surface, the pulses are reflected to the sensor, where the time lapse between the emission and reception of these sound waves is meticulously calculated. This duration is directly proportional to the distance between the sensor and the liquid surface, allowing the device to accurately determine the liquid level without any physical contact.

One of the standout features of ultrasonic-level sensors is their remarkable versatility and adaptability across different environments and materials. They excel in applications that demand accurate, non-contact measurements across a wide range of distances, making them an ideal choice for industries such as water treatment, where constant monitoring of water levels is crucial for efficient plant operation. Similarly, in the realm of fuel management, whether in stationary fuel tanks or mobile fuel storage, ultrasonic sensors provide vital data that ensures safe and efficient fuel storage and handling. Furthermore, their application extends to bulk storage monitoring, where the maintenance of optimal storage levels is essential for operational efficiency and safety.

Ultrasonic sensors are particularly advantageous in environments where the liquid's physical properties are variable or difficult to measure using traditional contact methods. Unlike sensors that rely on conductivity or the liquid's optical properties, ultrasonic sensors remain unaffected by changes in color, viscosity, or chemical composition. This characteristic is crucial in sectors like the chemical processing industry, where the liquids involved can frequently change in terms of their physical and chemical properties. Additionally, these sensors are inherently safe and clean, as they do not require direct contact with the liquid, thus eliminating the risk of contamination or chemical reaction— a significant advantage for applications in the food and beverage and pharmaceutical industries.

I would like to dive deeper into the components of an ultrasonic module, breaking down each element and its significance in the overall system. Think of this as piecing together a technological puzzle where every piece plays a critical role in how the final picture— i.e., the ultrasonic module—functions.

Ultrasonic Transmitter: Imagine you're at a lake, skipping stones to see how far they go. In a similar way, the ultrasonic transmitter throws out ultrasonic pulses into the air. These pulses are like invisible sound waves that move in a straight line and are too high-pitched for us to hear. The transmitter is like the arm that throws the stone, but here, it's launching sound waves instead of stones.

Ultrasonic Receiver: Now, imagine some of those stones you skipped bounce back to you. The ultrasonic receiver's job is to catch these "bouncing" sound waves. But instead of catching stones, it's detecting the ultrasonic pulses that bounce back after hitting an object. It's kind of like playing a game of echo, where the receiver listens for the echo of the sound waves to understand if there's anything ahead.

Control Circuit: This part is the brain of the operation. Once the transmitter sends out a wave and the receiver catches it bouncing back, the control circuit calculates how much

time that took. It's like timing your echoes in the canyon and figuring out how far away the canyon wall is based on how long it takes for the echo to return. This time is then used to calculate the distance to the object the pulse hit.

Transducer: The transducer is a bit of a shape-shifter. It can take electrical energy and change it into ultrasonic sound waves that the transmitter sends out. Then, it can do the reverse, taking the ultrasonic waves the receiver catches and turning them back into electrical signals for the control circuit to analyze. So, it's like translating between two languages: the language of electronics and the language of sound waves.

PCB (Printed Circuit Board): Think of the PCB as the stage where all our components perform. It holds everything together, providing pathways for electrical signals to move between components. It's the platform that lets our transmitter, receiver, control circuit, and transducer communicate and work together smoothly.

Housing: The housing is like a protective shell or a case for our device. It keeps all the sensitive components safe from dust, water, or anything else that could damage them. It also makes the device easier to handle and use. Think of it as packing your electronics in a sturdy box when you move, so they don't get damaged.

Connector: Finally, the connector is like a doorway that lets the ultrasonic module talk to other devices. It's how the module sends out its findings (like the distance to an object) to a computer or another system that needs that information. So, it's essentially the module's way of sharing its discoveries with the world.
So, when you put all these pieces together, you get an ultrasonic module that can tell you how far away things are by sending out sound waves and listening to their echoes. It's a neat example of how we can use different components to interact with the world in ways we can't on our own, like seeing with sound.

Moreover, the non-contact nature of ultrasonic sensors minimizes wear and tear, reducing maintenance requirements and extending the lifespan of the equipment. This aspect, combined with their ability to operate over large distances and in challenging conditions (such as in the presence of vapors, foam, or high-pressure environments), underscores the ultrasonic liquid level sensor's role as a critical component in modern industrial and environmental management systems.

Beyond the float and liquid level sensors, the spectrum of water sensing technologies extends to encompass a variety of devices each designed for specific monitoring tasks. Water leakage sensors, for instance, are indispensable tools in both residential and industrial settings, offering early detection of leaks to mitigate potential water damage and prevent consequential losses. Quality sensors, on the other hand, play a pivotal role in environmental conservation efforts, aquaculture, and the management of water treatment facilities by providing essential data on a range of parameters, including pH levels, turbidity, and the presence of contaminants. These insights are crucial for maintaining water safety and quality. Additionally, flow sensors contribute significantly to efficient water management by measuring the velocity of water movement through

pipes or channels. This capability is vital in various applications such as irrigation systems, municipal water supply management, and a plethora of industrial processes, where precise control over water flow is a prerequisite for operational success and sustainability. Collectively, these specialized water sensors form a comprehensive toolkit for advanced water management, safeguarding resources, and ensuring environmental compliance across multiple domains

When selecting a motor for a water pump, there are several considerations to consider between brushed, brushless, and servo pump motors. Each type offers distinct advantages and drawbacks, which can significantly impact their suitability for specific applications. SD2 sensor table comparison

Name\Feature	Purpose	Connection Type	Reason for Choosing
Hoya red water sensor	Detecting rain	Direct to Nano	Space-efficient, easy integration
MH sensor series	Detecting rain	Direct to Nano	Space-efficient
Orbit 57069N	Detecting rain	Direct to system	
Waterproof Ultrasonic Sensor	Measuring water level	Direct to Nano	Direct connection to Nano, no WiFi
YoLink LoRa	Measuring water level	Requires WiFi	Need wifi to connect

3.15 Motors Technology Comparison

Brushed Motors: Brushed motors are among the oldest designs, characterized by their simplicity and lower cost due to direct contact between their brushes and the commutator. This direct contact facilitates easy control but requires regular maintenance to manage wear and tear on the brushes. Brushed motors are notably durable in harsh environments because their straightforward design lacks sensitive electronic components. However, their reliance on physical brushes limits their lifespan and efficiency and can introduce additional noise and potential for sparks, which might not be ideal for all applications.

Brushless Motors: Brushless motors, in contrast, offer increased efficiency and a longer lifespan since they eliminate the need for brushes, thereby reducing friction, heat generation, and maintenance requirements. They're capable of higher speeds and can produce more torque per watt than brushed motors. This makes them a preferable option for applications requiring high performance and reliability. The lack of brushes also means fewer sparks and less noise, contributing to a cleaner and quieter operation. However, the initial cost of brushless motors can be higher, reflecting their advanced design and the need for an electronic controller to manage the motor's operation.

Servo Motors: Servo motors are unique in that they can be based on either brushed or brushless designs but are part of a closed-loop system with feedback mechanisms to precisely control the motor's position or speed. They're highly controllable and offer incredible precision and efficiency, making them ideal for applications where accurate positioning is crucial. Servo motors are excellent for intermittent use with specific positioning requirements rather than continuous operation. They are more complex and expensive than both brushed and brushless motors, reflecting their sophisticated control systems and high performance. The choice between brushed, brushless, and servo motors for water pump applications depends on maintenance, efficiency, and the specific performance requirements of your project. Brushed motors are a budget-friendly option for rugged environments and simple applications. In contrast, brushless motors offer a balance of efficiency, longevity, and performance for more demanding applications. Servo motors are the go-to for precision control in sophisticated systems, albeit at a higher cost and complexity.

Motor Type	Efficiency %	Initial Cost (Relative)	Maintenance Frequency	Lifespan (Relative)	Application Suitability
Brushed	75-80	1	High	Shorter	Simple, low-cost application s
Brushless	85-90	1.5-2	Low	Longer	High efficiency and performance needs
Servo	Up to 90+	2-3	Medium	Varies	Precision control requiremen ts

3.16 Motor comparison and selection

When selecting parts for motor controls, particularly in applications that involve motors like brushed, brushless, and servo motors, it's crucial to consider a range of factors to ensure optimal performance, efficiency, and compatibility with your project's requirements. Here are some key aspects to keep in mind:

Voltage Requirements: Voltage is a pivotal parameter in motor operation, dictating the motor's ability to function correctly within an application. Brushed motors are versatile, accommodating a broad spectrum of voltages, which makes them amenable to diverse applications with minimal control complexities. However, the adaptability of brushed motors to various voltages does not exempt them from the need for compatible control systems to manage their operation effectively, though these systems tend to be less complex than those required for other motor types.

In contrast, brushless and servo motors demand more sophisticated control mechanisms due to their intricate design and operation principles. These motors are designed for specific voltage ranges, and operating them outside these ranges can lead to inefficiency, potential damage, or failure. The precision control systems for these motors not only manage voltage but also optimize performance through advanced algorithms and feedback mechanisms, ensuring that the motor operates within its intended voltage specifications for peak efficiency and longevity.

Work Capabilities: The capacity of a motor to perform its intended tasks—its work capabilities—is another critical consideration. This capacity is often evaluated in terms of torque and speed. Servo motors excel in applications that demand high precision and control, especially at low speeds, providing high torque for meticulous movements. This makes them ideal for tasks requiring exact positioning and control.

Brushless motors strike a balance between speed and torque, offering improved efficiency and a longer lifespan than their brushed counterparts. Their design minimizes friction and heat generation, leading to better overall performance and durability. When evaluating a motor for a specific application, it's crucial to consider the required work capabilities—both the speed at which the device must operate and the torque it must provide—to ensure the selected motor and control system can meet these demands effectively.

Power Usage: Efficiency is paramount, particularly in battery-powered applications or where energy consumption directly impacts operational costs. Brushless motors are generally more efficient than brushed motors, thanks to their design which eliminates the friction and energy loss associated with brushes. This efficiency translates into lower power consumption for the same amount of work.

Servo motors, with their advanced control systems, are designed to use power judiciously, consuming only what is necessary for the task at hand. However, the complexity of these control systems can mean that they draw power even when the motor is not actively driving a load, potentially leading to higher overall power consumption if not carefully managed.

Motor Controls: The choice of motor control system is dictated by the application's specific requirements. Simple applications that do not require precise positioning might be well-served by the straightforward controls of brushed motors. In contrast, applications necessitating precise control over speed, position, or torque will benefit from

the more sophisticated control systems associated with brushless or servo motors. These advanced systems may incorporate feedback loops, Field-Oriented Control (FOC), and programmable settings to achieve the desired operational modes and performance levels.

3.17 Technology Comparison: H-Bridge vs Half-H Bridge

When considering the technology for motor controls, particularly in choosing between H-Bridge and Half-H Bridge configurations, along with PWM (Pulse Width Modulation) for speed control, it's essential to understand their functionalities and applications to make an informed decision.

An H-bridge is a circuit configuration commonly used to control the speed and direction of DC motors. It consists of four switches (transistors or MOSFETs) that allow for the reversible direction of the motor's rotation. PWM control can be applied in this setup to vary the speed of the motor by adjusting the duty cycle of the input signal, effectively controlling the voltage and thus the speed of the motor. This modulation enables precise speed control over the motor by altering the on-time and off-time phases of the PWM signal, with the ratio of these times determining the motor's speed. The versatility in drive modes offered by the H-Bridge, such as lock anti-phase and phase-magnitude drive, allows for sophisticated control strategies, enhancing the motor's response to different operational demands.

On the other hand, a Half-H Bridge configuration uses only two switches and cannot provide directional control on its own, limiting its application compared to the full H-Bridge. However, it can be simpler and less expensive to implement for applications where direction control is not required or is managed by other means.

PWM serves as a critical method for controlling motor speed in both setups, but its implementation and effectiveness can vary significantly between them. By generating PWM signals, you can finely tune the motor's performance, adjusting speed with high precision while also impacting the system's overall efficiency and power consumption. This is especially pertinent when using microcontrollers, as the generation of PWM signals involves considering several constraints, including frequency and duty cycle, to match the specific requirements of the motor and its application.

For projects involving pumps or similar applications like the motor we are using where speed and direction control are crucial, an H-Bridge with PWM speed control offers a robust solution. It provides the flexibility needed for precise motor control, accommodating various operational modes and ensuring efficient power usage. The choice between an H-Bridge and a Half-H Bridge, and the implementation of PWM, should be guided by the specific needs of the application, including the complexity of control required, the directionality of motor operation, and cost considerations.

3.18 Solar technology comparison

To compare solar panels, we need to consider several factors to ensure we make the best choice for our project. Initially, we discovered that panels made from Monocrystalline perform better than those made from polycrystalline, even though they both weigh about the same. Monocrystalline panels are more efficient and work faster. Next, we must consider the voltage, amperage, and wattage that the panels support to ensure compatibility with our project. After researching what is available in the market, we found that most panels support 6 and 12 volts and 1 to 100 watts.

3.19 Solar part comparison

Features/name	Flexible solar panel	Eu Goov	Mini Solar panel
Material	polysilicon	polysilicon	Monocryst alline
Panel voltage	12 to 18v	6v	12v
power	300w	1w	10w
USB output	5v	none	none
Number of USB ports	2	0	
size	43*20 cm	110*60 mm	136*110
Cost	$21.49 plus tax	15.78 plus tax	6.78 plus tax
Come with controller	yes	no	no
seller	Ali Express	Amazon	temu

Selection\Feature	types of solar panel	Dimension	Come with voltage controller
12V 20W panel	Monocrystalline	16"L x 13.1"W x 0.8"H	Yes
5v 200mA	Polycrystalline	4.33"x 2.36" (L*W);	No
5v USB panel	Monocrystalline	6.85"L x 6.46"W x 0.58"H	NO

SD2 solar panel table comparison

3.20 Water Filter Technology Comparison

When comparing water filter technologies, several factors must be considered to determine the most suitable option for specific needs. Reverse Osmosis (RO) systems utilize semi-permeable membranes to effectively remove a wide range of contaminants, making them ideal for areas with poor water quality. However, they typically have a higher initial cost and require periodic maintenance, including membrane replacement. Activated carbon filters are efficient at removing chlorine, odors, and certain chemicals, offering moderate initial costs but necessitating regular cartridge replacements. UV disinfection systems use ultraviolet light to eliminate microbial contaminants, providing a chemical-free method of water disinfection with moderate initial costs and low ongoing maintenance. Ion exchange systems soften water by removing hardness minerals and heavy metals through resin exchange, requiring periodic regeneration but offering benefits for areas with hard water. Ceramic filtration, utilizing porous ceramic material, effectively removes microbial contaminants and sediment particles at relatively low initial costs and minimal maintenance. Finally, distillation systems produce purified water by boiling and condensing water vapor, offering high efficiency but with higher initial costs and periodic maintenance needs. Each technology presents unique advantages and limitations, and the choice depends on factors such as water quality, budget, and intended use.
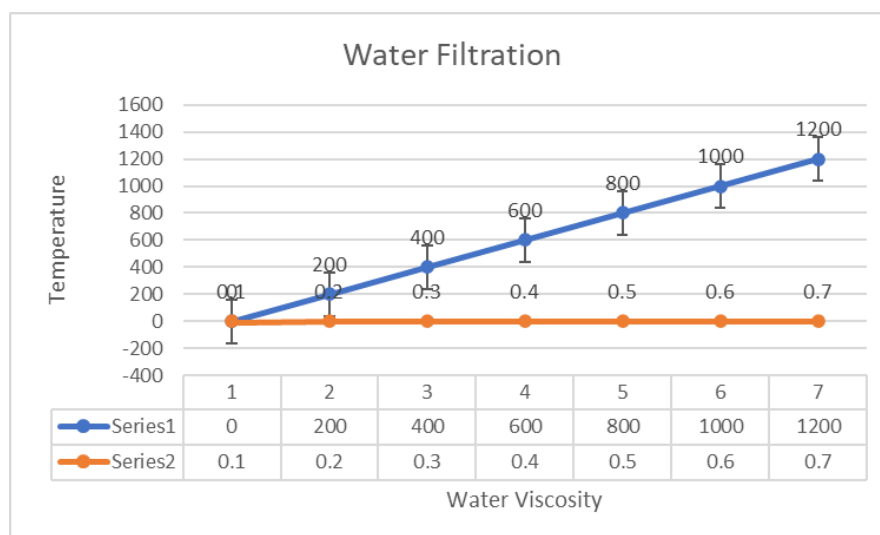
Figure 3.20 Water filtration showing temperature to water viscosity

3.21 Water Filter Parts Comparison

In the quest to harness rainwater for practical use, the role of a water filtration system cannot be overstated. Given that rainwater, while inherently clean as it descends from the sky, often collects various contaminants as it lands on buildings, roads, and other surfaces, it becomes imperative to purify this water before it's deemed suitable for use. Our project, focusing on the utilization of rainwater, thus relies heavily on an effective water filtration system. Each component within this system plays a pivotal role in ensuring the water is free from impurities and safe for use.

Filter Element: At the core of any filtration system lies the Filter Element, a crucial component responsible for the actual process of removing impurities from water. While rainwater is collected, it may carry along materials from surfaces it comes into contact with, including metals like steel from pipes, or other particulates. The Filter Element can be composed of various materials such as plastics for cost efficiency, steel for durability, or copper for its antimicrobial properties, each chosen based on the specific impurities expected to be encountered. Understanding the composition and functionality of the Filter Element is key, as it directly impacts the efficiency of the filtration process and the quality of the water produced.

Copper Connectors: serve as the vital link between the water source and the filtration system. Made from copper, these connectors are celebrated for their longevity and exceptional resistance to corrosion, a necessary attribute given the varying quality of rainwater. The choice of copper not only ensures the system's durability but also contributes to maintaining water quality, thanks to copper's natural antibacterial qualities.

Gaskets or Seals: To ensure a watertight seal within the filtration system, Gaskets or Seals are indispensable. Typically made from rubber or silicone, these components prevent any potential leakage between the filter housing and the copper connectors. Their role is

crucial in maintaining the system's integrity and efficiency, preventing unfiltered water from bypassing the Filter Element, and guaranteeing that all water is properly purified.

Inlet and Outlet Ports: The Inlet and Outlet Ports mark the entry and exit points for water within the filtration system. The Inlet Port is directly connected to the water source, welcoming unfiltered rainwater into the system, while the Outlet Port channels the filtered water towards its intended use, be it irrigation systems or storage tanks. These ports are designed to facilitate the smooth flow of water, ensuring efficient processing and distribution of the purified water.

Pressure Release Valve: Included in many filtration systems is a Pressure Release Valve, a safety feature designed to manage and relieve any excess pressure that may build up within the filter housing. This is particularly important in high-pressure systems where the risk of damage or system failure is heightened.

Integrating these components into a singular, cohesive water filtration system requires not only technical knowledge but also a deep understanding of how each part interacts within the system. This process is akin to orchestrating a complex ballet of engineering, where each component must perform its role flawlessly to ensure the success of the whole. As we embark on this journey to assemble such a system, our guiding principles remain clear: effectiveness, durability, and reliability. These principles steer us toward the ultimate goal of harnessing rainwater as a sustainable resource, providing a blueprint for others to follow in addressing the critical need for clean, accessible water.

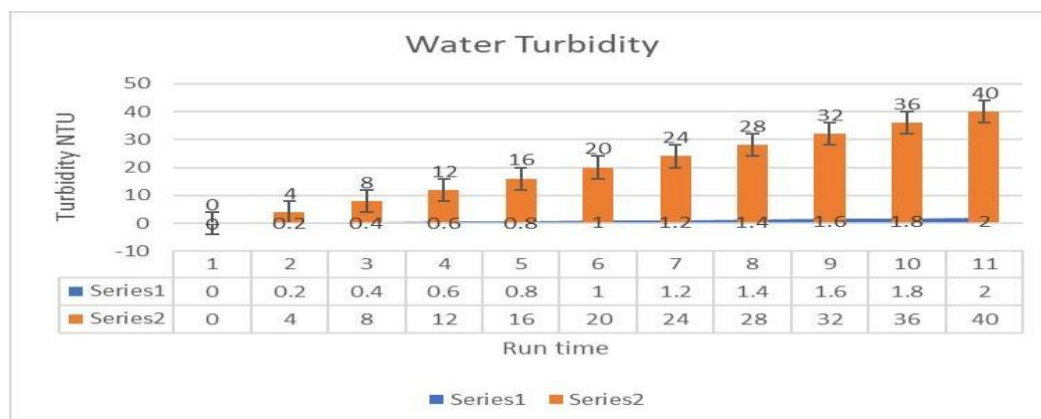| Component	Description	Material	Functionality
Filter Element	Removes impurities from water; the main element of the filter	Plastic, steel, copper	Filters out contaminants from water
Copper Connectors	Connects water source to filter; made of copper	Copper	Provides durability and corrosion resistance
Gasket or Seal	Made of rubber or silicon; ensures a watertight connection between the filter housing and the connector	Rubber, silicon	Prevents leaks and ensures seal
Inlet and Outlet Ports	Openings in filter housing for water entry and exit	N/A	Allows water to enter and exit the filter
Pressure Release Valve	Relieves excess pressure inside the filter housing, mainly in high-pressure systems	N/A	Prevents damage from pressure buildup

Looking at different water filters shows us how each part works to clean water. Filtration is a really smart and effective way to make dirty water clean and safe to drink. Our project is especially important for countries where it's hard to find clean water and people often get sick or even die because the water is so dirty. By using water filters in homes, we can make a big difference.

When we look at different water filters, we learn about what makes each one special and how they clean the water. This helps us pick the best kind of filter for the job. We need to think about what kinds of bad stuff are in the water that we need to get rid of, how easy it is for people to use and take care of the filter, and how much it costs. It's important that the filters are not too expensive so that families can actually afford them.

Also, teaching people about why clean water is important and how to use these filters correctly is key. If people understand how to use the filters and keep them working, they can stay healthy and avoid getting sick from the water. So, by studying water filters and figuring out the best ones to use, we're taking a big step towards helping people have safer water to drink. This project isn't just about putting filters in homes; it's about making life better and healthier for lots of people.

Descriptions	FILTER
PRICE	$10
DESCRIPTION	Mention in Ali's express
MARKET VALUE	$0.49
LIFE	Lifetime
WORKING	Work with ease
BUILT	New in this era
REVIEWS	Very good
MARKETS	Ali Express
MECHANISM	Easy

The following delineates the characteristics and specifications of the water filtration system implemented in our project. This comprehensive analysis is instrumental in illustrating the comparative advantages of our chosen filter against alternative options available in the market. By presenting this information in a structured table format, we aim to highlight the intrinsic value and distinct features of our filtration system. This comparative insight is not only crucial for the continued development and refinement of our project but also serves as a valuable resource for stakeholders and other project teams in identifying and selecting the most suitable filtration solution for their specific needs. Through this detailed evaluation, we endeavor to contribute to the broader discourse on water purification technologies, thereby aiding in the selection process of the most efficient and effective filtration systems for various applications.

Water Turbidity

	1	2	3	4	5	6	7	8	9	10	11
■ Series1	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
■ Series2	0	4	8	12	16	20	24	28	32	36	40

Run time

■ Series1 ■ Series2

Selection

Some of the comparisons are mentioned in the above chart. We can easily compare the two filters from their descriptions. These comparisons can easily lead you to choose the filter for your project. As our project requires filtration that is why I have seen the videos of how the mechanism works and then I have made some graphs for the filtration of the water which can help us to measure the values for the filtration.

3.22 Battery Product Evaluation Hardware part

Duracell Ultra Lithium AA

The Duracell Ultra Lithium AA battery competes directly with the Energizer L91 Ultimate Lithium, offering users a choice in the lithium AA battery market. While Energizer holds patents on specific design elements, Duracell has developed its proprietary technology to deliver reliable performance. The Duracell Ultra Lithium AA boasts a capacity of 3400 mAh, slightly lower than the Energizer L91, but still providing ample power for various applications. It maintains a stable 1.5V output throughout its lifespan, ensuring consistent performance. With a weight of 15 grams and adherence to standard AA dimensions, the Duracell Ultra Lithium AA is suitable for a wide range of devices, including those in our project. A pack containing four batteries is priced at $11.99, making it a competitive option at $3 per battery. While slightly cheaper than the Energizer L91, the Duracell Ultra Lithium AA offers comparable performance and reliability.

3.23 Battery product comparison

Best Rechargeable: Panasonic's Eneloop AA Batteries are lauded for their remarkable charging capability, offering up to 2,100 recharge cycles. They're pre charged using solar energy, maintaining their charge impressively over time. While they may have a higher initial cost and slower charging times, their longevity and performance make them a valuable investment for those looking for reliable, rechargeable options.

AmazonBasics High-Performance AA: For those seeking a balance between cost and performance, AmazonBasics High-Performance AA Batteries emerge as a compelling choice. They boast a 10-year shelf life and are designed to prevent leaking, making them a practical option for low-drain devices like remote controls and clocks. While they may not be suitable for high-drain devices, their affordability and decent performance in household applications make them a great budget-friendly option

3.24 Battery Product Decision

After careful consideration, we have opted to proceed with the Energizer L91 lithium AA battery. This decision is grounded in its proven performance, reliability, and comprehensive technical information availability. Although the EBL alternative offers cost savings, it compromises on capacity and lacks detailed specifications. Our project necessitates batteries capable of consistently delivering at least 1.5V over an extended period, and Energizer's data assures us of the L91's suitability for this purpose. While choosing the EBL option would save $0.70 per battery, sacrificing 500 mAh of capacity and facing uncertainty regarding specifications outweighs the monetary benefits.

3.25 Buck Converters

Buck converters, known as step-down converters, effectively lower input voltage to produce a lower output voltage. They regulate energy flow to an inductor by intermittently switching a MOSFET, which then transfers it to the output. These converters find applications in various battery-powered devices and voltage regulation scenarios, offering efficiency and simplicity. Suitable for low to medium voltage applications, they operate within a voltage range from a few volts to several tens of volts.

3.26 Flyback Converters

Flyback converters, another type of SMPS, utilize inductors to store energy during transistor on-time and transfer it during off-time. Equipped with a transformer, they provide step-up, step-down, or isolation voltage conversion based on winding configuration. Commonly used in low to medium-power applications such as LED drivers and offline power supplies, flyback converters ensure electrical isolation between input and output.

3.27 Resonant Converters

Resonant converters exploit resonant circuits to achieve high efficiency, operating at specific resonant frequencies to minimize switching losses. They minimize power dissipation by allowing circuit elements to resonate with each other, resulting in zero-voltage or zero-current switching. These converters are commonly used in high power applications like telecommunications and electric vehicle chargers, where efficiency and power density are crucial.

3.28 Linear Power Supplies

Linear power supplies regulate voltage by dissipating excess power as heat via linear regulators. Widely used in low to moderate-voltage applications, they prioritize simplicity and low noise over efficiency. These supplies are typically larger and less efficient, making them suitable for scenarios where efficiency is not paramount.

3.29 AC/DC Power Supply Technology Decision

After extensive deliberation, we have chosen to proceed with a power supply based on buck converter technology. This decision stems from the elimination of linear power supplies due to their large size and higher cost compared to alternatives. Resonant converters were considered overly complex for our project requirements. While flyback converters offer step-up functionality, which is unnecessary for our application, they were also discarded. The buck converter emerged as the most suitable option, aligning with our need for step-down AC/DC conversion straightforwardly and cost-effectively.

3.30 AC/DC Power Supply Technology Product Evaluation

Product: KNACRO Mini AC-DC Power Supply Module is a buck power supply module capable of converting 100-264VAC to 3.3VDC, supporting an output of up to 700 mA. With compact dimensions of 29.5×20.1×17.5 millimeters and an efficiency rating of 80%, it offers an affordable solution priced at $6.40.

Product: MakerFocus AC-DC Converter Module, another buck topology-based power supply, converts 85-264VAC to 3.3VDC, accommodating an output current of up to 3A. Featuring comprehensive documentation and adherence to safety and compliance standards, it measures 62.5 x 51 x 28 mm and boasts an efficiency of 78%. Priced at $8.56, it provides a reliable alternative.

3.31 Research

Transformers are pivotal components in electrical systems, facilitating the crucial task of voltage regulation. In our project, where precision and reliability are paramount, the role of transformers in stepping down the utility voltage of 120V before rectification cannot be overstated. When considering transformers for this purpose, two primary types emerge: conventional transformers and autotransformers. Conventional transformers, also known as isolated transformers, offer a tried-and-tested solution characterized by electrical isolation and enhanced safety measures. However, the necessity of employing two transformers inherently leads to increased size and cost implications, factors that need careful consideration in our project's design and budgetary constraints.

Conversely, autotransformers present an intriguing alternative, boasting a more streamlined design and cost-effective implementation by utilizing a single inductor.

Their compact nature and reduced winding size offer advantages in space constrained applications, aligning closely with the efficiency goals of our project. Yet, it's crucial to acknowledge that autotransformers are not without their caveats. The potential risk of failures stemming from shorts across windings presents a tangible concern, one that necessitates meticulous mitigation strategies to uphold operational integrity and longevity.

Moving beyond transformers, the rectification process emerges as another critical juncture in our project's electrical system. Converting an AC signal to a stable DC signal is imperative for seamless operation and accurate data processing. Here, the choice between half-wave rectifiers and full-wave rectifiers warrants thorough deliberation. Half-wave rectifiers, characterized by their simplicity and cost effectiveness, offer a compelling proposition, particularly in applications where stringent regulation of DC output is not a prerequisite. However, the limitations inherent in half-wave rectification, including potential instability under high current loads, prompt us to explore alternative solutions.

Enter full-wave rectifiers, distinguished by their comprehensive rectification capabilities and enhanced stability. While these rectifiers entail a marginally higher degree of complexity and cost, their ability to provide a stable DC signal even under demanding conditions aligns closely with the performance benchmarks of our project. Also, the design intricacies associated with full-wave rectification, including considerations of rated forward voltage drop and current handling capacity, underscore the need for meticulous attention to detail and rigorous testing protocols to ensure optimal performance and reliability. Transformers and rectifiers serve as foundational pillars in our project's electrical infrastructure, underpinning its functionality and performance. Through meticulous evaluation and strategic decision-making, we aim to harness the potential of these components to realize our project's objectives with efficiency, precision, and reliability.

3.32 Vue JS vs React JS vs Vanilla JS

Technologies	Supported Operating Systems	Features	Programming Language	Cost
React JS	Web, and Mobile	Reusable components State management Routing Largely supported community Hot reload	Javascript	Free
Vue JS	Web, and Mobile	Framework includes state management and paradigm Components Routing Mid-size supported community Hot reload	Javascript	Free
Vanilla JS	Web, and Mobile	Complicated state management Complicated routing Less supported community	Javascript	Free

Vue.js is one of the fastest-growing frameworks in the world. It has an active community and is well-received by developers, particularly in China. It has great performance metrics and a small size, making it ideal for smaller projects. It uses a component-driven architecture but with a template-driven approach. HTML templates are used to structure and control components. Vuex is an integrated state management solution.

React is a JavaScript library developed by Facebook. It has become very popular and has an active community of developers who contribute to the ecosystem. It is widely used by many large companies. React is known for its powerful virtual DOM implementation. It provides great performance, especially when dealing with large applications (StackShare). React uses JSX syntax for more explicit component composition. This makes it easier for developers to build reusable UI components. How does React manage the application state? React does not have native state management. Instead, it is often used with external libraries such as Redux and MobX to manage application states in complicated situations.

Vanilla JavaScript has several advantages over other JavaScript frameworks or libraries, such as Documentation - Vanilla JavaScript does not have a central documentation source like other frameworks such as React/Vue.js. However, developers can check the official documentation of JavaScript on MDN (Mozilla Developer Network). Vanilla JavaScript takes advantage of direct manipulation of DOM/browser APIs, so you can optimize your performance using best practices and browser optimizations.

At the end of the day, each technological stack has its own strengths and use cases, and each has its own set of advantages and disadvantages. React Vue.js Vanilla If you are looking to build a more advanced application, you will need some expertise. That is why we have chosen React for our project. What are the strengths of each stack? For React, it is all about the tooling and abstractions to make UI development easier. Vue.js provides the tooling for this. For Vanilla, it is all about flexibility and control. When choosing the right technology stack for your project, think about your project requirements, the ecosystem support, and your personal preferences.

3.33 Flask & Python vs MERN vs LAMP

Web Stacks	Technologies	Programming Language	Database	Operating System
MERN	MongoDB, Express JS, React JS, Node JS	Javascript frontend and backend	MongoDB	Cross platform for windows and linux requirements
LAMP	Linux, Apache, MySQL, PHP or Python	Python or PHP, and Shell/Bash	MySQL	Linux
Custom Stack	React, Postgresql, Flask Python, Linux	Javascript, Shell/Bash, and Python	Postgres	Cross platform for windows and linux, but preferably Linux

Flask-Python has an ever-growing community of extensions and libraries that can be used to build APIs, authenticate users, integrate databases, and test. However, the community of Flask is usually smaller than that of Ruby on Rails. Python Object Oriented Machines (ORMs) like SQLAlchemy or Peewee can be used to integrate databases (StackShare).

After comparison, we have selected a framework that the software engineer is already comfortable with and can expand his skill set with that is widely used in the backend community. Overall, both Flask Python, MERN and LAMP are great frameworks for API building. However, the decision should be based on your project needs, programming language preferences, ecosystem needs, speed of development, community support, and other factors. You should evaluate each framework's strengths and weaknesses before deciding. For this project, however, we have chosen to use Flask and Python as the main backend libraries to build out the application.

3.34 Postgres vs Mongo vs MySQL Database

Databases	Data Storage	Key Features	SQL or NoSQL	Data Representation
Postgres	Stored as rows in a table and relational database with schemas	Supports large databases and is easily scalable for larger applications.	SQL	Structured rows in table
MongoDB	JSON-like documents with schema-less pattern	Horizontal scaling approach to have json based documents to query.	NoSQL	Mixed Data in JSON Document
MySQL	Stored as rows in a table and relational database with schemas	Supports large databases and is easily scalable for larger applications.	SQL	Structured rows in table

PostgreSQL is a tabular database management system (DBMS) that supports ACID transactions (atomicity, consistency, isolation, durability). PostgreSQL is an ideal RDBMS for applications that have structured data and relationships between entities (StackShare).

MongoDB is an open-source, document-based, NoSQL database. It stores data in JSON-like documents and is schema-less. MongoDB supports dynamic, nested, and other data structures. It is best suited for applications that have unstructured, semistructured, or mixed data and demand high scalability (StackShare). MySQL is also a relational database management system like PostgreSQL, with support for ACID transactions. It is widely used for applications with structured data and has a large community of users and developers (StackShare). After comparing the three database engines, I've chosen an engine that I am already familiar with and can advance skill sets with that is popular in the back-end community.

In summary, the choice between PostgreSQL, MongoDB, and MySQL depends on factors such as data model requirements, scalability needs, consistency requirements, and developer preferences. Each database has its own strengths and trade-offs, and selecting the right one involves evaluating these factors in the context of the specific project requirements.

3.35 AWS vs Azure vs DigitalOcean Cloud Providers

Hosting Platforms	Is there a free tier?	Key Features	Featured Customers	Cost
AWS	Yes - 12 Months	Cloud computing, Cost Effective, VPC, High Availability, DNS, CDN.	Sony, Adobe, Facebook, Netflix	~$2/month
Azure	Yes - 12 Months	Cloud computing, Cost Effective, VPC, High Availability, DNS, CDN.	Verizon, Samsung, Pixar, eBay, Xerox	~$20/month
Digital Ocean	Yes - 2 Months	Automatic scaling and container deployment.	Payload, Tango, Playflow	~$50/month

Amazon Web Services (AWS), Azure, and Digital Ocean are the top three cloud computing platforms (StackShare). Each platform offers a range of services that are tailored to your specific needs. Below is a comparison of the three platforms based on several factors: AWS: AWS is the oldest and most well-established cloud provider. It has the largest market share. Azure: Azure is the second largest cloud provider. It is strong in enterprise integration because it integrates with Microsoft products such as Active Directory, Office 365, etc. Digital Ocean is a simpler and more developer-friendly alternative. Database Engines: After comparing the database engines, we have decided to choose an engine that is already familiar to the software computer engineer Amazon web services and can easily expand their skillset with it.

4.0 Standard and Design Constraints

When it comes to standards and design we have to be cautious of all the small details and consider all the details to make sure that our product is safe for people to use and will not harm anyone using it therefore we consider many things some of them are: electricity safety standard, environmental regulations, material selection, size and space constraints, energy efficiency, accessibility standards, budgetary constraints, and regulatory requirements.

4.1 Standards

Standards are very important to follow for many reasons. Some of these include making it easy for users to replace parts, and reducing costs in building products instead of creating new parts from scratch (which would require money, effort, and time). Standards are also based on extensive research conducted by many companies, leading to specific standards that ensure consistency, interoperability, regulatory compliance, market access, efficiency, cost reduction, and meeting customer expectations.

Following CSA B805/ICC 805:2022 guidelines for the layout, components, setup, and functioning of rainwater harvesting systems are provided by this standard. It includes systems meant for non-potable (toilet flushing, irrigation, etc.) as well as potable (drinking water) purposes. precipitation runoff from roofs or stormwater runoff—that is, precipitation that has come into contact with the ground or a green roof—can serve as the source water for these systems. Also following this standard is important as it has several benefits like safety, efficiency, and compliance. The standard describes the best ways to guarantee the security and caliber of the collected rainwater, particularly if it is meant for human consumption. In addition, the standard can aid in the design of rainwater collection, storage, and utilization systems that are efficient. Furthermore, we can make sure our rainwater harvesting system meets all applicable building norms and requirements.

As our project is not intended for drinking water reuse, we are not required to implement rainwater harvesting for potable water. However, it is imperative that we establish a separate water line for this reusable water to circumvent compliance with those standards. Moreover, we must ensure that our system adheres to all relevant standards to guarantee user safety.

Standards play a vital role in ensuring that goods and services consistently meet predetermined performance and quality levels. This consistency fosters trust among customers and helps businesses build a reputation for reliability. Moreover, standards facilitate interoperability, enabling seamless collaboration between different systems or products, particularly in industries where such collaboration is essential. Government agencies and trade associations enforce regulations and standards across various sectors, ensuring compliance with environmental, health, and safety regulations as well as legal requirements. Adhering to these standards can open up new markets for companies, both domestically and globally. Additionally, standards often lead to cost savings and

improved efficiency by streamlining processes and procedures. By following established protocols and best practices, businesses can optimize efficiency, minimize waste, and ultimately exceed customer expectations regarding performance, safety, and quality. This commitment to industry standards not only enhances consumer satisfaction but also fosters long term loyalty.

4.2 Solar Panel Standards

According to Energy Sage, solar panels can be made of different materials like thin film, polycrystalline, or monocrystalline. Although monocrystalline and polycrystalline do the same job and weigh about the same as monocrystalline solar panels made out of a single crystal of silicon and polycrystalline made out of many silicon bits mixed together, monocrystalline is better as it is more efficient than polycrystalline so fewer of monocrystalline will do the same job.

4.3 Charge controller standard

Charge controllers, essential for managing the power flow from solar panels to batteries, adhere to several standards to ensure efficiency and safety. Some common standards include: the UL 1741 standard ensures that the charge controller meets safety requirements for inverters, converters, controllers, and interconnection system equipment. IEC 62109 is an international standard covering the safety requirements for inverters, converters, and controllers for use in photovoltaic power systems. CE Certification indicates compliance with European Union directives regarding safety, health, and environmental protection standards. ISO 9001 ensures that the manufacturer follows quality management system standards, which can reflect on the reliability and consistency of the product. NEC (National Electrical Code):
Compliance with NEC standards ensures safe installation and operation within the United States. FCC Compliance: Important for charge controllers with communication capabilities to ensure they don't interfere with other electronic devices. RoHS Compliance: Ensures that the product does not contain hazardous substances, contributing to environmental sustainability.

Adhering to these standards ensures that charge controllers are safe, reliable, and interoperable with other components of solar power systems. The Standard of the Controller has a special kind of impact on our project because as I mention the hardest part of our project is to connect the Solar Panel to the Components so the motor can start working for flowing water. So We need a good quality Charger for the Solar panel in order to avoid the short circuit and any other trouble.

4.4 Battery Standards

 After doing a lot of research on which battery will be needed for our project, we found out that we can use this formula to determine which battery size will be needed to run our project which is $T = 10*A / W$ (time = battery capacity (amp hours) / power usage) by using this formula we can determine how many hours our battery will keep running our system. In order to use this formula we did need to

calculate all the project components Amps and What's needed to run the components. Battery is an important part of this project, As we were using the Solar Panel. Battery standards refer to specifications and guidelines established to ensure interoperability, safety, and performance consistency among different types and brands of batteries. These standards are crucial for various industries, including consumer electronics, automotive, renewable energy storage, and industrial applications.

Some of the key battery standards include the International Electrotechnical Commission (IEC): The IEC sets global standards for electrical, electronic, and related technologies. Several battery-related standards fall under its purview, covering aspects like battery safety, performance testing, and environmental considerations. International Organization for Standardization (ISO): ISO develops standards across various industries, including batteries. ISO standards cover areas such as battery performance testing, environmental impact assessment, and safety requirements. UL Standards: Underwriters Laboratories (UL) is a global safety certification company that develops standards for a wide range of products, including batteries. UL standards ensure that batteries meet safety and performance criteria, particularly for consumer electronics and industrial applications. Society of Automotive Engineers (SAE): SAE develops standards specifically for the automotive industry. SAE J1791, for example, defines standard terminology and test procedures for evaluating the performance of automotive batteries. Institute of Electrical and Electronics Engineers (IEEE): IEEE develops standards for various aspects of electrical and electronic technologies, including batteries. IEEE standards cover topics such as battery management systems, battery safety, and performance evaluation methods. European Committee for Electrotechnical Standardization (CENELEC): CENELEC develops standards for the European market, including battery-related standards concerning safety, performance, and environmental considerations. Japanese Industrial Standards (JIS): JIS establishes standards for industrial activities in Japan, including battery-related standards covering performance testing, safety requirements, and labeling. Chinese National Standards (GB/T): China's GB/T standards cover various aspects of battery technology, including safety requirements, performance testing methods, and environmental considerations.

These standards ensure that batteries meet certain quality, safety, and performance benchmarks, enabling compatibility and reliability across different devices and applications. Adhering to these standards also helps manufacturers, consumers, and regulatory bodies ensure that batteries are safe, efficient, and environmentally responsible.

4.5 Design Constraints

Understanding and adhering to constraints plays a crucial role in the successful execution of any project, serving as a roadmap that outlines both the possibilities and limitations inherent within it. These constraints, encompassing a broad spectrum from time and cost to resources, quality, regulatory compliance, environmental considerations, and material availability, are fundamental in shaping the project's scope and direction. By closely

aligning with these constraints, we can streamline our project's execution, enhancing its speed, functionality, and overall effectiveness.

The significance of a well-conceived design cannot be overstated, as it underpins every aspect of project development. Just as an architect relies on blueprints to construct a building, meticulously considering factors like capacity, area, and soil integrity, our project too is governed by a specific set of design principles. These principles not only guide the project's physical manifestation but also ensure its feasibility and adherence to predefined constraints.

In the context of our project, which focuses on a water filtration system equipped with dual tanks and a solar panel, the design is intentionally straightforward to facilitate execution by any competent electrical engineer. This simplicity, however, does not detract from the necessity of rigorous planning and constraint consideration. The system's design, accommodating two tanks—one positioned at the base and the other mounted on the roof—caters to a specific functional requirement while adhering to our project's spatial and capacity limitations.

A critical design constraint we must navigate is the system's water capacity, which is capped at 10 gallons. This limitation is not arbitrary but is a calculated decision based on a thorough analysis of the project's objectives, available resources, and the intended application's practical considerations.

In essence, the constraints and design of our project are intertwined, each informing and shaping the other. By understanding and embracing these limitations, we position ourselves to deliver a project that is not only viable and sustainable but also tailored to meet the specific needs and challenges of the context in which it will operate. Through this meticulous approach to design and constraint management, we aim to achieve a balance between innovation and practicality, ensuring our project's success and its potential positive impact on the target community.

4.6 Time Constraint

When it comes to time constraints, it is very important to establish a system for the group that everyone can follow. For example, using a Google Doc allows everyone to contribute their part and provide feedback or suggestions as needed. A group chat also helps ensure that everyone stays updated with class information. Additionally, scheduling weekly group meetings at a time that works for all members can help plan and collaborate on tasks together.

As Dr. Chan emphasized in his lecture, working on the SD1 paper regularly is crucial to avoid procrastination and last-minute rushes. He provided an example of a group staying up all night at the UCF lab to finish their project, which left them stressed and overworked. Being in such a situation can jeopardize the timely completion of the project, potentially resulting in failing or barely passing the class. If the group fails to finish on

time, each member may be required to retake the class, delaying graduation, lowering GPA scores, and necessitating additional class fees.

Effective time management is essential, especially considering challenges like hurricane seasons in Florida, which disrupt plans due to power outages and internet issues. Additionally, unforeseen events like the COVID-19 pandemic shift priorities towards personal safety, impacting class attendance and group meetings.

By adhering to due dates and guidelines, groups can complete their projects on time. SD1 is structured to help students manage their workload with milestones like the 10-page, 60-page, and 120-page submissions throughout the semester. Regular meetings with assigned professors ensure that groups stay on track and meet all requirements to maintain the grade.

Finally, purchasing project components in advance is advisable to save costs and ensure timely delivery. For instance, buying items from platforms like AliExpress allows for cheaper purchases, albeit with longer shipping times. Alternatively, exploring options like Facebook Marketplace for items such as water tanks can result in significant cost savings compared to buying new from retail sources like Amazon.

Time is also an important character in any project. The time is the money and those who respect the time will never face any trouble in their life. We are taking SD2 in the summer so we won't have enough time to build the harder project. Since the summer is only 3 months, we have to choose those ideas which are good enough in a certain time. we did choose a simple kind of electronic item so we can finish our project in a particular time. The Hardest part of this project is to get the power from the Solar panel. We decided to take the power from the board but we did do Solar panels now and it will require time to get those connections from the board or solar panel to the breadboard.

4.7 Cost Constraints

Cost constraints refer to limitations or restrictions on the financial resources available for a particular project, initiative, or endeavor. These constraints play a significant role in decision-making processes across various domains, including business, engineering, research, and development.

When it comes to cost constraints, we must consider the prices of similar products already in the market. Our goal is to either develop a cheaper product or, if priced higher, offer better quality or options to compete effectively. The pricing of our system will vary based on customer selection, with larger systems costing more to build and sell. Additionally, the savings our system provides will depend on factors like rainfall, sunlight, and usage. More rain means more water can be saved, more sunlight translates to greater electricity savings, and the intended use of the water determines the required volume.

Building the full-size version of our product presents challenges due to portability, budget constraints, and longer demonstration times. With Dr. Wei's approval, our product will

include two ten-gallon water tanks, flexible tubes for water transfer, a system controller, rainwater and sunlight sensors, a water level sensor r, a water filter r, a table, and batteries. Based on component prices, our system's construction will cost around three to four hundred dollars, translating to approximately one hundred dollars per student. Prices may vary depending on component sourcing, but we ordered to order from AliExpress to maximize cost savings before SD2.

Considering our project's target market includes third-world countries, affordability is paramount without sacrificing functionality. We aim to minimize prices as much as possible while ensuring the product remains accessible, except for features unlikely to see significant use in those regions.

Navigating the financial aspect of any project, particularly for us as electrical engineers, is paramount. Our current venture, which is a comprehensive assembly including a Water Level Sensor, Water Filter, two storage tanks, a Printed Circuit Board (PCB), and a Solar Panel, among other crucial components, presents a significant challenge in terms of cost efficiency. The quest for affordable yet high quality materials has led us on an extensive journey through various online platforms and marketplaces, aiming to secure the best deals for our project essentials.

In our pursuit of cost-effectiveness, we've meticulously evaluated multiple suppliers, prioritizing those that offer the optimal balance between affordability, quality, and reliability. This approach has necessitated a thorough market research phase, where we compared prices, read through customer reviews, and verified the credibility of vendors. Our commitment to this project demands that we select components that not only meet our budgetary constraints but also uphold our standards of quality and come with reliable warranty coverage. This ensures that our project is not just economically viable but also durable and dependable in the long run.

Cost management in such a project is not a linear task but a multifaceted challenge that involves continuous monitoring and adjustment. It requires a strategic approach to budgeting, where every expenditure is planned, and potential cost overruns are anticipated and mitigated. Collaborative efforts across different teams and stakeholders are crucial to aligning financial objectives with project goals, ensuring that every decision made serves both the project's technical requirements and its financial sustainability.

To further enhance our cost management practices, we've incorporated regular review meetings to assess our financial progress and make necessary adjustments to our procurement strategy. This dynamic approach allows us to stay agile and responsive to market changes, ensuring that we can take advantage of new opportunities for cost savings or respond to unexpected price fluctuations.

Moreover, fostering a culture of financial discipline within our team is vital. By encouraging mindfulness around expenditures and instilling a sense of ownership over the project's budget, we can collectively contribute to a more cost-efficient execution of our plans. This includes exploring alternative solutions that may offer better value for

money, negotiating with suppliers for better rates, or even revising our design to accommodate more cost-effective components without compromising on quality.

Transparency and open communication are crucial complements to fostering financial discipline. Regularly sharing budget updates, cost breakdowns, and exploring potential cost-saving strategies together as a team will promote greater buy-in and creative problem-solving. This collaborative approach can spark innovative ideas for resource allocation, identify areas for optimization, and empower team members to make informed decisions that prioritize value without sacrificing project goals. Ultimately, a financially responsible team fosters a sense of shared accountability and empowers everyone to contribute to the project's success within budgetary constraints.

We leverage data analytics to track historical spending patterns and identify trends. This information can be used to predict future costs, optimize resource allocation, and make informed procurement decisions based on factual evidence.

Cost constraints refer to limitations or restrictions on the financial resources available for a particular project, initiative, or endeavor. These constraints play a significant role in decision-making processes across various domains, including business, engineering, research, and development. Effectively managing cost constraints is critical to ensuring that a project stays within budget while still meeting its objectives. This involves careful planning, budgeting, and monitoring of expenses to avoid cost overruns and ensure financial sustainability.

When considering cost constraints, it is essential to evaluate the prices of similar products already in the market. The goal is to either develop a cheaper product or, if priced higher, offer superior quality or additional features to compete effectively. The pricing strategy for our system will vary based on customer selection, with larger systems costing more to build and sell. Additionally, the cost savings our system provides will depend on factors like rainfall, sunlight, and usage. For instance, more rain can lead to greater water savings, more sunlight can result in higher electricity savings, and the intended use of the water will determine the required volume. These variables must be carefully considered to optimize the cost-efficiency of the product.

Constraint Type	Description	Examples
Time Constraints	Limitations on the duration or timeline for completing a project or task.	● Sprint durations in Agile methodologies ● Time-to-market requirements for product launches
Cost Constraints	Restrictions on the financial resources available for a project or initiative.	● Budget limitations ● Cost per unit ● constraints for manufacturing ● Resource allocation constraints
Design Constraints	Specifications or requirements that dictate the design parameters or characteristics of a product or system.	● Size and weight limitations ● Compatibility requirements ● Regulatory compliance standards

Constraints in any project can be categorized into time, cost, and design constraints, each playing a pivotal role in shaping the project's execution and outcomes. Time constraints encompass deadlines and the need to meet specific market or development timelines. Cost constraints involve budget limitations and financial resource allocation, directly impacting project scope and resource management.

Design constraints dictate the physical and regulatory parameters within which the project must operate, such as size, weight, and compliance with legal standards. Together, these constraints define the boundaries and opportunities for project development and success.

4.8 UX Standards

Enclosed are the schematic representations and color palettes delineating the Water Saver brand's typographic and design elements, which are to be meticulously adhered to in the development of the front-end application interface. These guidelines serve to ensure consistency and coherence in the visual and interactive aspects of the application, aligning with the overarching brand identity and ethos.

Typography

Typefaces	Readability, legibility, and appropriateness for the target audience.
Hierarchy	Use variations in font size, weight, and style to create visual contrast and structure.
Spacing	Proper spacing helps improve the flow of text and enhances the overall reading experience.
Consistency	Use a limited set of typefaces and styles to create a cohesive and harmonious design language.

Colors

Color Palette	Choose primary and secondary colors that complement each other and evoke the desired emotional response.
Accessibility	Ensure that the chosen color palette meets accessibility standards and guidelines, making the design inclusive and usable for all users, including those with visual impairments.
Consistency	Establish guidelines for color usage and ensure adherence across all design assets and touchpoints.
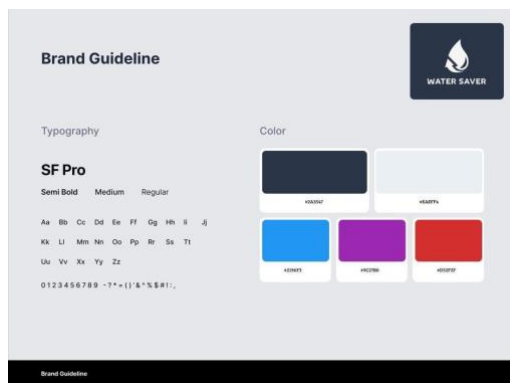
Figure - Brand Guideline 1
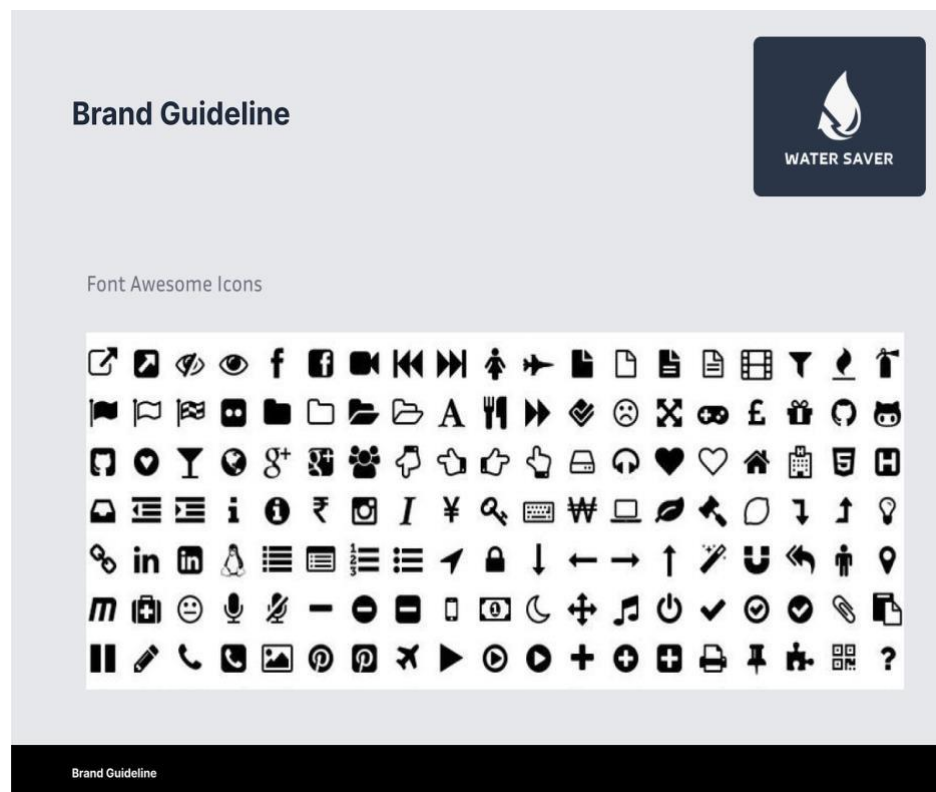
Figure - Brand Guideline 2

4.9 Application Brand & Component Standards

Below is the design system of brand and component standards that the application is going to use to build a theme within React Web UI. Water Saver Theme Provider will work with Material UI in the Application Layout to leverage a modular system throughout the codebase. Material UI leverages out-of-the-box components that can be themed. Below are some components that the application plans to use: tables, date ranges, buttons,

label buttons, accordions, alerts. By having standards, you will improve the application with modular components that will improve user experience with using the application when they can navigate simply by utilizing the same components in different features of the application: Reporting, Analytics, Dashboard, etc. Brand Guidelines are important to companies to never have customer confusion on branding mismatches that can harm them. Below shows a range of brand guideline figures to how the application will utilize the UI Component Library known as Material UI with a styled theme provider based on the figma designs. When using a component library, you're cutting development hours to build an application as you no longer need to build out the code paradigm for the components, which could be weeks of development for the application.
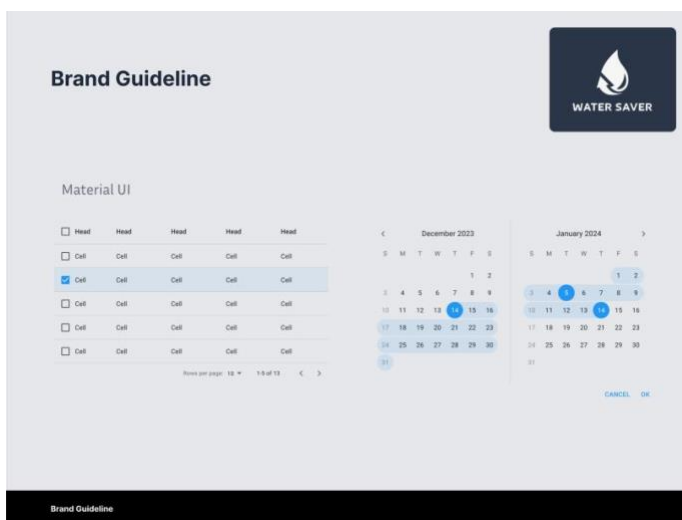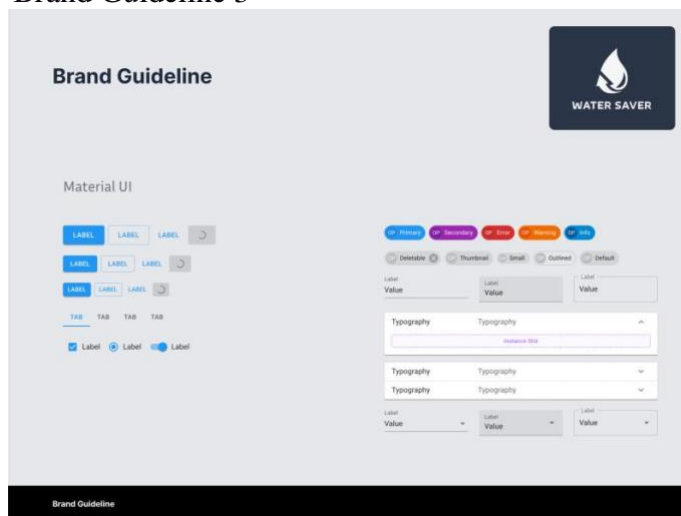

Figure - Brand Guideline 3

Figure - Brand Guideline 4
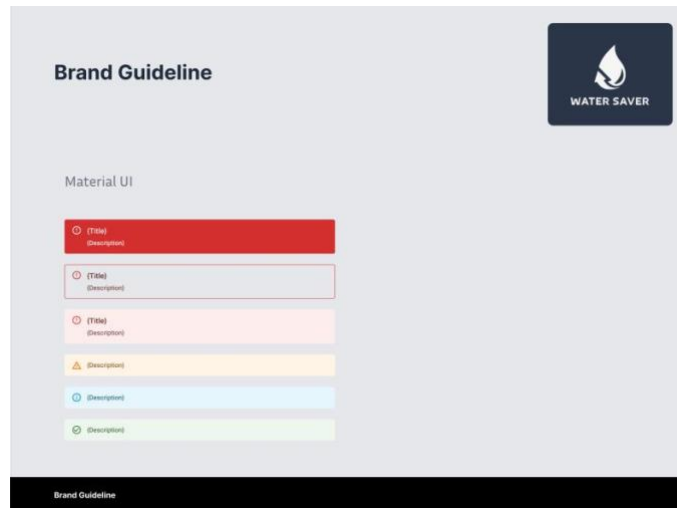
Figure - Brand Guideline 5

4.10 Email and Notification Standards

Below are the feature concept templates that will be used to send notifications or emails to users on the platform. These notifications can include: Forgot password, Verify email address, Welcome to WaterSaver, Low battery notification, and Water level threshold notification.

Notification emails can be used for various purposes such as confirming transactions, providing updates, or sending alerts. Guidelines for creating effective notification emails include clear subject lines, personalization, brief and precise content, branding elements, call to action, mobile responsiveness, visual hierarchy, prompt timing, confirmation, unsubscribe option, testing, and compliance with regulations. Personalize emails by addressing recipients by name, keep content concise and include only necessary information. Incorporate branding elements to maintain brand consistency and increase recognition. Use headings, bullet points, and formatting to create a clear visual hierarchy and make content scannable. Send notification emails promptly after the event or action to avoid confusion and frustration. Ensure compliance with relevant regulations such as GDPR or CAN-SPAM Act.

Figure - Brand Guideline 6

5.0 AI Usages

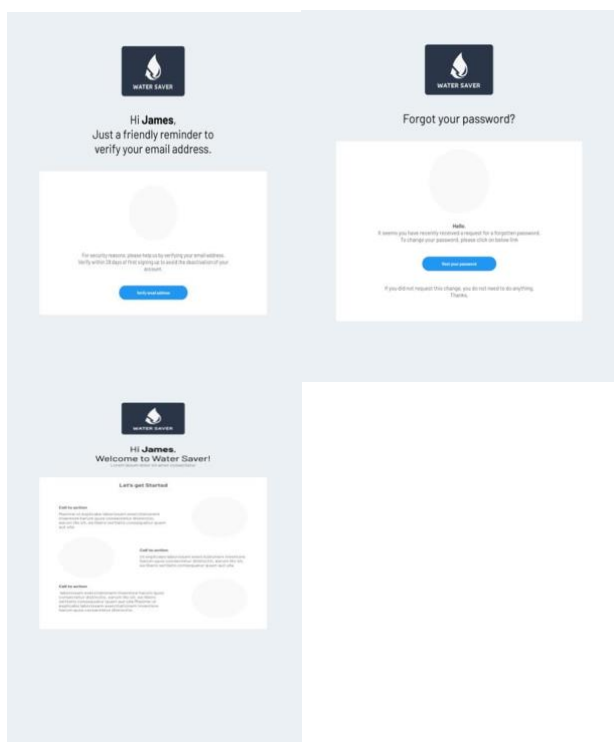Artificial Intelligence (AI) represents a paradigm shift in technology, embodying a tool of immense power and versatility that stands at the disposal of humanity. This innovation has undeniably reshaped numerous aspects of daily life, work, and academia, offering unprecedented opportunities for efficiency, creativity, and problem-solving. However, the advent of AI also introduces a complex array of ethical, safety, and reliability challenges, painting a picture of a double-edged sword that requires careful handling.

On one hand, AI's capabilities to analyze vast amounts of data, recognize patterns, and generate solutions have rendered it an invaluable asset across diverse sectors. Professionals leverage AI to streamline processes, augment decision-making, and unlock insights from data that were previously inaccessible, thereby enhancing productivity and fostering innovation. In educational contexts, students harness AI as a dynamic resource for research and learning, gaining access to a wealth of information and tools that can significantly improve the quality and speed of their work. By leveraging AI, students can explore ideas, refine their thinking, and achieve a higher caliber of academic work, all with a degree of efficiency that was once unimaginable.

Conversely, the versatility of AI opens the door to potential misuse and ethical dilemmas, particularly in the realm of academia. The ease with which students can obtain information through AI can tempt some to bypass the rigors of authentic research and original thought, opting instead for the unethical shortcut of plagiarism. Such practices not only undermine the integrity of academic work but also impede the learner's intellectual development. Furthermore, the reliability of AI-generated content, while often impressive, is not infallible. Relying on AI without critical evaluation can lead to the dissemination and reinforcement of inaccuracies, thereby contaminating the educational process with misinformation.

Moreover, the broader implications of AI's dual nature extend beyond academia. The automation capabilities of AI, while enhancing efficiency, carry the risk of displacing human workers, raising significant concerns about job security and economic inequality. The potential for AI to be weaponized or used in the perpetration of cybercrimes further underscores the need for robust ethical frameworks and stringent security measures.

To navigate the paradoxical landscape of AI, it is imperative for users, developers, and policymakers alike to foster a culture of responsibility and critical engagement. Educational institutions should cultivate digital literacy, emphasizing the importance of ethical research practices and the critical assessment of AI-generated content. Simultaneously, the development of AI technologies must be guided by ethical considerations, with a focus on transparency, accountability, and the mitigation of potential harms.

5.1 How AI Works

Artificial Intelligence, or AI as we often call it, is kind of like the brain behind a computer that allows it to think and make decisions sort of like how humans do. It's a really wide field that uses a bunch of different methods to make machines smart enough to handle tasks that usually need a human brain to figure out.

So, imagine you're typing something into Google to find information. AI works in a similar way, but it dives way deeper. Let's say you drop a question or a comment into a chat box. What happens next is pretty cool – AI kicks into gear, sifting through heaps of data, examining the words you used, how you put your sentence together, and the main ideas you're talking about. It's like it's trying to get into your head to figure out exactly what you're after.

Then, it gets to work figuring out the best response. It might pull up an answer it already knows from a giant pool of information it has access to or craft a new response on the spot using some smart tricks it has up its sleeve. After it decides on what to say, voila, it pops the answer right back at you in the chat. If you keep asking questions, it either builds on what it already talked about, using what it just learned about what you're asking, or it starts from scratch if you switch topics.
AI is all about blending together loads of data, some seriously complex algorithms, and a ton of computing power to mimic the way humans think and solve a wide array of tricky problems. It's like having a super-smart buddy who can crunch numbers, analyze data, and even understand languages at an incredible speed.

But here's where it gets even more interesting – as AI keeps getting better and smarter, it's starting to ask some big questions. Like, how do we make sure it makes fair decisions? And what happens to jobs that AI can do instead of people? These are super important issues that we've got to think carefully about as AI becomes a bigger part of our lives.

5.2 AI prospects

The prospects for Artificial Intelligence (AI) are vast and continually evolving, with the potential to profoundly impact numerous aspects of society, economy, and technology.

AI is a very helpful tool when used correctly, as it can provide users with new ideas to advance their tasks and make their jobs faster, easier, and more efficient. By utilizing AI, users can produce more work with less effort in a shorter amount of time. For example, Zety is a platform that utilizes AI to create resumes based on simple questions that users can fill out in 30 minutes or less. Users are provided with many templates and wording options to choose from. Conversely, users would take a longer time to complete the resume without AI, as it would require time for designing, planning, and choosing wording, resulting in lower quality compared to the AI-powered option. AI can be used for so many different purposes.

Some of them are Automation, Healthcare, Education, Finance, Transportation, NLP, Environmental Sustainability, Cybersecurity, Creative Industries, and Ethical and Societal Implications. Overall, the prospects for AI are promising, with the potential to

drive innovation, transform industries, and improve quality of life. However, realizing the full benefits of AI requires collaboration, interdisciplinary research, ethical guidelines, and thoughtful deployment to ensure that AI technologies serve the best interests of society.

5.3 AI considerations

The AI platform can be very dangerous in many ways, as it is a powerful tool that people can misuse. For example, scammers nowadays use it to impersonate other people's voices. They can deceive parents by mimicking their children's voices and claiming to be in an emergency, urging the parents to send money immediately to resolve the situation. They may even call from a different phone number, claiming the phone is out of charge or lost. Consequently, parents may fall victim to the scam, as they recognize their children's voices and may not doubt the authenticity of the call. Their primary concern is to assist their children in the supposed emergency. Unfortunately, this scenario has already occurred with many victims.

5.4 Using AI in Senior Design one

Incorporating Artificial Intelligence (AI) into senior design projects offers a nuanced balance of advantages and potential pitfalls, contingent on the manner in which students deploy this technology. AI has the capacity to serve as a valuable tool in the ideation and research phases, facilitating the generation of concepts and the accumulation of pertinent information for academic papers. Furthermore, AI-driven grammar correction tools can significantly enhance the quality of written work, mitigating the risk of deductions for grammatical inaccuracies.

However, the reliance on AI to undertake comprehensive writing tasks introduces the risk of plagiarism, as it may result in the submission of work that lacks originality or proper citation of sources. Such misuse not only undermines academic integrity but also impedes the learner's intellectual development.

For optimal utilization of AI in senior design projects, a balanced approach is recommended. Initial exploration and understanding derived from traditional study methods, such as engaging with literature, should form the foundation of the project. Subsequently, AI can be employed judiciously to refine data presentation and structure, always with a critical assessment of its output to ensure alignment with project objectives and accuracy.

It is imperative for scholars to maintain an active engagement in their learning and project development processes. Over Reliance on AI and other digital platforms may detrimentally affect cognitive skills, including critical thinking and problem-solving abilities. Therefore, while AI presents a resource for enhancing certain aspects of project development, it is crucial that students lead their projects with a foundation of comprehensive understanding acquired through diligent study.

5.5 Ways to Prevent Users from Using the Platform in the Wrong Way

We can prevent users from using the AI platform inappropriately by taking several steps. Firstly, we can educate them on how to use the platform ethically. Then, we explain the consequences of not following the guidelines, such as receiving zero on assignments or being removed from the course. Professors can also require the use of lockdown browsers during assignments to ensure users do not misuse the platform. Additionally, professors can check submissions for plagiarism to identify copied content. Furthermore, all AI platforms require sign-in information to verify the user's identity. Moreover, AI platform creators can restrict certain keywords and sentences to ensure the platform's safety, such as preventing users from asking how to hack other accounts.

5.6 Similar AI platform

There are many AI platforms out there to choose from that can do many amazing and helpful tasks, but we have selected the following two platforms because they are closely aligned with what ChatGPT can do and are useful tools that we are currently using for SD1, which we did also use in SD2.a diverse array of tools offers expansive functionalities to cater to various project needs. For our Senior Design 1 (SD1) and the forthcoming Senior Design 2 (SD2) projects, we have meticulously selected two platforms—Gemini and Copilot—in addition to ChatGPT, based on their alignment with our requirements and their unique capabilities that complement ChatGPT's offerings.

ChatGPT 3.5, while invaluable for its text processing capabilities, presents certain limitations, such as reliance on potentially outdated data, which may result in the provision of obsolete information on specific subjects. This limitation underscores the necessity of integrating additional AI tools that offer expanded functionalities.
Gemini, a product of Google, extends the capabilities of AI beyond text processing by incorporating text and image generation, as well as the ability to interpret voice commands and images within the chat interface. This multimodal approach facilitates a more versatile interaction with the AI, although it currently does not support code generation, marking an area for potential growth.

Conversely, Copilot, developed by Microsoft, specializes in code generation, offering a powerful tool for users with foundational coding knowledge. This platform exemplifies the potential of AI to streamline and enhance the coding process, though it requires users to possess a degree of coding proficiency to leverage its full capabilities effectively.

The selection of AI platforms for a project is a strategic decision that must account for the specific limitations and strengths of each tool. Recognizing these constraints is crucial, as it enables a more targeted and efficient search for the most suitable AI platform that meets the project's needs. It is imperative to conduct thorough research and possess a clear understanding of the project requirements before integrating AI tools, as the relevance and accuracy of the information provided by AI can vary across different platforms and versions.

While AI platforms like ChatGPT have become prevalent tools for information retrieval and project assistance, it's essential to maintain a critical perspective on their use. Over Reliance on AI can inadvertently impact cognitive skills and the ability to operate independently of technological assistance. As we integrate AI into our project development processes, fostering a balance between leveraging AI capabilities and maintaining active engagement in critical thinking and problem solving is vital.

5.7 ChatGPT

According to information from Wikipedia, ChatGPT, a creation of OpenAI launched on November 30, 2022, represents a significant advancement in chatbot technology, powered by an extensive language model. It affords users unparalleled control over conversation dynamics, including aspects such as length, style, detail, and language preference, all through the innovative use of prompt engineering. This approach allows for a nuanced interaction experience, where each user input is contextually integrated into the ongoing dialogue. By January 2023, ChatGPT had amassed a user base exceeding 100 million, significantly boosting OpenAI's valuation to $29 billion and prompting the emergence of rival technologies such as Gemini, Ernie Bot, LLaMA, Claude, and Grok, with Microsoft's Copilot, leveraging GPT-4, standing out as a key competitor.

While ChatGPT has been widely recognized for its groundbreaking contributions to AI, there are growing concerns regarding its implications on human cognitive capabilities, the potential for facilitating plagiarism, and the dissemination of misinformation. The platform is available in two distinct versions based on GPT-3.5 and the more advanced GPT-4, operating on a freemium model where enhanced features are available to "ChatGPT Plus" subscribers.

The introduction of ChatGPT heralded a new era in AI development, attracting significant investment and public interest in the field. Regarded as one of the most versatile AI tools available, ChatGPT has found widespread application across various domains, including education, where it serves as a valuable resource for information and project assistance. Despite its utility, the evolution from version 3.5 to the paid version 4 addressed user feedback regarding consistency and accuracy in responses, underscoring the platform's commitment to continuous improvement and user satisfaction.

Chatgpt 3.5	Chatgpt 4
Free	Monthly
Less Accurate	More Accurate
Wrong Answers	Most of the time answers are right
Take some time	Very quick

As of my last update in January 2022, GPT-3.5 and GPT-4 represent different iterations of OpenAI's Generative Pre-trained Transformer (GPT) models, with GPT-4 being a newer version.

It's important to note that the specific differences between GPT-3.5 and GPT-4 would depend on OpenAI's research advancements, technological innovations, and strategic priorities at the time of their development and release. For the most accurate and up-to-date information on GPT-4, it's recommended to refer to official announcements and publications from OpenAI.

5.8 Gemini

According to Wikipedia, Google introduced Gemini, a sophisticated language model developed by Google DeepMind, during the Google I/O keynote on May 10, 2023. It was positioned as an advancement over PaLM 2, with Google CEO Sundar Pichai mentioning that Gemini was still in its early stages of development. Unlike other language models, Gemini was unique in that it could process various types of data simultaneously, including text, images, audio, video, and code. It was developed in collaboration between DeepMind and Google Brain, branches of Google that had recently merged as Google DeepMind.

Gemini's capabilities were praised by DeepMind CEO Demis Hassabis, who believed it could outperform OpenAI's ChatGPT. In August 2023, The Information published a report detailing Google's plans for Gemini, aiming for a late 2023 launch. Google intended to surpass competitors by combining conversational text abilities with AI-powered image generation. Sergey Brin, Google's co-founder, came out of retirement to aid in Gemini's development, along with engineers from Google Brain and DeepMind.

With Gemini's impending launch, OpenAI accelerated its work on GPT-4 with multimodal features similar to Gemini. On December 6, 2023, Google officially unveiled "Gemini 1.0," consisting of three models: Gemini Ultra, Pro, and Nano, each designed for different tasks. Gemini was integrated into various Google products and services, but

its widespread availability was delayed for extensive safety testing. Gemini's performance surpassed other language models on industry benchmarks, prompting partnerships and global launches. Updates like Gemini 1.5 and Gemma, a family of lightweight models, followed in early 2024, signifying

Google's continued innovation in AI technology.

5.9 Microsoft Copilot

Copilot is built on OpenAI's GPT (Generative Pre-trained Transformer) architecture, similar to the technology behind GPT-3. However, Copilot has been fine-tuned specifically for code-related tasks. It can understand programming languages and patterns, making it capable of providing more contextually relevant code suggestions compared to traditional autocomplete or code suggestion tools

According to Wikipedia, Microsoft Copilot is a friendly helper created by Microsoft and launched on February 7, 2023. It's like a smart friend who can do lots of cool things! It can find information for you, make poems, and even write songs. Microsoft made Copilot to take over from Cortana, which they stopped working on. At first, it was called Bing Chat and was part of Bing and Microsoft Edge. But Microsoft decided to change its name to Copilot and put it in lots of their other apps. They even put it in Windows 11, so you can find it right on your computer's taskbar. Copilot is like a smart buddy who can talk to you in many different languages and help you with lots of stuff. Some people can use it for free, but others can pay for extra features. There are different versions of Copilot, like Copilot Pro, which has even more cool stuff, and you can also make your chatbots with it! This version of AI has something different which makes the work easy for big projects. As we know these days everyone is working on different projects and sometimes we all need help to make a plan of work so this AI helps people to come up with their ideas and after having a good idea they can implement it.

Developers can interact with Copilot through plugins in various integrated development environments (IDEs) or directly within GitHub's interface. By leveraging Copilot, developers can potentially save time, reduce errors, and learn new programming techniques by observing the suggestions it provides.

However, it's important to note that while Copilot can be a helpful tool, it's not a replacement for human developers. Developers should review and understand the code suggestions provided by Copilot to ensure they align with their project's requirements, coding standards, and security best practices.

Descriptions	Classifications	Others
Built	January 2022	January till today
Owner	GitHub	Own by a Private Company
Work	Help to write Stuff	Same work as ChatGPT
Quality	Best	Better than Other AIs

The above table shows the classification of the Copilot and there are some other parts of the copilot that we can't compare with other AI's. The best we can do is to read about the copilot and then we have to make the right decisions on how to make a good AI product and then the project can be made with the help of different AI's.

5.10 AI table comparison

AI table comparison involves evaluating different artificial intelligence (AI) models or techniques based on various criteria to determine their effectiveness and suitability for specific tasks or applications. These criteria may include accuracy, speed, scalability, resource efficiency, interpretability, and ease of implementation. By comparing different AI models side by side in a structured manner, researchers and practitioners can gain insights into their strengths and weaknesses and make informed decisions about which approach to adopt. For example, when comparing machine learning algorithms for image classification, researchers may analyze factors such as model accuracy on test datasets, training time, and computational resources required for deployment. Similarly, when comparing natural language processing (NLP) models, criteria such as language understanding capabilities, response time, and model size may be considered. AI table comparison serves as a valuable tool for guiding the selection and optimization of AI models to meet specific project requirements and objectives.

AI table comparison is a systematic approach that allows researchers to evaluate and compare multiple AI models or techniques across various dimensions. For instance, in the context of computer vision tasks, criteria such as robustness to variations in lighting conditions, ability to generalize across different datasets, and computational complexity may be included in the comparison. By structuring the evaluation process in a table format, practitioners can easily identify the strengths and weaknesses of each AI model, helping them make informed decisions about which model best suits their needs. Moreover, AI table comparison facilitates the replication of experiments and fosters transparency in research by providing a clear overview of the evaluation criteria and results.

	chatGPT 3.5	Gemini	Copilot
Developer	Open AI	Google AI	Microsoft
Price	free	free	free
Release date	November 2022	March 2023	February 2023
Parameters	175B	137B	
Capabilities	● Question and answer ● Translation ● Text generation ● Code generation	● Question and answer ● Translation ● Text generation ● Image generation	● Code Completion ● Programmer Assistance ● Context-aware ● code suggestions ● Improves code quality and efficiency ● Integrates with various coding environments
Weaknesses	● Outdated knowledge in the free tier	● Limited access to the paid version ● No code generation yet	● Not suitable for open-ended conversation ● Lacks factual accuracy for noncode tasks ● Requires familiarity with coding environments

The above table shows the Comparison of different AI and we can easily see the difference between all these AI's. We have to make the right decision which AI is better and when it comes to the quality I think we have the right to choose the best option.

Furthermore, AI table comparison enables practitioners to assess the trade-offs between different AI models and techniques. For example, in applications where real time

processing is crucial, such as autonomous driving systems, speed and latency may be prioritized over model complexity. Conversely, in tasks where model interpretability is essential, such as medical diagnosis, simpler models with higher interpretability may be preferred over more complex ones. By systematically comparing AI models across various criteria, practitioners can make informed decisions that balance competing objectives and constraints, ultimately leading to the development of more effective and reliable AI systems.

The One more table above shows the quality versions of all the AI's. There are so many other versions of AI's in the world and it's better to combine the information from all the versions and then make the best decision. The time Savier stuff has a big game in the world and we did take a part of our own decisions.

5.11 Conclusion

To sum up, artificial intelligence (AI) can be a helpful tool when used properly, like a magic wand that makes tasks easier and faster. However, if not used carefully, it can also lead to problems. For instance, students can benefit from AI by improving their schoolwork efficiency, but excessive reliance on it may hinder learning and even lead to unethical behavior like cheating. AI analyzes user queries and provides tailored responses, similar to a smart version of a Google search. While AI offers many benefits, such as speeding up tasks and improving productivity, it also poses risks, such as potential misuse by scammers. Therefore, it's crucial for users, including students, to learn how to use AI responsibly and for educators to provide guidance and oversight to ensure its proper use, fostering a balance between leveraging its advantages and mitigating its risks.

Artificial intelligence (AI) undoubtedly has the potential to revolutionize various aspects of our lives, from education and healthcare to business and entertainment. When used properly, AI can indeed be likened to a magic wand, simplifying complex tasks, automating processes, and enhancing decision-making capabilities. For students, AI-powered tools can offer personalized learning experiences, adapt to individual needs, and provide valuable insights to improve academic performance. Moreover, AI-driven platforms can streamline administrative tasks for educators, allowing them to focus more on teaching and mentoring students.

However, like any powerful tool, AI also comes with its own set of challenges and risks. One of the primary concerns is the potential for over-reliance, where users may become dependent on AI systems to the point where they neglect critical thinking and problem-solving skills. In educational settings, students may rely too heavily on AI tools for tasks such as research or problem-solving, undermining their ability to think critically and independently. Moreover, the ease of access to information provided by AI can tempt students into unethical behaviors, such as plagiarism or cheating, if not properly monitored and guided by educators.

Problems - Criteria	Solutions	Neglection	Responsible	Required	Cost
Heavy Rain Water	This will be solved by the Storage Method	More Water	Water Damage	Pipes and Clips	$20
Tanks Maintenance	Buy the expensive tanks	Have more money	Tanks Cleanliness	Cement and Others	$0
Water Filtration	Take a good quality Filters	Have market experience	Filter Washing Liquid	Filtration Company	$10
Water Moving Tanks	Motors should be from good companies	Motor Production cost	Motor Oil and Fuel	Water Sucking Motors	$30

The table outlines various problems related to water management, along with their corresponding criteria and proposed solutions. Neglecting water storage can lead to issues such as heavy rainwater causing damage, which can be mitigated by implementing proper storage methods. Increasing water storage capacity can address the problem of insufficient water availability. Water damage caused by leaking pipes and clips can be resolved by investing in quality materials, albeit at a cost of $20. Regular maintenance of water tanks is necessary to ensure cleanliness and functionality, with expensive tanks being a viable solution for those with the required financial resources. Cleaning tanks can be done inexpensively using materials like cement. Water filtration is crucial for ensuring water quality, with the choice of high quality filters and proper market experience being essential. Filter washing liquids and services from filtration companies can further aid in maintaining filtration systems, with costs varying around $10.

Figure 10 gallons Water tank

Selection\Feature	Tank Size	Project Realism	Feature Application
Initial Plan (Small Tanks)	1 gallon	Less realistic	Limited
Revised Plan (10-Gallon Tanks)	10 gallon	More realistic	Comprehensive

SD2 water tank comparison table

While not a standard product, a custom-made 10-gallon water glass tank would be a truly unique centerpiece. Imagine a crystal-clear container showcasing ten gallons of water, offering an unobstructed view of any aquatic life or decorative elements placed inside. This unique tank would be ideal for a small freshwater fish or plant display, creating a visually stunning focal point in your home. However, keep in mind that glass is more fragile than traditional acrylic tanks and may require special care and support to prevent cracks or breakage, especially when filled with water.

6.0 Hardware Design

Hardware is very important in Our project since it includes a lot of hardware that will need to be installed. Our project hardware will include all the following: solar panel, water level sensor, rainwater sensor detector, battery, voltage controller, water pump, water filter, tube, and two water tanks. Our hardware design centers on an integrated rainwater harvesting system comprised of several key components: a network of durable yet lightweight rainwater collection units equipped with high efficiency filtration systems to ensure the purity of captured water, a centralized storage facility constructed from eco-friendly materials to accommodate large volumes of collected rainwater, and a sophisticated distribution network featuring smart sensors and valves to regulate water flow and optimize usage according to demand. Additionally, our design incorporates solar-powered pumps and energy efficient pumps to minimize reliance on external power sources, maximizing sustainability and reducing operational costs. This comprehensive system is complemented by user-friendly interfaces and mobile applications, empowering individuals and communities to monitor water usage, track conservation efforts, and engage in collective action towards a more water-secure future.

6.1 Hardware Selection

Selecting hardware for our project is crucial for its success. This decision hinges on a deep understanding of the project's design, constraints, and specific needs. The meticulous selection of components brings our design to life and demonstrates the practical impact of our work. By considering factors like performance, compatibility, durability, and size, we ensure that our chosen hardware aligns with our project goals. Optimal hardware not only maximizes performance but also saves space and enhances reliability. Ultimately, careful hardware selection minimizes errors and increases the likelihood of project success.

A. ESP32 wroom Microcontroller:

The ESP32-WROOM microcontroller is an ideal choice for our water management system due to its integrated WiFi and Bluetooth capabilities, which facilitate seamless internet connectivity and HTTP request handling. Its numerous GPIO pins accommodate various sensors and devices, including two distance sensors, a rain sensor, battery level reading, temperature sensors, and relays. The dual-core CPU and higher clock speed allow for concurrent task management, essential for sensor data acquisition, processing, and network communication. Additionally, its low power consumption and power-saving modes extend battery life, making it suitable for remote or off-grid installations. The ESP32-WROOM's ample RAM and flash memory support running multiple libraries, such as those for DHT sensors, OneWire, DallasTemperature, NTPClient, WiFi, HTTPClient, and ArduinoJson, without memory constraints. Compatibility with the Arduino IDE simplifies development, while the robust community and extensive documentation provide valuable support and resources. By leveraging these features, our system can efficiently manage sensors, process real-time data, and communicate

effectively with our web server, ensuring a robust and scalable solution for water management and sustainability.

B. Relay:

Using relays in our system provides an efficient and reliable method to control high-power devices like fans based on sensor inputs. The relays offer robust switching capabilities, allowing us to handle the varying loads without compromising the microcontroller's safety. This integration ensures that the system operates seamlessly under different conditions, such as temperature fluctuations detected by the DHT11 sensor, by activating the fans when temperatures exceed 70 degrees Fahrenheit. Additionally, the relays' ability to be controlled through GPIO pins in our code facilitates precise and immediate response to environmental changes, ensuring optimal performance and energy efficiency in our water management system.

C. 20x4 LCD display:

The 20x4 LCD is an ideal choice for our system and code due to its superior display capacity and readability. It allows us to present more information simultaneously, which is critical for monitoring multiple sensors and system states. With four lines of text, we can display distance measurements, temperature readings, rain sensor data, battery voltage, and real-time clock updates without constant screen refreshing or data overwriting. This enhances the user's ability to quickly assess system performance and status briefly, making the interface more intuitive and efficient for real-time monitoring and management tasks. Additionally, the LCD screen serves as a reliable source of information when users do not have access to their phones. While the primary mode of accessing real-time data is through the app, which offers convenience and remote monitoring, the LCD screen ensures that users can still obtain accurate measurements and system status directly from the device itself. This dual-mode accessibility is particularly beneficial in situations where mobile device access is limited or impractical. The integration of the LCD screen with our system ensures continuous visibility of crucial data, thereby enhancing the overall user experience and system reliability. This setup guarantees that users have immediate and reliable access to critical information, whether they are near the device or monitoring it remotely through the app.

D. Ultrasonic sensors:

Ultrasonic sensors are optimal for our water-saving system due to their precise and reliable distance measurement capabilities, which are crucial for accurately monitoring water levels. These sensors emit ultrasonic waves that bounce back upon hitting an object, allowing the system to calculate the distance based on the time taken for the echo to return. In the provided code, two ultrasonic sensors are set up using trigger and echo pins (trigPin, echoPin, newTrigPin, newEchoPin) to measure distances. The code includes functions to get distance readings, averages multiple readings for accuracy, and uses these measurements to control the relay and other components, ensuring efficient water management and system responsiveness. This water level sensor is particularly well-

suited for our project because of its compact size. We needed a sensor that could fit discreetly in a space where the wires would remain hidden, contributing to a more professional look. The sensor fits perfectly within a 3D-printed mold that integrates seamlessly into our design. This setup prevents any disturbances to the ultrasonic waves, ensuring accurate detection when the water level approaches the top. The sensor was specifically chosen for its compatibility with our mold, which is implemented inside the fish tank to stop waves from interfering with the measurements. This precise and reliable sensor significantly enhances our system's ability to manage water levels effectively.

E. Water pump:

Widely adopted brushless DC water pumps maintain operating voltages between 9V and 24V, well below the safety threshold of 36V for human safety. This substantial reduction in voltage significantly reduces the risk of electric shock incidents. In regions with erratic voltage, stability is ensured through power adapters (transformers) that provide consistent power and the option to rely on batteries during power outages. Brushless DC pumps rectify issues of low energy efficiency, bulkiness, and noise. brushless DC water pumps are the best option making them capable of enduring high pressures. The water pump integrates seamlessly with our system and code due to its relay-based control, which allows for precise activation in response to specific environmental conditions detected by various sensors. The system monitors rain levels, distances from ultrasonic sensors, and other environmental factors. The relay connected to the pump (pin 23) is activated or deactivated based on conditions like rain detection and distance readings from the ultrasonic sensors. When rain is detected, the system intelligently manages the pump to prevent water wastage. This setup ensures efficient water management and conservation, driven by real-time sensor data processed in the code.

F. DHT11 temperature sensor:

The DHT11 sensor is optimal for our system and code due to its simplicity, reliability, and low-cost temperature and humidity measurements, making it well-suited for monitoring the PCB box environment. The sensor is set up using the DHT library and connected to pin 25, with initialization in the setup function through dht.begin(). During operation, the sensor reads temperature in Celsius using dht.readTemperature(), and the value is converted to Fahrenheit for display and control purposes. The DHT11 sensor integrates seamlessly with our other components and provides essential environmental data for system functionality. We initially chose these fans because we did not anticipate our components being at risk of overheating, and these fans can operate at just three volts. Multiple tests showed that this setup did not affect the motor in any way. However, we observed that when we increased the motor's power, the fans also sped up significantly, putting them at risk of burning out. To address this issue, we switched from the Raspberry Pi Pico to the ESP32 microcontroller. The ESP32 operates at 3.3 volts, allowing us to manage the board's temperature more effectively. This change ensures that our fans run efficiently without overheating, keeping our system safe and maintaining optimal performance.

G. Rain sensor detector:

The rain sensor detector integrates seamlessly with our system due to its ability to provide real-time rain detection, enabling automated control of the relay and other connected devices based on weather conditions. In the setup, the rain sensor is connected to pin 34, where it continuously monitors moisture levels. The analogRead() function retrieves the sensor data, and the system logic checks if the rain value exceeds a threshold (e.g., 1000). If rain is detected, the system updates the relay state to manage connected devices, accordingly, enhancing the system's responsiveness to environmental changes. Additionally, the sensor data is transmitted to a server for remote monitoring and analysis. This rain sensor will continuously monitor the weather, and as soon as it starts raining, it will trigger the relay to turn on, which in turn activates the motor to fill up the storage for the user to utilize as needed. We initially considered using a weather app to pull information for the microcontroller to predict rain, but in Florida, the weather can be highly unpredictable, making such predictions unreliable. Due to this bipolar weather, we opted for a rain detector. The sensor operates after being soaked in water for 30 seconds, ensuring accurate detection before triggering the relay to turn on the motor. This integration ensures that the entire project works together seamlessly, efficiently managing water based on real-time conditions.

H. PCB fans and heat sink:

The PCB fans and heat sink are integral to our system, providing essential cooling to prevent overheating of components during operation. Our PCB faces significant thermal challenges due to the components we've chosen, which are not very "thermally" efficient. After consulting with our professor, we determined that a heat sink and two fans are essential for cooling our board. The fans blow air through the heat sink, effectively lowering the temperature. While our power board can operate at temperatures up to the mid-80s, it becomes dangerously hot when temperatures reach 100°F or higher. During testing, we observed our board overheated, forcing us to halt the demonstration. We haven't determined the maximum operating temperature, but we plan to conduct further testing after the demo to identify this critical limit. Therefore, we are using a temperature sensor to monitor the internal temperature of the box. Two fans are connected to the microcontroller via specific pins and are programmed to activate only when the temperature reaches a dangerous level. Once activated, the fans work to lower the temperature, effectively cooling the system and preventing overheating. This setup ensures that the fans operate only when necessary, maintaining a safe operating temperature for our components. In our code, the fans are controlled by pins 26 and 27, and they activate when the temperature exceeds a specified threshold (70°F) detected by the DHT11 sensor. This setup ensures efficient thermal management, maintaining optimal performance and longevity of the electronics. The fans are triggered by reading the temperature and sending the appropriate signals to the designated pins, automatically adjusting the cooling based on real-time temperature data.

I. DS18B20 Water temperature sensor:

The DS18B20 water temperature sensor is ideal for our system due to its precision, digital output, and ease of integration with the OneWire protocol, which simplifies connectivity by requiring only one data pin. In our setup, the DS18B20 is connected to pin 32, and its readings are processed using the DallasTemperature library. The code initializes the sensor in the setup() function and periodically requests temperature updates in the loop(), converting the values to Fahrenheit for display on an LCD and logging. This ensures reliable and accurate water temperature monitoring, critical for the system's functionality.
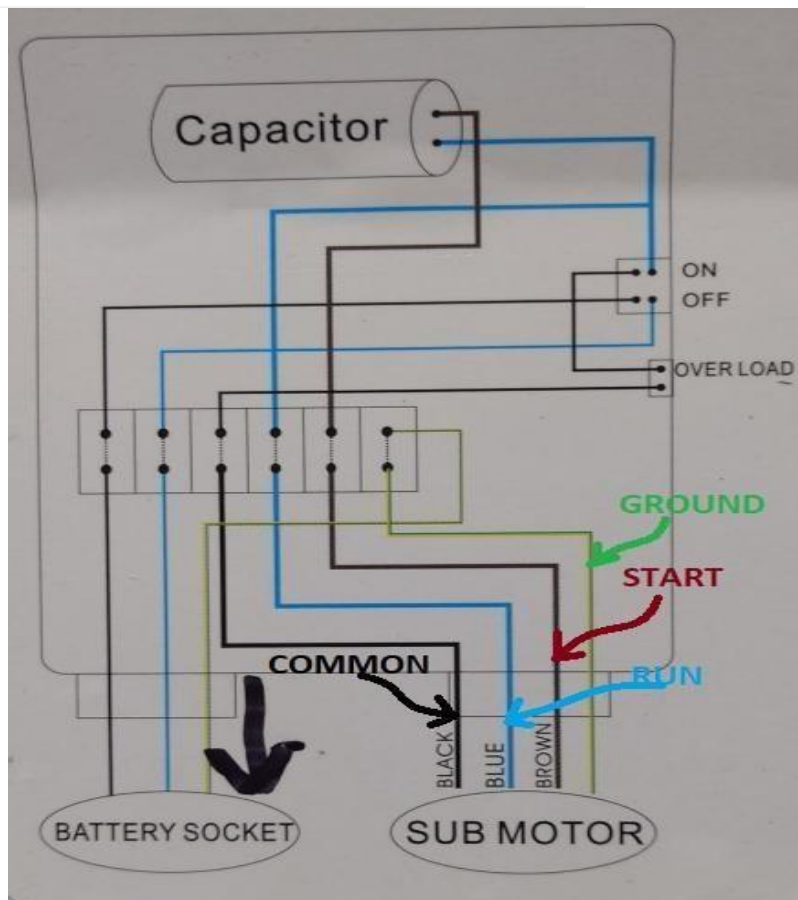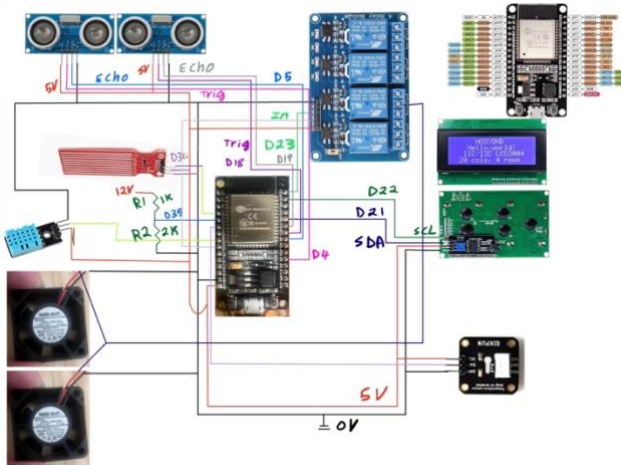

Figure Battery Schematic

Power Supply

When comparing solar panels for our project, we must carefully consider various factors to ensure optimal performance and compatibility. Initially, we found that Monocrystalline panels outperform Polycrystalline panels in terms of efficiency and speed despite their similar weight. Monocrystalline panels are known for their higher efficiency due to their uniform crystal structure, which enables them to convert sunlight into electricity more effectively. This increased efficiency translates to faster energy generation, making Monocrystalline panels a preferable choice for projects where maximizing energy output is essential.

Furthermore, it's crucial to evaluate the voltage, amperage, and wattage supported by the solar panels to ensure they align with our project's requirements. After researching available options in the market, we discovered that most panels support voltage ratings of 6 and 12 volts, with wattage ranging from 1 to 100 watts. Assessing these specifications is vital to ensure compatibility with our project's power requirements and to determine the number of panels needed to achieve the desired energy output. By carefully considering factors such as efficiency, speed, voltage, amperage, and wattage, we can select the most suitable Monocrystalline panels that meet our project's needs and maximize energy generation for our application.

In addition to efficiency and power output, it's important to consider the physical characteristics and durability of the solar panels. Monocrystalline panels typically have a sleeker design and are more aesthetically pleasing compared to Polycrystalline panels. This can be important if the panels will be visible and need to blend in with their surroundings, such as on a rooftop or in a residential setting.

Durability is also a key factor, especially if the panels will be exposed to harsh weather conditions or potential damage. Monocrystalline panels are often more durable and have a longer lifespan compared to Polycrystalline panels due to their higher-quality materials and manufacturing processes. They are less prone to degradation over time and can withstand extreme temperatures and weather events more effectively.

Another consideration is the cost-effectiveness of the panels. While Monocrystalline panels tend to be more expensive upfront, they often offer better long-term value due to their higher efficiency and durability, resulting in lower overall lifetime costs. Polycrystalline panels may be a more economical choice for budget-conscious projects, but they may not provide the same level of performance and longevity as Monocrystalline panels.

Additionally, the installation requirements and available space should be taken into account when selecting solar panels. Monocrystalline panels typically require less space for the same power output compared to Polycrystalline panels, making them suitable for installations with limited roof or ground space. However, both types of panels can be mounted in various configurations, such as fixed tilt, adjustable tilt, or tracking systems, to optimize their performance based on the available sunlight and location.

Finally, it's essential to consider the warranty and manufacturer reputation when choosing solar panels. A longer warranty and a reputable manufacturer can provide peace of mind and assurance of quality and reliability over the panels' lifespan.

By carefully evaluating these factors, we can select the most suitable Monocrystalline panels for our project, ensuring optimal performance, durability, and cost-effectiveness while maximizing energy generation from sunlight.
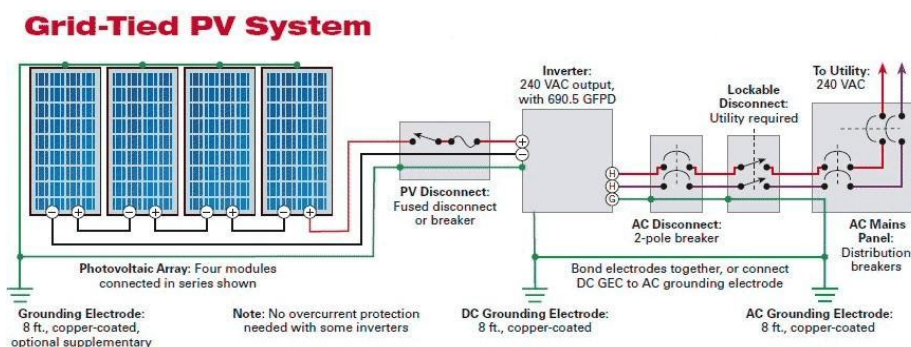

Figure Solar Panel Schematic

Battery

When considering rechargeable batteries, Panasonic's Eneloop AA Batteries stand out for their exceptional charging capability, offering up to 2,100 recharge cycles and maintaining their charge impressively over time, thanks to pre-charging using solar energy. While they may have a higher initial cost and slower charging times compared to other options, their longevity and performance make them a valuable investment for those seeking reliable rechargeable batteries. For a balance between cost and performance, AmazonBasics High-Performance AA Batteries are a compelling choice with a 10-year shelf life and leak prevention design, making them practical for low-drain devices like remote controls and clocks. Although not suitable for high-drain devices, their affordability and decent performance in household applications make them a great budget-friendly option.

In the realm of battery selection, after careful deliberation, the decision to proceed with the Energizer L91 lithium AA battery was made due to its proven performance, reliability, and comprehensive technical information availability. Despite the cost savings offered by the EBL alternative, the compromise on capacity and lack of detailed specifications led to the preference for the Energizer option. With the project requiring batteries capable of consistently delivering at least 1.5V over an extended period, the Energizer L91's suitability was assured by detailed technical data, outweighing the monetary benefits of the EBL option.

Regarding power supply technology, the decision to opt for a buck converter-based solution was made after thorough consideration. Linear power supplies were eliminated

due to their larger size and higher cost compared to alternatives, while resonant converters were deemed overly complex for the project's requirements. Additionally, flyback converters, offering step-up functionality unnecessary for the application, were discarded. The buck converter emerged as the most suitable option for straightforward and cost-effective step-down AC/DC conversion, aligning with the project's needs efficiently.

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Furthermore, the Energizer L91 lithium AA batteries offer exceptional energy density and longevity, making them ideal for high-drain applications such as portable electronics, cameras, and wireless devices. Their lightweight and compact design also contribute to their versatility and ease of use, making them suitable for a wide range of applications in our project.

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The buck converter provides efficient voltage regulation by stepping down the input voltage to a stable output voltage suitable for the project's components, ensuring reliable and consistent performance. Its compact size and high efficiency make it well-suited for integration into the project's design while minimizing energy losses and maximizing battery life. Additionally, the buck converter's simplicity and reliability simplify the overall system design and maintenance, contributing to the project's success and longevity.

Overall, the combination of Energizer L91 lithium AA batteries and a buck converter-based power supply solution ensures reliable and efficient power delivery for our project, meeting its performance requirements while optimizing cost and energy efficiency.
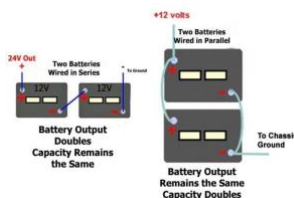
Figure Battery Regulators

Water Sensor

When selecting a motor for a water pump, it's crucial to consider the unique requirements and constraints of the application, as well as the advantages and drawbacks of each motor type. Brushed motors offer simplicity and cost effectiveness, making them suitable for budget-conscious projects or rugged environments where maintenance is feasible. However, their reliance on physical brushes can lead to wear and tear over time, requiring regular upkeep. In contrast, brushless motors provide higher efficiency, longer lifespan, and better performance, making them ideal for applications requiring high reliability and energy efficiency. While the initial cost of brushless motors may be higher, their superior efficiency and longevity can result in cost savings over time, especially in applications with high usage rates or stringent performance requirements. Additionally, servo motors offer precise control and positioning, making them suitable for applications where accuracy is paramount, albeit at a higher cost and complexity.

Beyond motor selection, the choice of sensors for liquid level measurement is critical, particularly in environments where direct contact with the liquid is impractical or undesirable. Capacitive liquid level sensors offer a non-invasive solution for accurately measuring liquid levels through tank walls, making them well-suited for industries such as food and beverage, pharmaceuticals, and chemical processing. Their non-contact nature minimizes the risk of contamination and corrosion, ensuring reliable measurements even in challenging environments. On the other hand, ultrasonic liquid level sensors harness sound waves to provide precise and reliable measurements without physical contact with the liquid. Their versatility and adaptability make them ideal for applications across various industries, including water treatment, fuel management, and bulk storage monitoring. By carefully evaluating the specific requirements and operating conditions of the application, engineers can select the most suitable motor and sensor technologies to ensure optimal performance, efficiency, and reliability for their water pump system.

In addition to motor selection, the choice of sensors for liquid level measurement is crucial for ensuring the efficiency and reliability of the water pump system. Capacitive liquid level sensors offer a non-invasive solution for accurately measuring liquid levels through tank walls, making them well-suited for industries such as food and beverage, pharmaceuticals, and chemical processing. These sensors work by detecting changes in capacitance as the liquid level rises or falls, providing precise measurements without direct contact with the liquid. Their non-contact nature minimizes the risk of contamination and corrosion, ensuring reliable operation even in harsh or corrosive environments.

Furthermore, capacitive liquid level sensors are highly versatile and can be easily integrated into various types of tanks or vessels, including plastic, glass, or metal containers. Their compatibility with different liquids, ranging from water and oils to chemicals and solvents, makes them suitable for a wide range of applications.

Additionally, capacitive sensors offer features such as adjustable sensitivity and output options, allowing for customization to meet specific application requirements.

On the other hand, ultrasonic liquid level sensors utilize sound waves to provide precise and reliable measurements without physical contact with the liquid. These sensors emit ultrasonic pulses that bounce off the liquid surface and are then detected by the sensor. By measuring the time it takes for the sound waves to travel to the liquid surface and back, ultrasonic sensors can accurately determine the liquid level. Ultrasonic liquid level sensors are known for their versatility and adaptability, making them ideal for applications across various industries, including water treatment, fuel management, and bulk storage monitoring. They can accurately measure levels in tanks of various shapes and sizes, including those with irregular geometries or obstructions. Additionally, ultrasonic sensors are not affected by the properties of the liquid being measured, such as color, viscosity, or chemical composition, making them suitable for a wide range of liquid types.

Overall, by carefully evaluating the specific requirements and operating conditions of the water pump system, engineers can select the most suitable motor and sensor technologies to ensure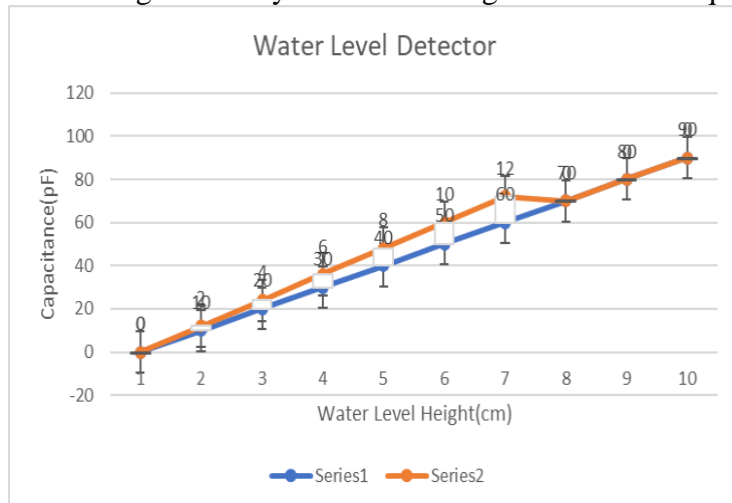 optimal performance, efficiency, and reliability. Whether choosing between brushed, brushless, or servo motors, or deciding between capacitive and ultrasonic liquid level sensors, the goal is to design a system that meets the needs of the application while maximizing efficiency and minimizing maintenance requirements.
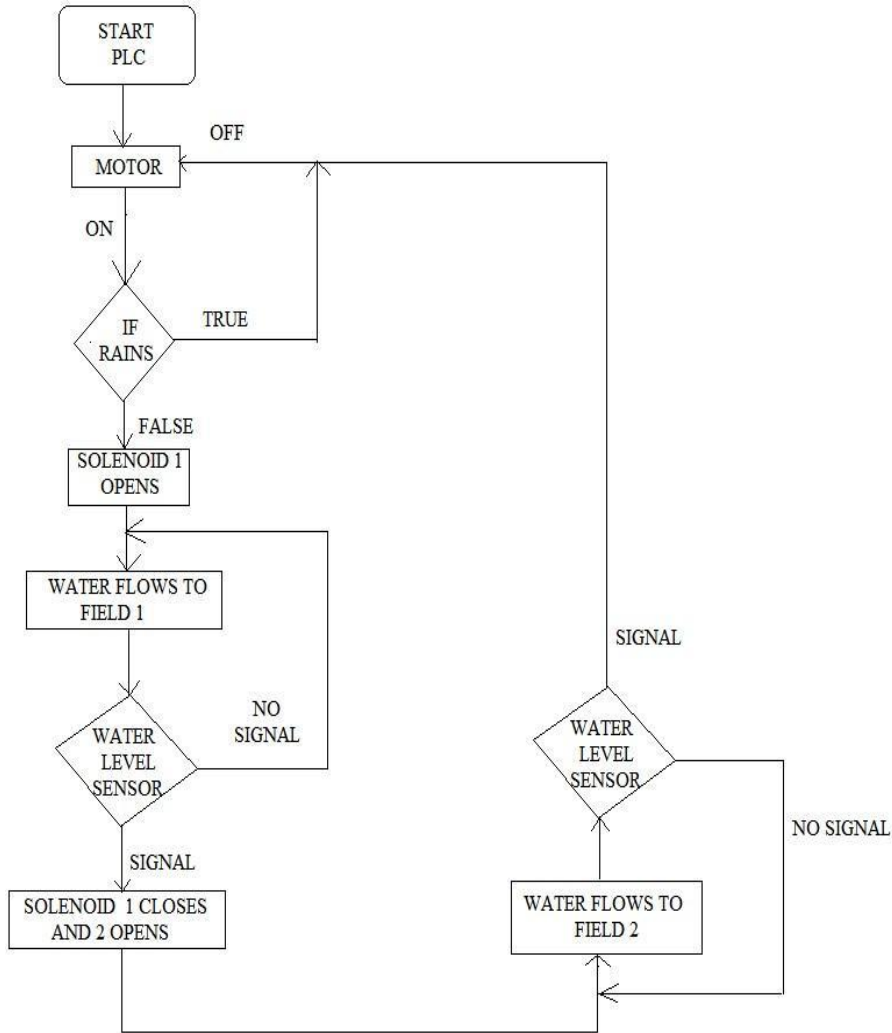
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Figure Water level chart

6.2 System Hardware Design

We've chosen EasyEDA as our tool for creating schematic and PCB designs due to its user-friendly interface and comprehensive library of components. EasyEDA is particularly beneficial for beginners, offering a straightforward learning curve and a vast array of readily available parts. Additionally, it provides options for creating custom footprints and accessing user-contributed footprints, enhancing flexibility and customization in our designs.

In our schematic design process, we opted to utilize net ports to enhance readability and organization, avoiding cluttered layouts with criss crossing wires. This approach streamlines the design and makes it easier to understand at a glance. Each system is briefly explained alongside its respective schematic, ensuring clarity and coherence in our documentation. Figure 6.1 presents an overview of the schematic in a block diagram format, providing a visual representation of the system architecture.

SYSTEM SETUP

In this section, we are showing how our system works. We built our Arduino code based on this diagram.

A. Embedded system in our design:

Our system starts working either when the rainwater sensor detects rain or when a user activates the system; otherwise, it remains off. We have two water tanks: one at the bottom to collect rainwater from the house roof via a gutter and tube, which passes through a water filter to remove large objects like leaves. The water is then transferred to the top tank until the water level sensor detects that the tank is full, at which point the system stops sending water until the user activates it again. The reason for placing one tank on top is to allow gravity to distribute the water immediately to the user. When both tanks are full, the overflow water is diverted away from the bottom tank. To make our project more efficient, we decided to use solar power and a 12V battery to power the system.

B. Embedded Engineering:

The code initializes various libraries and hardware configurations, connects to WiFi using provided credentials, and sets up an NTP client for time synchronization. It defines pin configurations for sensors and actuators, including ultrasonic sensors, a rain sensor, a temperature sensor, and a relay. The setup function initializes serial communication, connects to WiFi, initializes the LCD, sets pin modes, and begins sensor operations. It creates a queue for sensor data and a task to send HTTP POST requests with sensor data to a specified server URL. The loop function updates the time, reads and processes data from the sensors, displays the data on the LCD, and controls the relay based on specific conditions involving rain detection and distance measurements. It also debounces the relay state to prevent rapid switching. Sensor data includes distance measurements from two ultrasonic sensors (one using averaging), rain sensor values, battery voltage, and temperatures from the DHT11 and DS18B20 sensors, with the results displayed on both the LCD and the serial monitor. Construction delves into the intricate process of bringing theoretical designs to life through the creation of functional prototypes. It outlines the systematic approach undertaken to finalize the design, source and select components, and meticulously assemble.
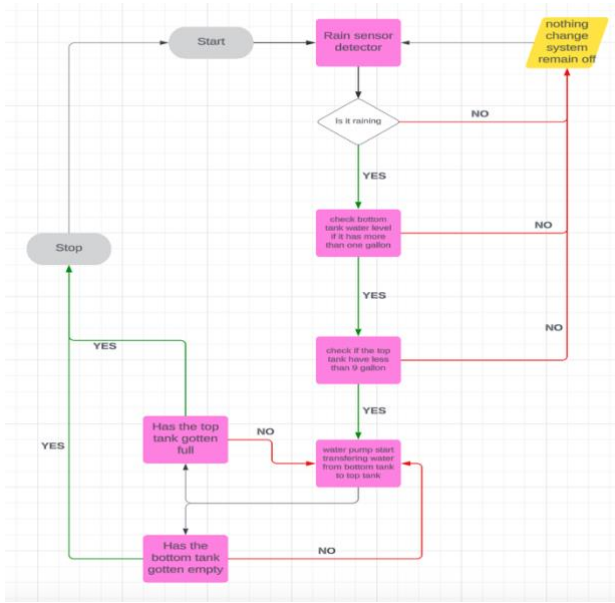
Fig. 2 Code setup functionality

Fig. 3 Hardware integration block diagram

6.3 Microcontroller Design

The ESP32-WROOM microcontroller offers a compelling platform for a wide range of projects due to its integrated Wi-Fi and Bluetooth capabilities, robust processing power, and low power consumption. To effectively leverage its potential,careful consideration of several key design factors is essential.

Core Design Considerations

Peripheral Selection: The ESP32-WROOM boasts an extensive array of peripherals, including GPIOs, ADC,DAC, I2C, SPI, and UART. Carefully selecting the appropriate peripherals for your project is crucial. Consider factors such as required functionality, power consumption, and pin availability.

Power Management: Efficient power management is vital for battery-powered or low-power applications. The ESP32 offers various sleep modes to conserve energy.

Implement strategies to minimize power consumption during idle periods and optimize power usage for active components.

Software Development: The ESP32 is compatible with Arduino IDE, making it accessible for developers.However, for more complex projects, consider using frameworks like ESP-IDF for direct hardware access and optimization. Prioritize code efficiency, modularity, and maintainability.

Wireless Connectivity: Configure Wi-Fi and Bluetooth modules according to your project's requirements.Consider security measures like encryption and authentication to protect data transmission.

Real-Time Capabilities: If your project demands real-time performance, optimize code for minimal latency and jitter. Explore the use of FreeRTOS or other real-time operating systems (RTOS) for task scheduling and resource management.

Additional Considerations

Hardware Design: For custom hardware, consider factors like PCB layout, component placement, antenna design,and power supply circuitry. Ensure proper grounding and shielding to minimize noise and interference.

Thermal Management: If the project involves high power consumption or operation in demanding environments,implement thermal management techniques like heat sinks or fans to prevent overheating.

Security: Protect your project from vulnerabilities by implementing secure coding practices, using encryption, and regularly updating firmware.

Testing and Debugging: Rigorous testing is essential for ensuring the system's reliability and performance. Utilize debugging tools and techniques to identify and resolve issues efficiently.

By carefully considering these factors, you can harness the full potential of the ESP32-WROOM and create successful projects.
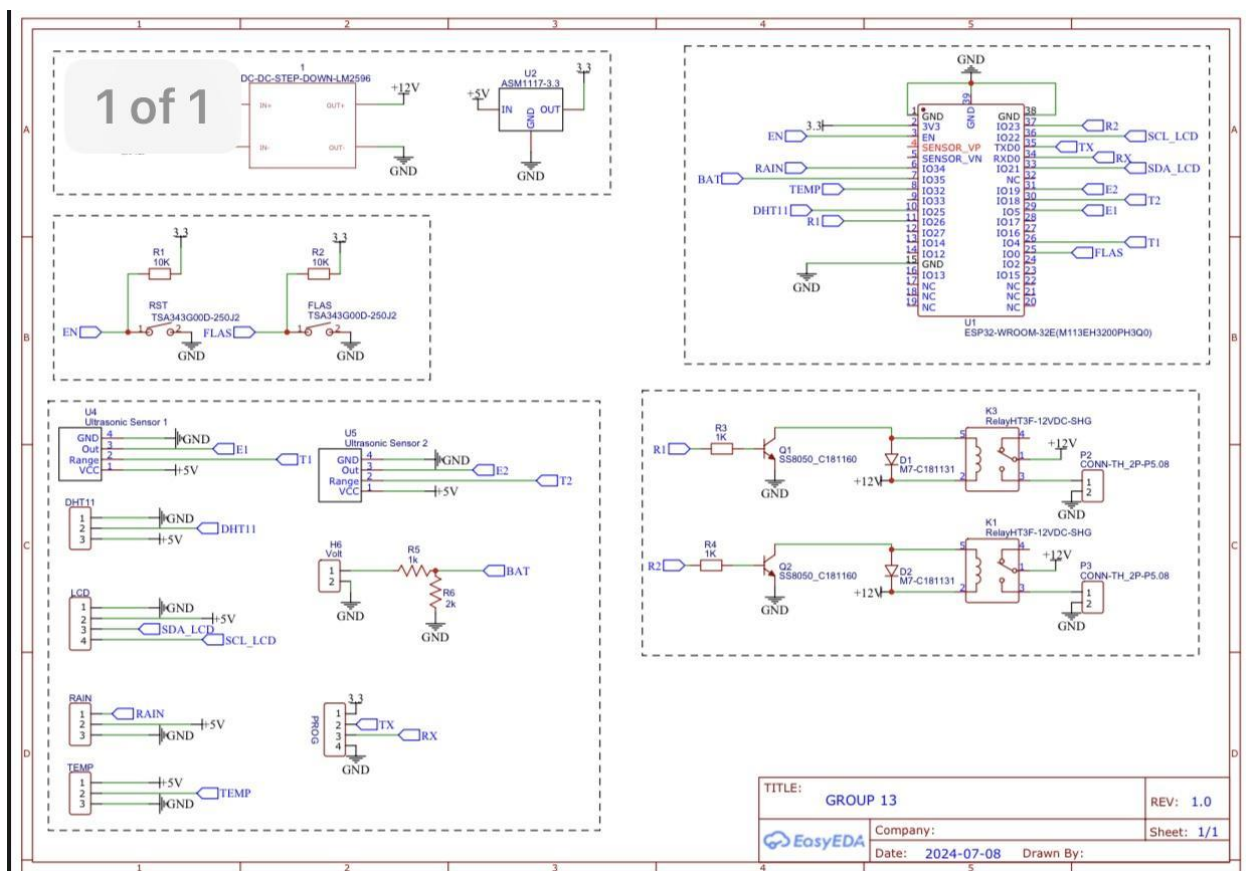
Figure ESP 32 Wroom Schematic

Power Design

When designing the power system for our project, the selection of solar panels plays a pivotal role in ensuring optimal performance and compatibility. After thorough evaluation, Monocrystalline panels emerge as the preferred choice due to their superior efficiency and speed compared to Polycrystalline panels. With their uniform crystal structure, Monocrystalline panels excel in converting sunlight into electricity more effectively, resulting in faster energy generation. This increased efficiency is crucial for projects prioritizing maximum energy output.

In addition to efficiency, it's essential to assess the voltage, amperage, and wattage supported by the solar panels to ensure alignment with our project's requirements. Most panels in the market offer voltage ratings of 6 and 12 volts, with wattage ranging from 1 to 100 watts. By carefully evaluating these specifications, we can determine the number of panels needed to meet our project's power needs and achieve the desired energy output. Furthermore, considering factors such as efficiency, speed, voltage, amperage, and wattage allows us to select Monocrystalline panels that not only maximize energy generation but also ensure compatibility and efficiency in our power system design.

Figure Battery

Battery Design

In the design of our power system, the selection of rechargeable batteries is critical for ensuring reliable and sustainable energy storage. Panasonic's Eneloop AA Batteries offer exceptional charging capability, boasting up to 2,100 recharge cycles and maintaining charge effectively over time, thanks to pre-charging using solar energy. Despite their higher initial cost and slower charging times, their longevity and performance make them a valuable investment for applications prioritizing reliability. For a more budget-friendly option without compromising too much on performance, AmazonBasics High-Performance AA Batteries provide a 10-year shelf life and leak prevention design, suitable for low-drain devices like remote controls and clocks.

When designing a 12V battery, the choice of chemistry is a critical first step that depends on specific application requirements such as energy density, cycle life, and operating temperature range. Common chemistries for 12V batteries include lead acid, lithium-ion, and nickel-metal hydride (NiMH). Each chemistry offers different trade-offs in terms of performance and cost, allowing engineers to tailor the battery to the needs of the application.

The battery's voltage and capacity are determined by the number and arrangement of individual cells. For a 12V battery, typically six cells are connected in series, with each cell providing around 2V. This series connection ensures that the total voltage output of the battery meets the desired 12V requirement.

A Battery Management System (BMS) is essential for monitoring and controlling the battery's state of charge, voltage, temperature, and overall health. It ensures safe operation by preventing overcharging or over-discharging, balancing cell voltages, and protecting against short circuits and thermal runaway.
Enclosure and packaging are crucial aspects of battery design to protect the cells from physical damage and environmental factors. The battery enclosure must be robust and durable, providing adequate ventilation to dissipate heat generated during charging and discharging. Additionally, the design should facilitate easy and secure connection to external devices or circuits through compatible terminal types capable of handling expected current loads.

Safety features are paramount in battery design to prevent accidents and ensure user safety. This includes built-in protections against short circuits, overcurrent, overvoltage, and thermal runaway. Fuse protection and internal circuitry that disconnects the battery in case of an unsafe condition are essential safety measures.

The battery design should also incorporate a charging system compatible with the chosen chemistry to optimize charging efficiency while preventing damage to the cells. This may involve implementing constant voltage or constant current charging methods, depending on the battery chemistry.

Considerations for capacity, performance, cycle life, and environmental impact are also important. The battery's capacity and performance characteristics, such as voltage stability and discharge rate, should meet the requirements of the intended application. Design considerations should address the battery's expected cycle life and aging characteristics to ensure long-term reliability and durability. Additionally, designing for sustainability involves considering the environmental impact of the battery throughout its lifecycle, including material selection, energy efficiency, and end-of-life disposal practices.

Rigorous testing procedures should be implemented to verify the performance, safety, and reliability of the battery design. This includes testing individual cells, as well as the assembled battery pack, under various operating conditions. Compliance with relevant safety and performance standards, such as UL certification for lithium ion batteries or DOT regulations for transportation, is also essential to ensure regulatory compliance and market acceptance.
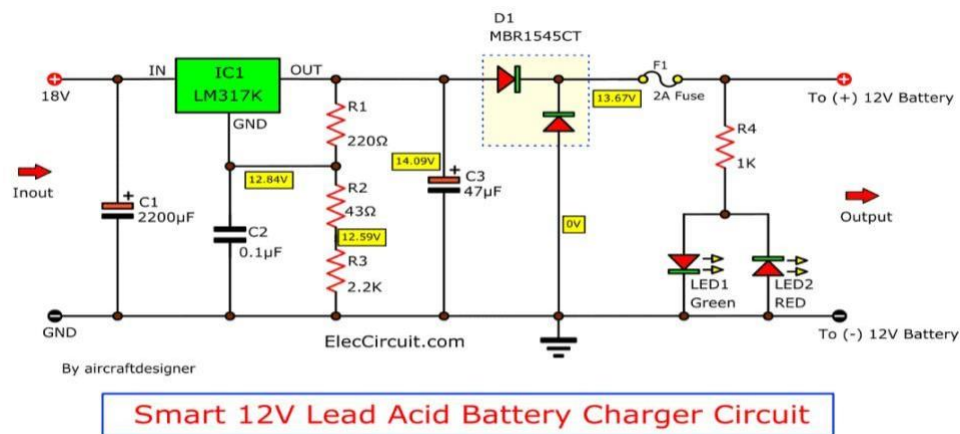

Figure 12V battery Schematic

Water Level Sensors

In designing the sensor system for liquid level measurement, the selection of the appropriate technology is paramount to ensure accurate and reliable data acquisition,

particularly in environments where direct contact with the liquid is impractical or undesirable. Capacitive liquid level sensors offer a non-invasive solution by detecting changes in capacitance as the proximity of the liquid alters the dielectric constant in their vicinity. This technology allows for accurate measurements through tank walls, making it well-suited for industries such as food and beverage, pharmaceuticals, and chemical processing. The non-contact nature of capacitive sensors minimizes the risk of contamination and corrosion, ensuring reliable measurements even in challenging environments where maintaining cleanliness and integrity is critical.

Designing a water level sensor involves careful consideration of various factors such as accuracy, reliability, cost-effectiveness, and ease of installation. The basic principle behind a water level sensor is to measure the height or depth of water in a tank or reservoir and convert this information into an electrical signal that can be interpreted by a microcontroller or other control system. One common approach is to use a float-based sensor, where the movement of a float in response to water level changes is translated into an electrical signal.

A typical float-based water level sensor consists of a float attached to a stem or arm that rises and falls with the water level. This float is connected to a potentiometer or other position sensor that measures its vertical position. As the water level changes, the float moves up or down, causing the position sensor to output a corresponding voltage or resistance value. This signal is then processed by the control system to determine the water level.

Another type of water level sensor utilizes ultrasonic or pressure-based technology to measure the distance between the sensor and the water surface. Ultrasonic sensors emit high-frequency sound waves that bounce off the water surface and are then detected by the sensor. By measuring the time it takes for the sound waves to return, the sensor can calculate the distance to the water surface and thereby determine the water level.

Pressure-based water level sensors, on the other hand, measure the pressure exerted by the water column above the sensor. As the water level changes, so does the pressure, allowing the sensor to infer the water level based on the pressure readings.

In designing a water level sensor, considerations must be made for the specific application requirements. Factors such as the size and shape of the tank, the type of liquid being measured, the desired level of accuracy, and the environmental conditions all influence the choice of sensor technology and design. Additionally, factors such as power consumption, maintenance requirements, and compatibility with existing control systems should also be taken into account to ensure the sensor meets the needs of the application effectively and efficiently.
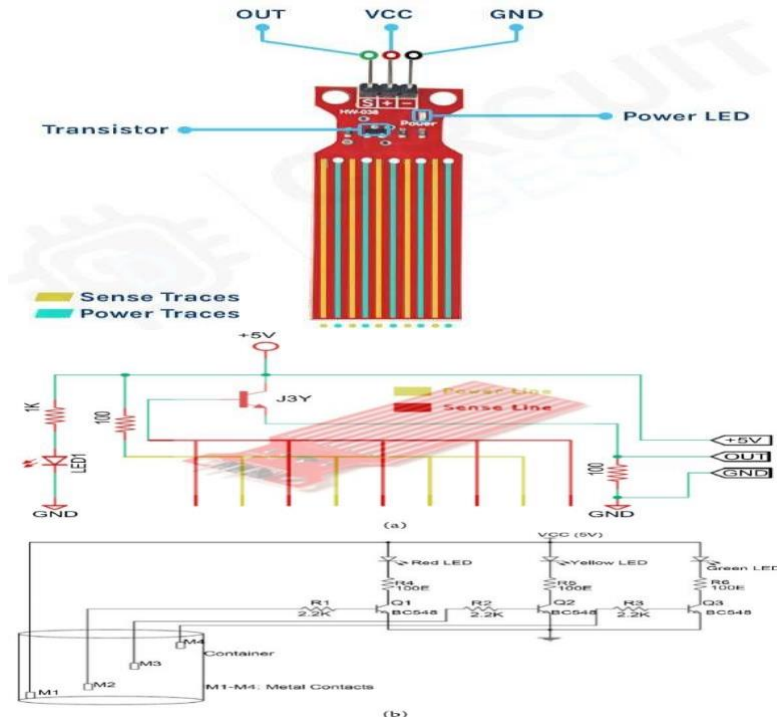
Figure Water Level Sensor
PCB Layout

We meticulously refined our PCB design to ensure maximum efficiency, paying close attention to component placement to minimize electromagnetic interference from the magnets. Strategically avoiding placing any components or traces beneath the magnets, we safeguarded against potential disruptions to their functionality. The vast majority of our components are situated on the top layer of the PCB, optimizing accessibility and organization. Conversely, on the bottom layer, we reserved space for the electromagnets and magnets, incorporating holes in the board to securely fasten them with screws. This layout decision not only enhances stability but also mitigates any interference that could arise from the magnets. Additionally, the bottom layer accommodates the hall sensors, strategically positioned to facilitate accurate readings by minimizing interference and ensuring precise detection.

PCB layout design is a critical aspect of electronic product development, as it determines the physical arrangement of components and interconnections on a printed circuit board (PCB). A well-designed PCB layout not only ensures proper functionality but also influences factors such as signal integrity, electromagnetic compatibility (EMC), thermal management, and manufacturability.

The PCB layout process begins with schematic capture, where the circuit design is translated into a graphical representation of component placement and connectivity. Once the schematic is complete, the layout designer arranges the components on the PCB to optimize performance, minimize signal interference, and meet design constraints such as size and shape.

During component placement, factors such as signal paths, power distribution, and thermal considerations are taken into account. Critical components may be placed strategically to minimize trace lengths, reduce noise, and ensure adequate cooling. High-speed signals require careful routing to maintain signal integrity and prevent signal degradation due to reflections or crosstalk.

Routing is the process of creating electrical connections between components by designing copper traces on the PCB. Proper routing techniques, such as avoiding sharp corners, minimizing trace lengths, and maintaining consistent trace widths, help ensure signal integrity and reliability. Differential pairs, high-speed signals, and sensitive analog or digital signals may require special routing considerations to minimize interference and noise.

Grounding and power distribution are crucial aspects of PCB layout design. A solid ground plane helps provide a low-impedance return path for signals and reduces electromagnetic interference. Proper power distribution ensures that all components receive stable and adequate power, minimizing voltage drops and ensuring reliable operation.

Thermal management is essential for preventing overheating of components and ensuring long-term reliability. Components that generate heat, such as power devices or processors, may require heat sinks or thermal vias to dissipate heat efficiently. Proper spacing between components and adequate airflow are also important considerations for thermal management.
Finally, manufacturability considerations are essential to ensure that the PCB can be produced reliably and cost-effectively. This includes factors such as component placement for automated assembly, clear labeling and documentation, and adherence to design rules for the chosen fabrication process.

In summary, PCB layout design plays a crucial role in the success of electronic products. By considering factors such as component placement, routing, grounding, power distribution, thermal management, and manufacturability, designers can create PCB layouts that meet performance requirements while also being reliable, cost-effective, and easy to manufacture.
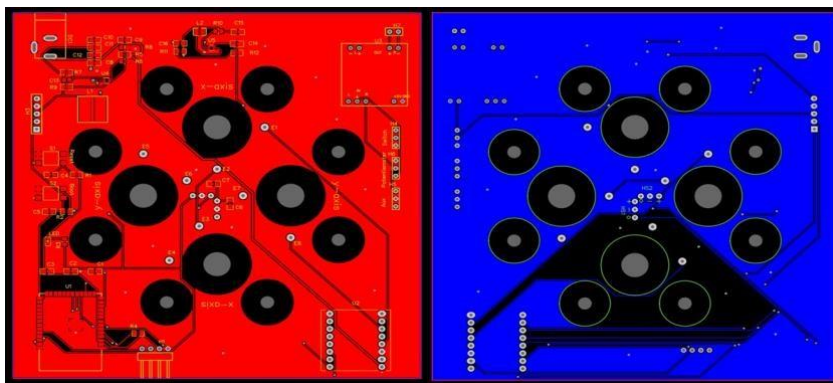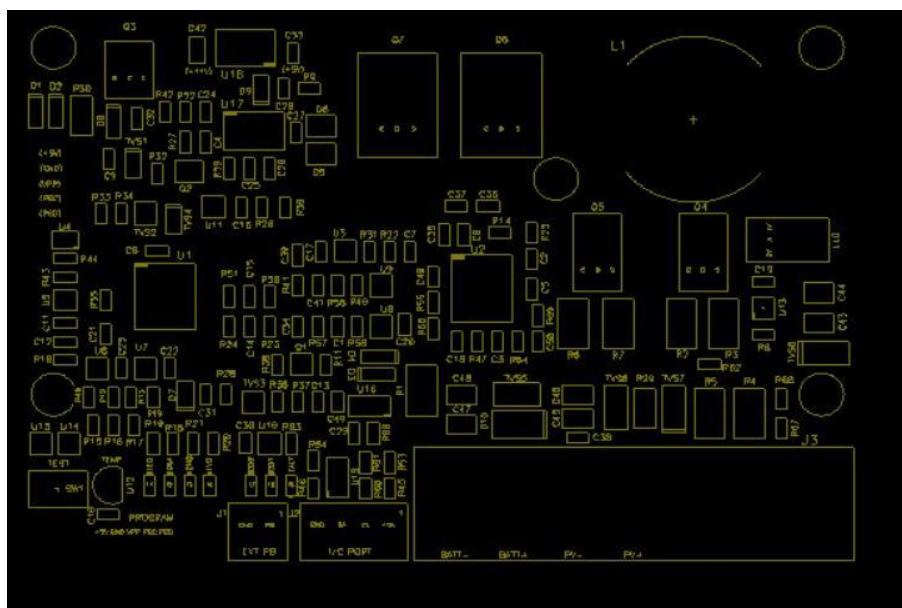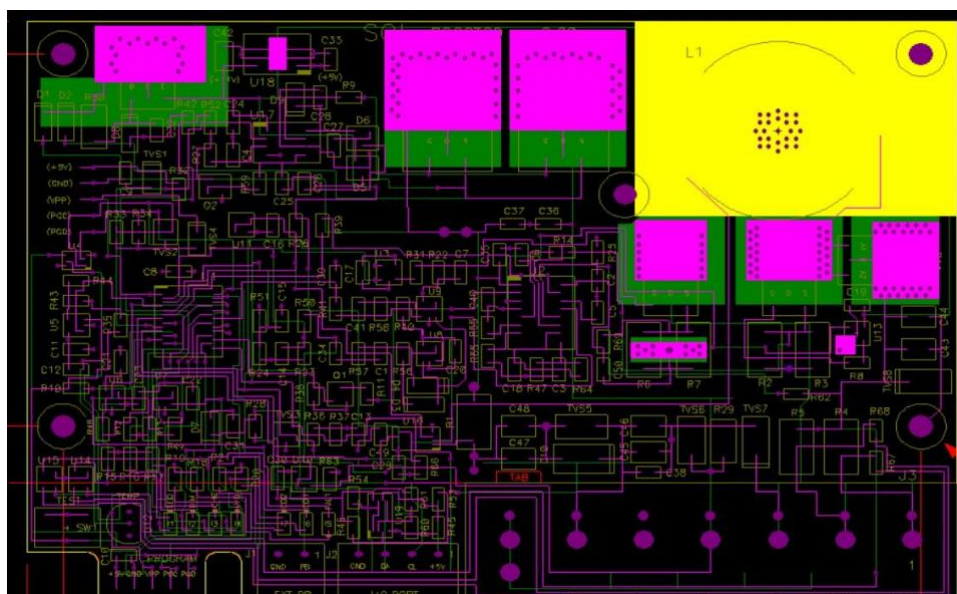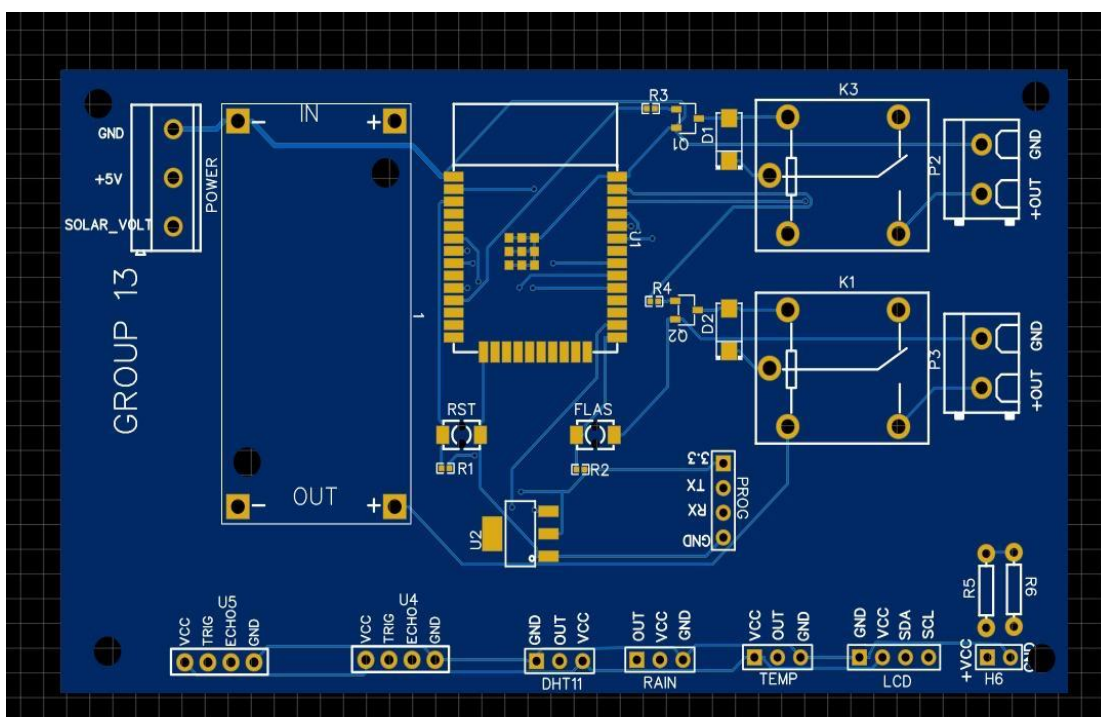

Figure PCB top and bottom layers

Water Filter design

The hardware design of a water filter involves integrating various components to effectively remove contaminants from water. Key elements include the filter housing, which holds the filtration media such as activated carbon or a membrane, and inlet and outlet ports for water flow. Additionally, the design may incorporate a pressure release valve to manage excess pressure within the filter housing, ensuring safe operation. Connectors made of durable materials like copper facilitate secure connections between the water source and the filter. Gaskets or seals made of rubber or silicon provide a watertight seal between the filter housing and connectors to prevent leaks. Depending on the filtration technology used, components such as ceramic filters, UV lamps, or ion exchange resin may also be incorporated into the design to target specific contaminants. Overall, an effective hardware design balances functionality, durability, and ease of use to deliver clean and safe drinking water.

Designing a water filtration system involves several key considerations to ensure efficient and effective removal of contaminants while maintaining safety and reliability. The first step is to assess the specific water quality issues and determine the appropriate filtration technology and treatment process. Common filtration methods include sediment filtration, activated carbon filtration, reverse osmosis, and UV disinfection, each targeting different types of contaminants.

The filtration system typically consists of multiple stages, each addressing different types of impurities. For example, sediment filtration removes large particles like dirt and sand, while activated carbon filtration adsorbs organic compounds, chlorine, and other chemicals. Reverse osmosis membranes are effective at removing dissolved salts, heavy

metals, and other contaminants, while UV disinfection kills bacteria, viruses, and other microorganisms.

In designing the system, factors such as flow rate, pressure drop, and maintenance requirements must be considered. The flow rate should be sufficient to meet the demand for clean water while ensuring thorough filtration, and the pressure drop across the system should be minimized to maintain adequate water pressure. Additionally, the system should be designed for easy maintenance, with accessible filter cartridges or membranes that can be replaced as needed.

The filtration system may also include pre-treatment and post-treatment components to optimize performance and extend the life of the filters or membranes. Pretreatment methods such as sedimentation, flocculation, or coagulation can help remove larger particles and reduce fouling of the filtration media. Post-treatment steps such as pH adjustment or remineralization may be necessary to improve water taste and quality after filtration.

Furthermore, considerations for system sizing, material selection, and cost effectiveness are essential. The system should be sized appropriately to handle the expected water flow and quality, and materials should be chosen for durability and compatibility with the water and treatment chemicals. Cost-effectiveness can be achieved through careful selection of components, optimizing energy usage, and implementing efficient maintenance practices.

Overall, a well-designed water filtration system integrates multiple technologies and treatment processes to effectively remove contaminants and provide clean, safe drinking water. It balances performance, reliability, and cost to meet the specific needs of the application while ensuring long-term sustainability and environmental responsibility.
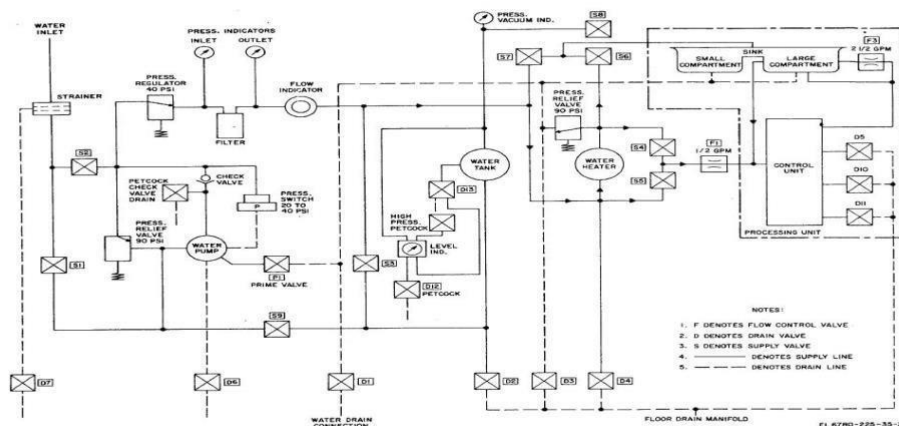

Figure Water Filter Schematic

A water filter schematic acts as a blueprint, revealing the intricate dance of components that transform cloudy, potentially unsafe water into clean, drinkable liquid. At its core, most water filter schematics depict a series of stages, each playing a crucial role in the purification process.

The journey often begins with a **pre-filter**, typically a mesh or fabric barrier. This initial stage captures larger particles like sediment, rust, and debris, protecting the subsequent filtration stages. The pre-filter is often the first line of defense and can be easily cleaned or replaced to maintain optimal performance.

Next, the water may encounter a stage dedicated to **chemical reduction**. This might involve an activated carbon filter, which absorbs chlorine, taste and odor causing compounds, and even some organic contaminants. Alternatively, ion exchange units can be employed to remove specific dissolved minerals like calcium and magnesium, often associated with hard water.

The heart of many filtration systems lies in the **membrane filtration** stage. Here, a semipermeable membrane acts as a microscopic barrier, allowing only purified water molecules to pass through while rejecting larger contaminants like bacteria, viruses, and heavy metals. Depending on the desired level of filtration, different membrane types like reverse osmosis or ultrafiltration membranes might be utilized.

Finally, a **post-filter** may be included as a final polishing step. This can further improve taste and odor or remove any residual particles left behind from previous stages.

The specific components and their arrangement within a water filter schematic will vary depending on the source water quality, desired level of filtration, and the overall system design. Nevertheless, understanding this basic framework provides valuable insight into the fascinating world of water purification technology.

7.0 Software Design

What is software design for a product? Software Design for a product is the process of creating a strong, flexible, and easy-to-operate software solution that satisfies the needs of users and their stakeholders. Some of the most common software design components include A comprehensive definition of the overall architecture and components of a software system. High-level architecture patterns, modules, and layers Selecting suitable architectural styles (such as client-server architecture, microservices architecture, etc.) based on performance, scalability, and maintenance requirements Data Storage Solutions (Database, Data Model, Data Access Layer, etc.) to meet the needs of the application's data.

7.1 Application Flow Chart

The application flow is made for users to be able to view information on their Water Saver system. A user can register or sign up with their Water Saver system device identifier, and then sign-in regularly once email is confirmed. If a user inputs the incorrect username or password then the application will let the user know their account information is invalid and to try again. Otherwise, the credentials are valid and the user will land on the Dashboard page which shares information about the customer's device and reporting. Customers often need analytics and reporting features in software for several reasons:

1.   Data-Driven Decision Making: Analytics and reporting provide valuable insights into various aspects of a business or process. By analyzing data, customers can make informed decisions to optimize their operations, improve efficiency, and identify areas for growth.

2.   Performance Monitoring: Customers need to track the performance of their systems, processes, or products. Analytics and reporting tools allow them to monitor key performance indicators (KPIs), such as sales trends, website traffic, user engagement, and customer satisfaction, in real-time or over specific time periods.

3.   Identifying Trends and Patterns: Analytics help customers identify trends, patterns, and anomalies in their data that may not be immediately apparent. By recognizing these patterns, customers can anticipate market changes, detect emerging opportunities, and mitigate risks.

4.   Measuring ROI: Customers invest time, money, and resources into software solutions, and they need to assess the return on investment (ROI). Analytics and reporting enable them to measure the impact of their investments by tracking metrics like revenue generated, cost savings, and efficiency gains.

5.   Compliance and Regulation: Many industries are subject to regulatory requirements regarding data collection, storage, and reporting. Analytics and reporting

tools help customers ensure compliance with these regulations by providing accurate and auditable reports.

6.   Customer Insights: Understanding customer behavior and preferences is crucial for businesses to tailor their products and services effectively. Analytics tools provide insights into customer demographics, purchasing patterns, and feedback, helping businesses improve customer satisfaction and loyalty.

7.   Forecasting and Planning: By analyzing historical data and trends, customers can create forecasts and develop strategic plans for the future. Analytics and reporting tools assist in predicting future demand, resource allocation, and market trends, enabling businesses to stay competitive.

Overall, analytics and reporting capabilities empower customers to harness the full potential of their data, drive informed decision-making, and achieve their business objectives more effectively.
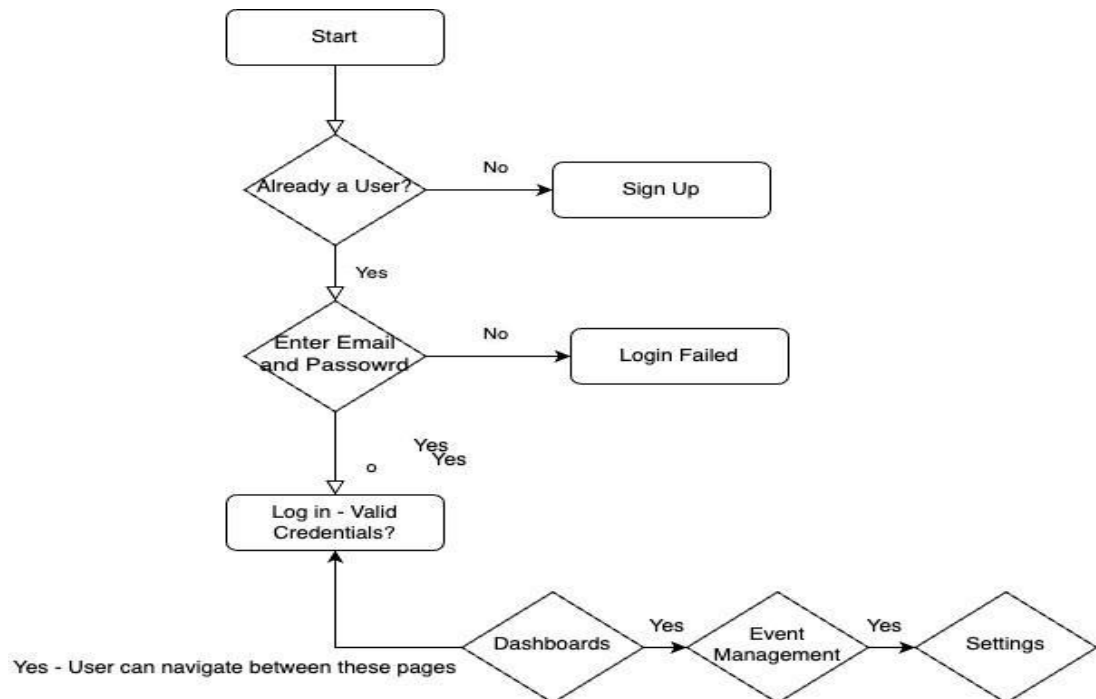

Figure 7.1 Flow Chart of Application Pages and Flow

7.2 Architecture Flow Chart

The architectural foundation of our project will be established on the robust and flexible infrastructure provided by AWS (Amazon Web Services), a decision that underscores our commitment to reliability, scalability, and security. Within this AWS ecosystem, several key services will form the pillars of our system's architecture, ensuring that every component operates seamlessly and efficiently.

At the core of our backend services, we did utilize EC2 (Elastic Compute Cloud), which will host all Docker services. This choice reflects our prioritization of scalable computing capacity, allowing us to adjust resources as needed to meet demand. Alongside EC2, our data management needs will be addressed by RDS (Relational Database Service), which will serve as our primary database, facilitating efficient and reliable data storage and retrieval processes.

To bolster the security and reliability of our system, we did integrate AWS Certificate Manager, Route 53, and CloudFront. This trio of services will manage SSL domains, ensuring that all connections to our system are secure and encrypted, thus safeguarding data integrity and user privacy. Furthermore, for the hosting of our React application's distribution build, we did leverage the AWS S3 (Simple Storage Service) Bucket, renowned for its durability and data availability.

Source code management is a critical component of our collaborative workflow, and for this purpose, we did employ GitHub SCM. This platform will enable our development team to collaboratively push code and deploy changes efficiently, fostering a dynamic and productive development environment. The deployment of the backend of our application will see the use of various images and packages, including an Ubuntu 22.04 EC2 Instance equipped with Docker NGINX, and Python 3.11 for our Flask API, among other essential tools and libraries.

For the front, our React UI will incorporate standard libraries such as Axios for HTTPS requests, Material UI and Styled Components for thematic consistency, React Router for navigation, Context API for state management, Nivo Charts for data visualization, and Font Awesome Icons to enhance user experience. Each chosen library and service reflects our meticulous approach to creating a system that is not only functional but also intuitive and secure for the end-user.

SSL certificate is a digital document that encrypts the data that is sent between a user's web browser and the web server. This ensures a secure connection over the internet. Water Saver will have an SSL web domain that uses Lets Encrypt, TLS 1.2, and Cloudfront. The intended domain used to access the website will be https://watersaver.app – the team will consider purchasing through namecheap.com and route to aws to build certificates.

Domain protection, Whois Information System (WHOIS) and ICANN are essential for managing online presence and protecting digital assets. Domain protection is the process of protecting and managing a domain name from unauthorized use, modification or transfer. It includes various strategies to protect domain ownership and prevent domains from being hijacked, cyber squatting or other malicious activity. Some of the key aspects of domain protection are: Registrar lock: Enables registrar lock to prevent unauthorized domain transfers Privacy protection: Hides personal information from publicly available WHOIS databases to avoid spam, identity theft or targeted attacks Renewal monitoring: Ensuring timely domain renewal to avoid domain expiration and loss of ownership DNS security: Using secure DNS protocols, such as DNSSEC, to protect DNS from spoofing

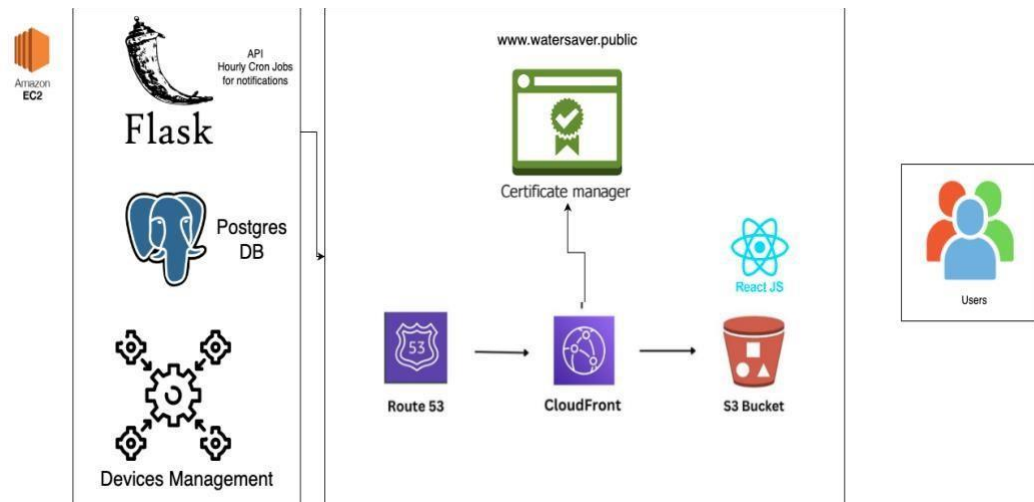or tampering SSL certificates: Encryption of data between servers and browsers to increase security and trust

Figure 7.2 AWS Flow Chart of services to use to let customers view data

7.3 Application Model Class Diagrams

Postgres database will be used for the architecture of the application. The following tables and schema will be built. SQLAlchemy will use it to build the constraints and validation for the API. The database will include primary, foreign, and other constraints required per query performance needs, etc. Indexes and unique values may be utilized in the model design. ORM Relationships will be utilized to allow users to have many notifications and products. Products will have many devices, in which device activity can be used to reference back to users' devices and products. Notification class models can then be used to interface with SES to send out notifications to user email addresses based on correlation and alert systems.

Entity-relationship diagrams (ERDs) are used for two main purposes: database design and database normalization. Database design uses ERDs to represent entities, attributes, and relationships between them in a database. Database normalization is the process of identifying and removing data anomalies in a database to improve its efficiency and integrity. Data modeling uses ERDs to visualize the relationships between various entities in a domain of interest, which helps to define key entities and attributes that form the basis for database schema design. Database normalization helps to optimize database performance and minimize redundancy. Documentation: ERDs provide a clear view of the structure and constraints of a database schema, which is invaluable to developers and database administrators. Class diagrams are mainly used in Object-Oriented Design to represent the structure and behaviors of software systems. ERDs, on the other hand, are used for Database Design, which focuses on the logic structure and relationships among entities in a database schema. These two diagrams play an important role in the development life cycle.
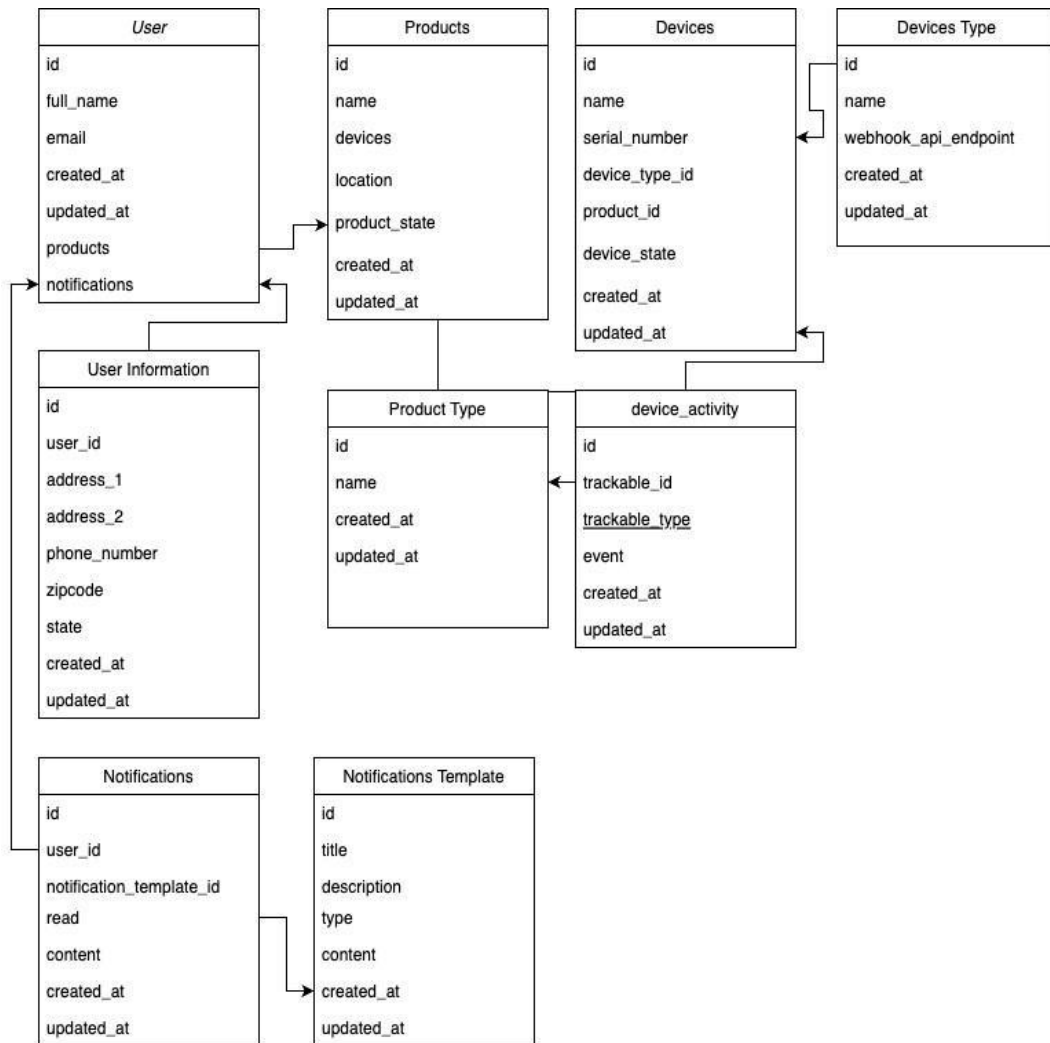
Figure 7.3 ERD - Class diagram models of Water Saver backend database

7.4 Microcontroller and Device Event Webhooks

The microcontroller will be a Raspberry PI that can communicate via network to send and receive webhook callbacks through the interval threshold that is configured per the Water Saver System. The microcontroller is connected to sensor devices in this project and the device will utilize a crontab that will start and if it recognizes a detection level where it should trigger an event then it should create an event payload to send to the event webhook from the Flask API. If it becomes unsuccessful after creating the payload it should try to retry the sending process and then create a specific device error payload to send to get to an exit state machine.
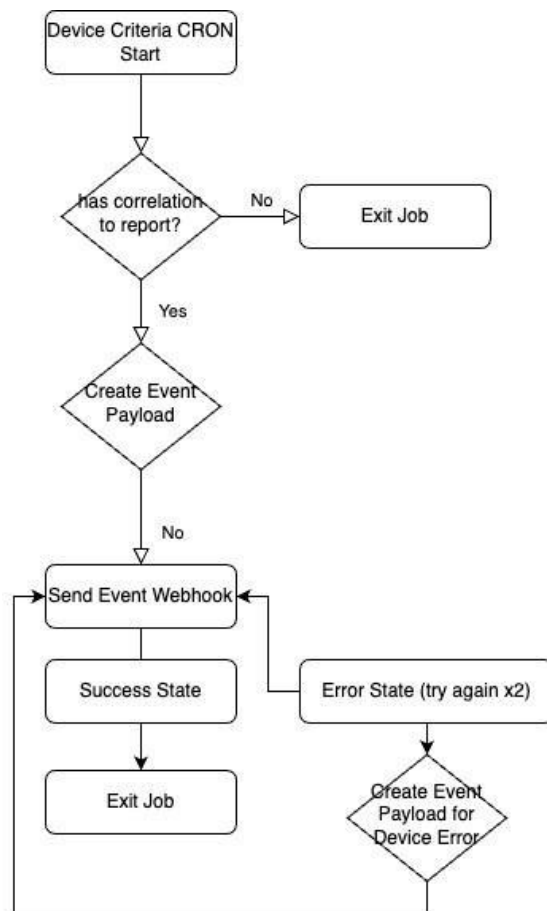
Figure 7.4 Webhook event flow with embedded sensor logic

7.5 User Interface Concept

User interface (UI) information refers to the visual and interactive elements presented to users within a software application, website, or digital product (React JS). UI information plays a critical role in guiding users, communicating functionality, and facilitating interaction.

Below is the initial idea of the user interface of Water Saver. The figure below shows the first view of the dashboard for product tracking for users. Dashboard View to include ideas for metrics, filters, and event logs such as Metrics - Battery level, Water level, and Temperature. Water Storage - Calculates the amount of water stored annually, ROI. Filters - Date time, By devices. Event log - Logs of sent events from devices.

 User interface (UI) information refers to the visual and interactive elements presented to users within a software application, website, or digital product. In the context of React JS, UI information is crafted using components that render dynamic and responsive interfaces.
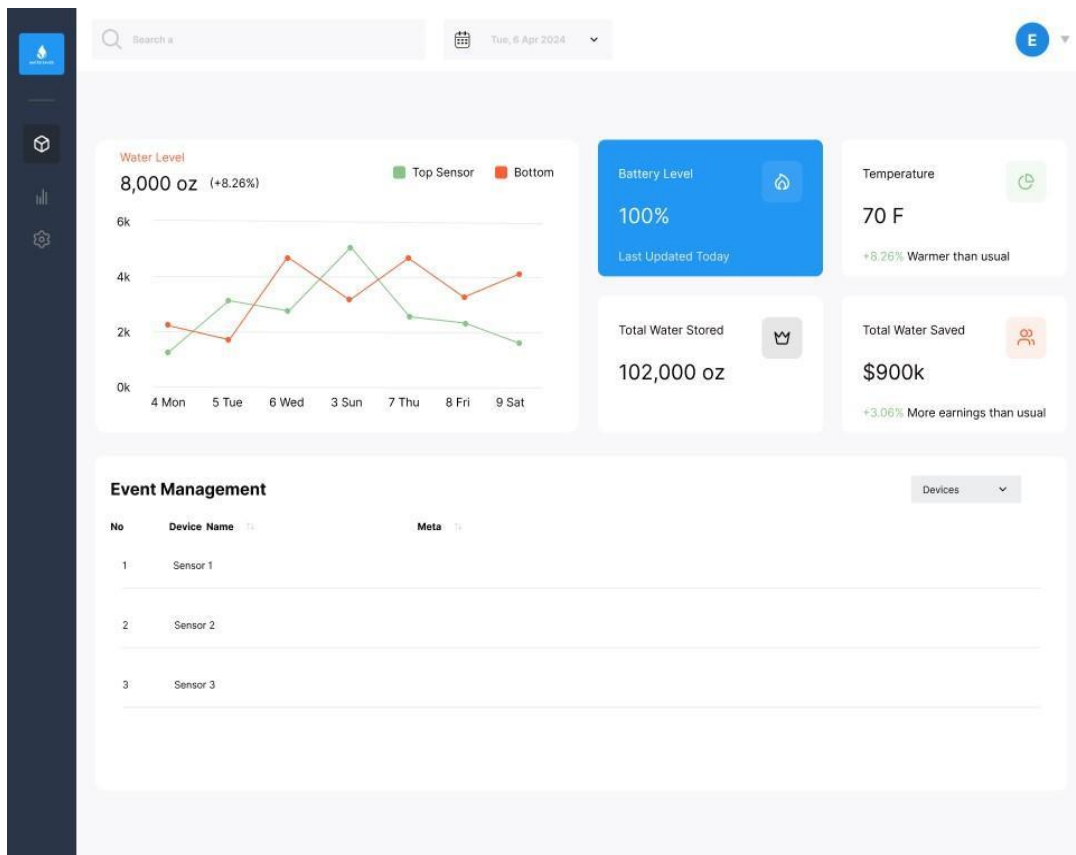
Figure 7.5 Application reporting view for user concept

8.0 System Fabrication/Prototype Construction

Hardware is very important in Our project since it includes a lot of hardware that will need to be installed. Our project hardware will include all the following: solar panel, water level sensor, rainwater sensor detector, battery, voltage controller, water pump, water filter, tube, and two water tanks. Our hardware design centers on an integrated rainwater harvesting system comprised of several key components: a network of durable yet

lightweight rainwater collection units equipped with high efficiency filtration systems to ensure the purity of captured

Construction, delves into the intricate process of bringing theoretical designs to life through the creation of functional prototypes. It outlines the systematic approach undertaken to finalize the design, source and select components, and meticulously assemble the prototype while integrating electronic and mechanical elements. The chapter emphasizes the importance of rigorous testing and debugging to ensure optimal performance and functionality, along with addressing challenges through innovative solutions. Furthermore, it highlights the iterative nature of prototype development, with an emphasis on continuous learning and improvement. The chapter concludes by discussing valuable lessons learned and outlining future enhancements based on feedback and test results, paving the way for further innovation and refinement in subsequent phases of development.

8.1 Introduction to Prototype Development

The development of a prototype serves as a critical step in transitioning from theoretical designs to practical applications, allowing for the validation of both design choices and functionality. This prototype's creation is guided by specific objectives aimed at demonstrating the feasibility and operational viability of the project. The process is inherently iterative, enabling the team to refine and enhance the prototype based on continuous learning and feedback, thereby ensuring that each iteration brings us closer to an optimized and functional design.

The development of a prototype marks a significant milestone in the project lifecycle, providing tangible evidence of the project's potential and functionality. Through the creation of a prototype, the team can validate design decisions, test key functionalities, and identify any potential challenges or areas for improvement. This iterative process involves building, testing, and refining the prototype based on feedback and insights gained from each iteration.

The prototype development process begins with defining specific objectives and requirements that the prototype should meet. These objectives serve as a roadmap for the team, guiding their efforts towards achieving a functional and reliable prototype. As the prototype takes shape, the team continuously evaluates its performance against these objectives, making adjustments and refinements as needed.

Moreover, the prototype serves as a crucial tool for communication and collaboration within the team and with stakeholders. It provides a concrete representation of the project's vision, allowing team members to align their efforts and stakeholders to provide feedback and input. This collaborative approach fosters a shared understanding of the project goals and ensures that the final product meets the needs and expectations of all stakeholders.

Throughout the prototype development process, emphasis is placed on flexibility and adaptability. The team remains open to making changes and adjustments based on new insights, emerging technologies, or shifting requirements. This agility allows the team to respond effectively to challenges and opportunities as they arise, ensuring that the prototype evolves into a robust and effective solution.

In essence, the development of a prototype is a dynamic and iterative process that bridges the gap between concept and reality. It enables the team to validate their ideas, test their assumptions, and ultimately deliver a solution that meets the needs of users and stakeholders. By embracing this process, the team can navigate the complexities of product development with confidence and ultimately achieve success.

8.2 Design Finalization

Finalizing the design before moving to construction involves a meticulous selection of materials and components, ensuring they align with the project's objectives and operational requirements. This stage often leverages simulation and modeling tools to anticipate system behavior under various conditions, allowing for design adjustments that enhance performance and reliability. The rationale behind each choice is carefully considered, balancing factors such as durability, cost, and system compatibility.

8.3 Component Sourcing and Selection

Sourcing components for the prototype poses its own set of challenges, from ensuring the availability of parts to evaluating their cost and compatibility with the system. The selection process is critical, as it directly impacts the prototype's performance and feasibility. Navigating supply chain complexities and identifying reliable suppliers are essential steps in securing components that meet our stringent quality and performance criteria.

To mitigate these challenges, we leverage a multi-pronged approach. First, we prioritize sourcing readily available parts with established lead times to minimize project delays

8.4 Assembly Process

The assembly of the prototype is a step-by-step process, meticulously planned and executed to bring the design to life. This phase may include the development of custom tools or techniques to address specific assembly challenges. Visual aids such as diagrams or photos play a vital role in illustrating key stages, ensuring clarity and precision in the assembly process and facilitating smooth progression from one stage to the next.

8.5 Integration of Electronic and Mechanical Components

Integrating electronic and mechanical components is a nuanced task, requiring careful planning to ensure seamless operation. Challenges often arise in aligning the

functionalities of sensors, microcontrollers, and mechanical elements like pumps and tanks. Solutions are crafted through innovative engineering, ensuring that electronic controls effectively manage mechanical operations, resulting in a cohesive and efficient system.

Integrating electronic and mechanical components is a complex process that involves merging different technologies to create a cohesive and efficient system. One of the main challenges is aligning the functionalities of sensors, microcontrollers, and mechanical elements such as pumps and tanks to work together seamlessly.

For example, in a water management system, sensors may be used to measure water levels, while microcontrollers process this data and control the operation of pumps to maintain desired water levels in tanks. Ensuring that these components communicate effectively and respond appropriately to changes in the environment requires careful planning and coordination.

One solution to this challenge is innovative engineering, where engineers develop creative solutions to integrate electronic and mechanical components. This may involve designing custom interfaces or protocols to facilitate communication between different components, as well as implementing sophisticated control algorithms to manage complex operations.

Additionally, thorough testing and validation are essential to ensure that the integrated system functions as intended. This may involve simulating real-world conditions to evaluate the performance of the system under different scenarios and making adjustments as needed.

Ultimately, the goal of integrating electronic and mechanical components is to create a system that operates seamlessly, efficiently, and reliably. By addressing challenges through innovative engineering and thorough testing, engineers can develop systems that meet the needs of their intended applications while maximizing performance and functionality.

Selection\Feature	WiFi Connectivity	Overall Advantages	Reason for Choosing
Raspberry Pi	Does not connect to WiFi	Versatility, community support	Initial choice
NANO ESP32	Integrated WiFi	Lower power, integrated connectivity, smaller size, lower cost, faster boot	Easier setup and usage

SD2 microcontroler comparison table

8.6 Software Integration and Testing

Embedding software into the prototype is a critical phase, where code is carefully integrated with hardware components. The software testing phase is rigorous, aimed at identifying and rectifying any bugs or inconsistencies. This process ensures that the software effectively communicates with hardware, enabling the desired functionalities and enhancing the prototype's overall performance.

Embedding software into the prototype is a crucial step in the development process, as it involves integrating code with hardware components to enable the desired functionalities. During this phase, the software is carefully written and configured to interact seamlessly with the hardware, ensuring that the prototype operates as intended.

The software testing phase is rigorous and systematic, aiming to identify and rectify any bugs, errors, or inconsistencies in the code. Various testing techniques, such as unit testing, integration testing, and system testing, are employed to verify the correctness and reliability of the software. This process helps ensure that the software functions correctly under different conditions and scenarios, minimizing the risk of malfunctions or unexpected behavior during operation.

In addition to functionality testing, software integration also involves optimizing code efficiency and resource utilization. This includes optimizing algorithms, reducing memory usage, and minimizing processing time to enhance the overall performance of the prototype.

Throughout the software integration phase, collaboration between software engineers and hardware specialists is essential to ensure that the software interacts effectively with the underlying hardware components. Any issues or compatibility issues that arise during

testing are addressed promptly to ensure smooth integration and operation of the prototype.

Ultimately, successful software integration plays a critical role in the overall success of the prototype, enabling it to deliver the intended functionalities reliably and efficiently. By conducting thorough testing and optimization, engineers can ensure that the embedded software meets the project's requirements and contributes to the prototype's overall performance and functionality.

8.7 Initial Testing and Debugging

Initial testing of the assembled prototype is conducted to assess its performance and identify any issues. The debugging process is crucial, involving detailed diagnostics to pinpoint problems and implement solutions. This phase is instrumental in ensuring the prototype operates as intended, with all components functioning in harmony.

During the initial testing phase, the assembled prototype undergoes comprehensive evaluation to assess its performance and functionality. This testing serves as a critical checkpoint to verify that the prototype meets the project requirements and objectives.

The testing process involves subjecting the prototype to various operating conditions and scenarios to simulate real-world usage. This includes testing different functionalities, inputs, and outputs to ensure that all components are working as expected. For example, in a water pump system, tests may involve checking the pump's flow rate, the accuracy of water level sensors, and the responsiveness of the control system.

As the prototype is tested, any issues or discrepancies are identified through detailed diagnostics. This may involve analyzing sensor readings, inspecting circuit connections, or reviewing software logs to pinpoint the root cause of the problem.

Once issues are identified, the debugging process begins. This involves systematically troubleshooting the prototype to address any issues and implement solutions. Solutions may range from adjusting software parameters, recalibrating sensors, or replacing faulty components.

The debugging phase is instrumental in ensuring that the prototype operates as intended, with all components functioning in harmony. It requires patience, attention to detail, and technical expertise to diagnose and resolve issues effectively.

Throughout the testing and debugging process, documentation is essential to track the identified issues, their corresponding solutions, and any modifications made to the prototype. This documentation serves as a reference for future iterations and provides valuable insights for further improvements.

Overall, initial testing and debugging are crucial steps in the prototype development process, allowing engineers to validate the design, identify and address any issues, and ensure that the prototype meets the desired performance and functionality requirements.

8.8 Performance Optimization

Optimizing the prototype's performance involves fine-tuning both hardware and software elements based on test results. This could mean adjusting the software algorithms or making hardware modifications to enhance efficiency, reliability, and user experience. The goal is to achieve optimal performance that meets or exceeds project specifications.

After the initial testing phase, optimizing the prototype's performance becomes a key focus to ensure it meets or exceeds project specifications. This involves fine-tuning both hardware and software elements based on test results and user feedback.

In terms of hardware optimization, engineers may need to make modifications to improve the efficiency and reliability of the system. This could include adjusting component placement, upgrading certain parts for better performance, or refining mechanical elements to reduce friction or improve functionality.

Software optimization plays a crucial role in enhancing the prototype's performance as well. This may involve refining algorithms to improve accuracy, speed, or responsiveness. For example, in a water pump system, optimizing the control algorithm could lead to more precise water level management or more efficient energy usage.

During the optimization process, engineers continuously iterate on the design, making incremental improvements and testing each iteration to evaluate its impact on performance. This iterative approach allows for gradual refinement of the prototype, ensuring that each modification brings it closer to the desired level of performance.

Additionally, optimization efforts may also focus on improving the user experience by making the system more intuitive, user-friendly, and reliable. This could involve refining user interfaces, streamlining operation procedures, or implementing error handling mechanisms to prevent unexpected failures.

Throughout the optimization process, careful attention is paid to ensure that any changes made do not introduce new issues or compromise other aspects of the prototype's performance. Rigorous testing and validation are conducted at each stage to verify that optimizations effectively address identified issues and improve overall performance.

Ultimately, the goal of optimization is to achieve optimal performance that aligns with project specifications while maximizing efficiency, reliability, and user satisfaction. By continuously refining both hardware and software elements, engineers can ensure that the prototype meets or exceeds expectations and is ready for further development and deployment.

8.9 Challenges and Solutions

Throughout the fabrication and construction phase, several challenges may arise, demanding innovative solutions. These obstacles can range from technical difficulties with component integration to unexpected issues in system behavior. Addressing these challenges head-on, with creativity and engineering acumen, is crucial for the successful completion of the prototype.

During the fabrication and construction phase, engineers may encounter various challenges that require innovative solutions to overcome. One common challenge is technical difficulties with component integration, where different parts of the prototype may not fit together as expected or may not function properly when combined. This could be due to differences in specifications, compatibility issues, or unforeseen complexities in the design.

To address integration challenges, engineers may need to devise creative solutions such as redesigning components, modifying existing parts, or developing custom adapters or connectors to ensure seamless integration. This may involve iterative testing and adjustment to ensure that all components work together harmoniously.

Another challenge that can arise during fabrication and construction is unexpected issues in system behavior. This could include unexpected fluctuations in performance, malfunctions, or failures that were not anticipated during the design phase. These issues may stem from factors such as environmental conditions, material properties, or interactions between different system components.

To tackle such challenges, engineers must conduct thorough troubleshooting and diagnostic testing to identify the root causes of the problems. This may involve using specialized tools and techniques to analyze system behavior, isolate faulty components, and determine the most effective solutions.
In some cases, addressing unexpected issues may require redesigning certain aspects of the prototype or implementing additional safety measures to prevent future occurrences. Engineers may also need to consult with experts in relevant fields or seek advice from colleagues to find innovative solutions to complex problems.

Overall, overcoming challenges during the fabrication and construction phase requires a combination of technical expertise, problem-solving skills, and creativity. By approaching obstacles with determination and ingenuity, engineers can ensure the successful completion of the prototype and lay the foundation for further development and refinement.

8.10 Lessons Learned

Reflecting on the fabrication process offers valuable insights and lessons learned, which are instrumental for future projects or further iterations of the current prototype. This reflection encompasses both the successes and hurdles encountered, providing a roadmap for improvement and innovation in subsequent endeavors.

Reflecting on the fabrication process provides engineers with valuable insights into what went well and what could be improved in future projects or iterations of the current prototype. This reflection involves evaluating both the successes and the hurdles encountered during fabrication, as well as the strategies employed to address challenges and achieve goals.

One aspect of the reflection process is identifying the successes achieved during fabrication. This may include milestones reached, such as completing the assembly of the prototype within the allocated time frame, overcoming technical challenges, or achieving desired performance metrics. Recognizing these successes helps build confidence and motivation among team members and highlights areas where the project excelled.

Additionally, reflecting on the hurdles encountered during fabrication allows engineers to pinpoint areas for improvement and innovation. These hurdles may have included technical difficulties, supply chain issues, unexpected failures, or communication challenges within the team. By acknowledging these challenges and understanding their root causes, engineers can develop strategies to mitigate similar issues in future projects.

Furthermore, the reflection process involves evaluating the effectiveness of the strategies employed to address challenges during fabrication. This includes assessing the success of problem-solving approaches, communication methods within the team, and the utilization of available resources. Identifying which strategies were most effective and which could be improved helps refine project management processes and enhance overall project execution in the future.

Overall, reflecting on the fabrication process provides a roadmap for improvement and innovation in subsequent endeavors. By learning from both successes and challenges, engineers can optimize their approach to future projects, leading to more efficient processes, higher-quality outcomes, and continued growth and development within the team.
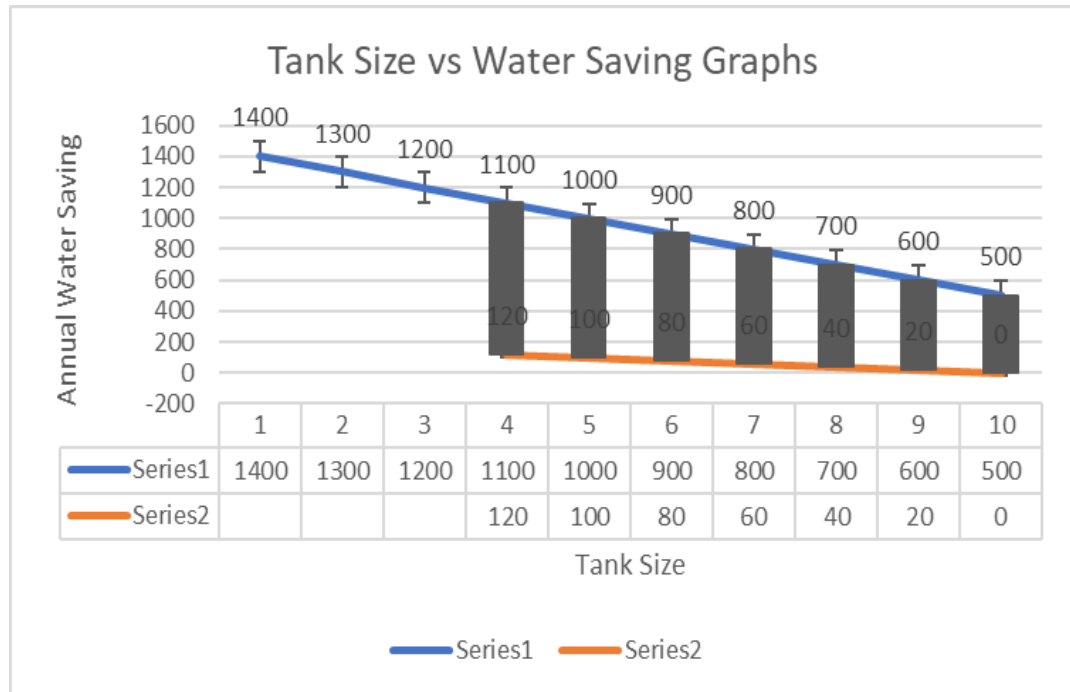
8.11 Future Enhancements

Concluding the chapter, future enhancements and modifications to the prototype are discussed, guided by feedback and test results. This forward-looking perspective outlines potential improvements in design, functionality, and user experience, setting the stage for the next phase of development and innovation.

Furthermore, future modifications may focus on expanding the functionality of the prototype to address additional use cases or requirements. This could involve integrating new sensors, adding communication capabilities, or enhancing automation features to provide users with more comprehensive and versatile functionality. By continually updating and expanding the prototype's capabilities, engineers can ensure its relevance and effectiveness in a dynamic and evolving environment.

Additionally, user experience enhancements may be prioritized to improve ease of use, accessibility, and overall satisfaction with the prototype. This could involve refining user

interfaces, incorporating user feedback into design decisions, or implementing intuitive controls and interfaces. By prioritizing user experience, engineers can ensure that the prototype is user-friendly and accessible to a wide range of users.

Overall, the discussion of future enhancements and modifications sets the stage for the next phase of development and innovation. By continually refining and evolving the prototype based on feedback and test results, engineers can ensure that it remains at the forefront of technology and continues to meet the needs of its users in a rapidly changing landscape.

Tank Size vs Water Saving Graphs

	1	2	3	4	5	6	7	8	9	10
Series1	1400	1300	1200	1100	1000	900	800	700	600	500
Series2				120	100	80	60	40	20	0

Annual Water Saving — Tank Size

9.0 System Testing and Evaluation

Hardware is very important in Our project since it includes a lot of hardware that will need to be installed. Our project hardware will include all the following: solar panel, water level sensor, rainwater sensor detector, battery, voltage controller, water pump, water filter, tube, and two water tanks. Our hardware design centers on an integrated rainwater harvesting system comprised of several key components: a network of durable yet lightweight rainwater collection units equipped with high efficiency filtration systems to ensure the purity of captured

Construction, delves into the intricate process of bringing theoretical designs to life through the creation of functional prototypes. It outlines the systematic approach undertaken to finalize the design, source and select components, and meticulously assemble.

System testing and evaluation are critical phases in the development of hybrid power systems, particularly concerning voltage control. Rigorous testing protocols are employed to assess the system's performance under various operating conditions, ensuring its reliability, efficiency, and safety. This testing encompasses both laboratory-based simulations and real-world field tests, allowing engineers to validate the effectiveness of voltage regulation techniques, component integration, and overall system architecture. Data collected during testing are meticulously analyzed to identify any anomalies or performance deviations, guiding iterative improvements and optimizations. Moreover, user feedback and operational insights gleaned from field tests inform further refinements, ensuring that the system meets or exceeds performance expectations while addressing end-user needs and preferences. Through comprehensive testing and evaluation, hybrid power systems can achieve the necessary reliability and functionality to deliver sustainable and resilient energy solutions.

9.1 Voltage Controller

The voltage controller is crucial for our project, as we have two power sources: solar power from the sun and wall power. Additionally, We are harnessing energy and storing it in batteries. It is essential to control the voltage to ensure that the system receives the correct amount needed. If the voltage is too high, it may cause misfires or damage components and devices. Conversely, if the voltage is too low, some devices may not function properly. Therefore, we did also incorporate an inverter to switch between using solar power, wall electricity, or the other way around.
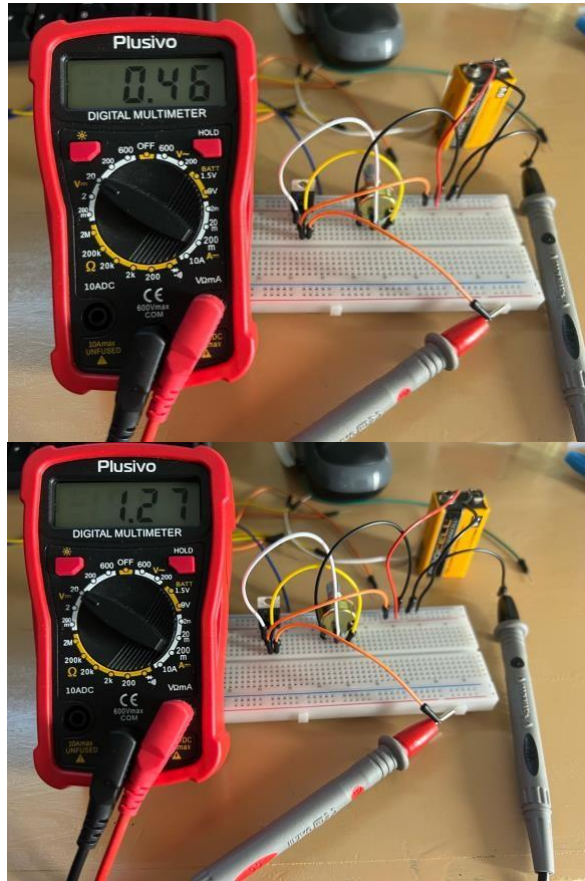
This image showcases the voltage controller integral to our dual-source power system, which harmonizes input from both solar panels and wall outlets. The controller's primary role is to regulate the voltage levels fed to the system, ensuring they are within safe operational thresholds to prevent any damage or malfunctions. It dynamically adjusts the input voltage, whether too high or too low, to maintain optimal conditions for the system's functionality. Additionally, the depicted inverter within the controller allows for seamless switching between the solar and wall power sources, enhancing our system's efficiency and reliability. This setup not only safeguards our equipment but also optimizes the use of available energy, ensuring a continuous and stable power supply to further enhance our project's operation and ensure detection. We have smart sensor monitors that monitor the water levels , which is essential for maintaining the optimum operating temperature of our power setup. By alerting us to any deviations from the ideal water level, the sensor plays a crucial role in preempting thermal fluctuations that could impact system performance. This proactive measure not only boosts the efficiency of our system but also significantly extends the lifespan of our components. we conduct a thorough evaluation of potential suppliers, assessing their quality control processes, reputation within the industry, and customer service history.

9.2 Rain water detector

Our system starts saving rainwater in two tanks once the rain sensor detects rain. It continues filling the tanks until they are full. When they are not in use, the system closes the valve and diverts the water elsewhere. Once the water level sensor detects that there is space for more water, the system checks if it's raining. If it is, it resumes collecting water. If it's not raining, the system remains inactive until it rains again.
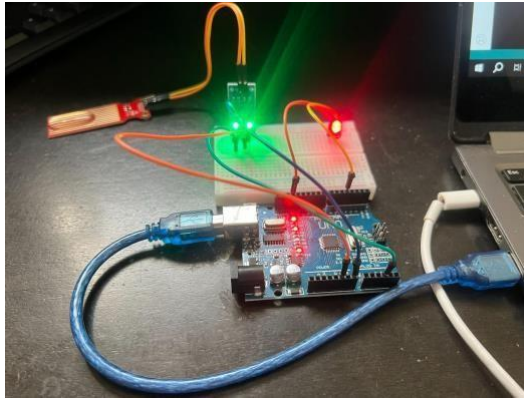

Figure 9.2 Rain water detector

9.3 Water level sensor

In our innovative WaterSaver system, the water level sensor plays a pivotal role in ensuring optimal water management. This sensor diligently monitors the levels in our storage tanks, preventing overflows and efficiently managing incoming rainwater. It intelligently decides whether to accept new water based on current tank capacity, particularly crucial during rainfall events. This feature is essential for maintaining system stability and efficiency, preventing both the wastage of precious rainwater and the risk of water damage from tank overflow. Through real-time level monitoring, our system ensures that every drop of collected rainwater is used judiciously, aligning with our goals of sustainability and effective resource management.

Figure 9.3 Water level sensor

The water level sensor in our system is designed to provide real-time, accurate measurements of the water levels within our storage tanks. Utilizing capacitive or ultrasonic sensing technologies, this sensor can detect even minute changes in the water

level, ensuring our system reacts promptly to prevent overflows or inefficiencies in water intake during rain events.

This sensor's data is crucial for automated control systems that manage the inflow and outflow of water, enabling precise control over the entire rainwater harvesting process. It interfaces seamlessly with a microcontroller that processes the sensor's data to make decisions about opening or closing valves, starting or stopping pumps, and activating overflow measures when necessary.

Moreover, the integration of the water level sensor enhances our system's intelligence. It allows for predictive analytics, where the system can forecast tank capacity needs based on historical data and weather predictions to optimize water usage and storage strategies. This smart management not only maximizes the utility of harvested rainwater but also contributes to the longevity and durability of the entire system by avoiding the physical stresses of overfilling.

By leveraging this technology, our project aims to provide a sustainable solution to water management challenges, particularly in areas where water scarcity is a significant concern. The sensor's role extends beyond mere measurement; it embodies the core of our system's ability to provide a reliable, efficient, and autonomous water management solution, ensuring that every drop of rainwater is captured, stored, and used effectively.

9.4 Design Considerations for Voltage Controller

When working on the design of a voltage controller for a hybrid power system that incorporates solar power, mains power, and battery storage, it is paramount to meticulously select components that align with the system's unique requirements. The selection criteria for these components hinge on several key factors. Firstly, compatibility with the varied power sources is crucial. The chosen components must adeptly manage the fluctuating voltage levels typical of solar energy, as well as the consistent voltage supplied by mains electricity. This ensures the system can seamlessly transition between these sources without disruption.

Scalability of components is another critical consideration. As energy needs evolve or as the project scales, the system should accommodate additional inputs—be it extra solar panels or expanded battery capacity—with minimal overhaul. This foresight in component selection mitigates future costs and complexities, paving the way for a more adaptable system.

Technical specifications of the components also demand careful attention. Optimal performance and safety are non-negotiable, necessitating components that not only meet but exceed industry standards. This includes specifications for maximum and minimum voltage thresholds, current handling capabilities, and thermal management features to prevent overheating. Ensuring these technical parameters match the system's operational demands is key to achieving a robust and reliable voltage control mechanism.

Integration of the voltage controllers with both solar and mains power sources is a complex but critical aspect of the system's design. This involves engineering a seamless interface where the voltage controller can intelligently switch between or combine these power sources based on availability, demand, and efficiency considerations. Achieving this level of integration requires a deep understanding of the electrical characteristics of each power source and the operational dynamics of the system as a whole. Through thoughtful design and strategic component selection, the voltage controller can become a cornerstone of the system's efficiency, reliability, and safety, ensuring it meets the project's goals and the end user's needs.

9.5 Voltage Regulation Techniques

When we talk about voltage regulation within hybrid power systems, selecting the appropriate technology is pivotal to optimizing performance and efficiency. This decision necessitates a thorough comparative analysis of the various voltage regulation technologies available, with a particular focus on two prevalent methods: Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT), especially in the context of solar power systems.

PWM controllers are a widely adopted choice for their simplicity and cost effectiveness. By adjusting the pulse width of the power supply to the load, PWM controllers can effectively manage the charge to the battery, extending its lifespan. However, the efficiency of PWM controllers can be lower compared to MPPT technologies, especially in varying weather conditions, as they do not always operate the solar panels at their maximum power point. Moreover, PWM controllers might not be as effective in environments where solar intensity frequently changes, leading to potential underutilization of the available solar energy.

On the other hand, MPPT controllers represent a more advanced technology designed to extract the maximum possible power from solar panels. By continuously adjusting the electrical operating point of the modules, MPPT controllers can ensure that the solar panels are operating at their optimum power point throughout the day. This ability to maximize energy extraction makes MPPT controllers particularly beneficial in regions with significant cloud cover or where the solar intensity varies widely throughout the day. However, the sophistication of MPPT technology comes at a higher cost, both in terms of initial investment and potential complexity in system integration. Additionally, the increased efficiency offered by MPPT controllers is most noticeable in larger systems, where the higher cost can be offset by the gains in energy production.

The choice between PWM and MPPT voltage regulation technologies involves a balance between cost, complexity, and efficiency. PWM controllers offer a reliable and economical solution for smaller systems or environments with stable solar conditions. In contrast, MPPT controllers, while more expensive, provide an efficiency advantage in larger systems or areas subject to variable weather patterns, making them a worthwhile investment for maximizing solar energy utilization. This analysis underscores the

importance of aligning the voltage regulation technique with specific system requirements and environmental conditions to achieve optimal system performance.

9.6 Role of Inverters in Voltage Control

When we had to look up hybrid power systems, inverters play a critical, multifaceted role in voltage control, primarily by converting direct current (DC) from solar panels or batteries into alternating current (AC) used by home appliances, industrial equipment, and for feeding into the grid. This conversion process is central not only to the functionality of such systems but also to their efficiency and reliability. Beyond mere conversion, inverters are tasked with managing voltage fluctuations, a common challenge in systems reliant on renewable energy sources. They achieve this through sophisticated algorithms that continuously monitor the DC input for any variations and adjust the AC output accordingly, ensuring a stable and consistent power supply even in the face of variable solar irradiance or load demands.

The selection of an appropriate inverter is a process underpinned by several key criteria, each vital to the system's overall performance. Efficiency stands out as a primary consideration; higher efficiency means that a greater portion of the generated DC power is successfully converted into usable AC power, with minimal losses. Capacity, or the inverter's ability to handle the power output from the solar panels or battery bank, is another crucial factor. An inverter must be adequately sized to manage the system's peak power demands without compromising performance or safety. Lastly, compatibility with existing system components ensures seamless integration, preventing potential operational issues and facilitating easier maintenance and potential future upgrades.

By carefully selecting inverters based on these criteria, systems can achieve not only optimal voltage control but also enhanced system longevity and reduced operational costs. The role of inverters thus extends beyond conversion, encompassing vital aspects of system stability, efficiency, and scalability, making them indispensable in modern hybrid power systems.

9.7 System Architecture and Voltage Control

The system architecture, especially in the context of hybrid power systems incorporating solar panels, batteries, and inverters, necessitates a sophisticated approach to voltage control to ensure stability, efficiency, and reliability. A crucial aspect of understanding this system's operation is through a diagrammatic representation that illustrates the power flow within the system. This visual depiction typically outlines how solar energy is captured, converted, stored, and ultimately used, highlighting the interconnections between the solar panels, battery storage, inverters, and the voltage controller.

The voltage controller, a pivotal component tasked with managing and regulating the voltage throughout the system. Its primary function is to maintain voltage levels within safe and optimal ranges, a critical requirement for protecting system components and

ensuring efficient operation. The voltage controller achieves this by interfacing dynamically with solar panels, batteries, and inverters, each of which plays a specific role in the power conversion and storage process.

Solar panels convert sunlight into DC power, which then flows to the voltage controller. The controller assesses this input for voltage levels and, depending on the system's current energy needs, decides whether to direct this power towards immediate consumption, to the batteries for storage, or through the inverter for conversion to AC power. In scenarios where the battery is the power source, the voltage controller similarly regulates the discharge to maintain stable system operation, ensuring that the inverter receives a consistent DC voltage for conversion to AC power.

The controller's ability to interface with these components is facilitated through a combination of hardware connections and software algorithms, enabling it to respond in real time to changes in power generation, consumption, and storage states. For instance, during periods of high solar output but low consumption, the controller might prioritize battery charging; conversely, during low solar output and high consumption, it might draw on battery reserves to supplement power needs.

To try to bring everything together, the system architecture designed for voltage control in hybrid power systems is a complex network where the voltage controller acts as the central hub, intelligently interfacing with solar panels, batteries, and inverters. This integrated approach ensures that power flow within the system is not just efficient and reliable, but also optimally managed to meet the varying demand conditions, thereby safeguarding component longevity and enhancing overall system performance.

9.8 Battery Management and Voltage Control

The integration of a Battery Management System (BMS) with voltage controllers emerges as a cornerstone for ensuring optimal voltage regulation and battery health. The BMS meticulously oversees the voltage across each battery cell, safeguarding against conditions that could compromise the battery's efficiency and lifespan. This vigilant monitoring is crucial for preventing overcharging and deep discharging, scenarios detrimental to battery health. By uniformly balancing the charge across the battery cells and maintaining operation within safe voltage thresholds, the BMS significantly contributes to the longevity and reliability of the battery pack.

Effective voltage control, facilitated by the BMS, incorporates several strategic measures designed to extend battery life. Among these, cell balancing stands out by ensuring equitable charge and discharge rates across all cells, thus averting potential imbalances that lead to premature battery degradation. Temperature-compensated charging is another vital strategy, adjusting charging parameters in response to fluctuations in battery temperature, thereby minimizing thermal stress. Furthermore, establishing precise charge and discharge cutoff voltages helps in maintaining the batteries within their safe operating limits, effectively reducing the risk of cell damage.

However, melding the functionalities of a BMS with voltage controllers presents a suite of technical challenges. Achieving seamless communication between the BMS and voltage controllers is imperative for real-time adaptation to changing load demands and power supply conditions. This necessitates sophisticated software algorithms and hardware interfaces that can dynamically adjust voltage outputs based on the BMS's feedback. Moreover, the variability in battery technologies and the specific requirements of different application scenarios complicate the integration process, requiring a tailored approach to system design and component selection. Overcoming these challenges is essential for developing a harmonized system that not only optimizes battery performance and system efficiency but also ensures the safety and durability of the power storage components.

9.9 Testing and Evaluation of Voltage Controller

The rigorous testing and evaluation phase for a voltage controller is critical, ensuring its functionality and reliability across a spectrum of operational scenarios. This phase adopts a comprehensive methodology designed to simulate a variety of load conditions, thereby assessing the controller's adaptability and performance. The approach meticulously orchestrates scenarios ranging from minimal to peak demand, incorporating sudden load shifts to evaluate the controller's responsiveness and stability. Continuous operation under maximum load conditions is scrutinized to gauge endurance, while efficiency at minimal demand is also tested, providing a holistic view of the controller's operational capacity. This testing regime extends to examining the controller's robustness against external variables such as fluctuating solar irradiance and mains voltage instability, ensuring its efficacy under all conceivable environmental conditions.

Incorporating real-world case studies into the evaluation process offers invaluable insights into the voltage controller's practical application. These studies meticulously document instances where the controller adeptly managed sudden shifts in power demand, highlighting successes and pinpointing areas ripe for improvement. By analyzing these real-life applications, one gains a nuanced understanding of the controller's performance, including its ability to maintain system stability and efficiency across diverse operational landscapes.

The evaluation of voltage controller efficiency and reliability hinges on defined metrics, providing a quantifiable measure of performance. These metrics encompass the controller's reaction time to load changes, its ability to maintain voltage within predefined safety margins, and its overall operational efficiency under varied environmental conditions. Reliability metrics also consider the controller's durability over time, including its resistance to wear under continuous use and its maintenance requirements. Together, these criteria form a robust framework for assessing the voltage controller's functionality, guiding ongoing improvements and ensuring the system's long-term viability and safety.

9.10 Safety Protocols and Voltage Control

The integration of safety protocols within voltage control systems is paramount, ensuring the protection of both the hardware components and the end users from potential electrical hazards. Voltage controllers, being at the heart of regulating power flow in renewable energy applications, are equipped with advanced safety features designed to preemptively address overvoltage and under-voltage conditions. These features typically include automatic shutdown mechanisms that activate when voltage levels exceed or drop below-set thresholds, thereby preventing damage to the system and connected devices. Additionally, real-time monitoring capabilities allow for the continuous assessment of voltage levels, with built-in alarms or notifications to alert operators to potential issues before they escalate into safety concerns.

Regulatory standards play a critical role in guiding the design and operation of voltage control systems in renewable energy setups. These standards, established by international safety organizations and local governing bodies, outline the minimum requirements for voltage stability, system reliability, and user safety. Compliance with these standards is non-negotiable, necessitating that voltage controllers undergo rigorous testing and certification processes to verify their adherence. These regulatory frameworks not only ensure that voltage controllers operate within safe electrical parameters but also promote uniformity and trust in renewable energy technologies.

The emphasis on safety protocols and regulatory compliance underscores the industry's commitment to delivering secure, reliable, and efficient voltage control solutions. By prioritizing safety in the design and implementation of voltage controllers, manufacturers and operators contribute to the sustainable growth of renewable energy applications, ensuring that these systems can be safely integrated into the broader electrical grid and utilized in various settings without compromising on safety or performance.

9.11 Future Directions in Voltage Control Technology

The understanding of the voltage control technology by the advent of emerging technologies and breakthroughs in material science and electronics. These innovations hold the promise of significantly enhancing the performance and efficiency of voltage controllers, especially within the domain of renewable energy systems. For instance, the introduction of advanced semiconductor materials like silicon carbide (SiC) and gallium nitride (GaN) is reshaping the efficiency and thermal performance of voltage control devices. These materials operate at higher temperatures, frequencies, and voltages than traditional silicon-based semiconductors, offering the potential for more compact, efficient, and faster switching voltage controllers.

Moreover, the integration of artificial intelligence and machine learning into voltage control systems is beginning to provide unprecedented adaptability and precision in real-time voltage regulation. These technologies enable voltage controllers to predict and respond to system fluctuations instantaneously, optimizing renewable energy output and enhancing grid stability. Additionally, innovations in nano-technology and flexible electronics are paving the way for new forms of voltage controllers that are more resilient,

efficient, and capable of self-repair, further pushing the boundaries of what is possible in voltage regulation.

As these emerging technologies continue to mature, their incorporation into renewable energy systems is expected to yield substantial improvements in terms of energy efficiency, system reliability, and operational lifespans. The ongoing research and development in this field not only underscore the dynamic nature of voltage control technology but also highlights its critical role in advancing the global adoption and integration of renewable energy sources.

9.12 Conclusion

In concluding our comprehensive examination and evaluation of the voltage controller within a hybrid power system, several key findings have emerged. Through rigorous testing under a variety of load conditions, the voltage controller has demonstrated a commendable ability to maintain stability and efficiency, adeptly managing fluctuations and ensuring consistent power supply. The integration of safety protocols has further underscored the system's reliability, effectively safeguarding against overvoltage and undervoltage scenarios.

The case studies and real-world applications of the voltage controller have provided valuable insights into its operational strengths and areas ripe for improvement. The advanced features designed to interface with solar panels, batteries, and inverters have shown promising results in optimizing power flow and enhancing system performance. However, the challenges encountered in integrating battery management systems and adapting to emerging technologies suggest avenues for further refinement.

Based on these observations, several recommendations can be made for system optimization and future research. Firstly, continued innovation in semiconductor materials and electronics could yield voltage controllers that are even more efficient, compact, and capable of operating at higher frequencies. Exploring the integration of artificial intelligence and machine learning offers the potential for more dynamic and predictive voltage regulation, adapting in real-time to changing environmental conditions and load demands.

Also, expanding research into nano-technology and flexible electronics may introduce novel voltage control solutions that are more durable, adaptable, and self healing, pushing the boundaries of current capabilities. It's also recommended to foster closer collaboration between researchers, manufacturers, and regulatory bodies to ensure that advancements in voltage control technology align with safety standards and industry needs.

The journey of the voltage control technology is ongoing, with the horizon brimming with opportunities for innovation. By heeding the lessons learned and embracing the potential of new technologies, the future of voltage control in renewable energy systems appears both bright and boundless, promising greater efficiency, reliability, and sustainability in our pursuit of cleaner, more resilient power solutions.

Overall Schematic

The overall schematic provides a comprehensive visual representation of the entire system, illustrating how each component interacts and connects with one another. It serves as a blueprint for the project, guiding the implementation and assembly process. With detailed annotations and labeling, the schematic ensures clarity and understanding of the system's architecture for both team members and stakeholders
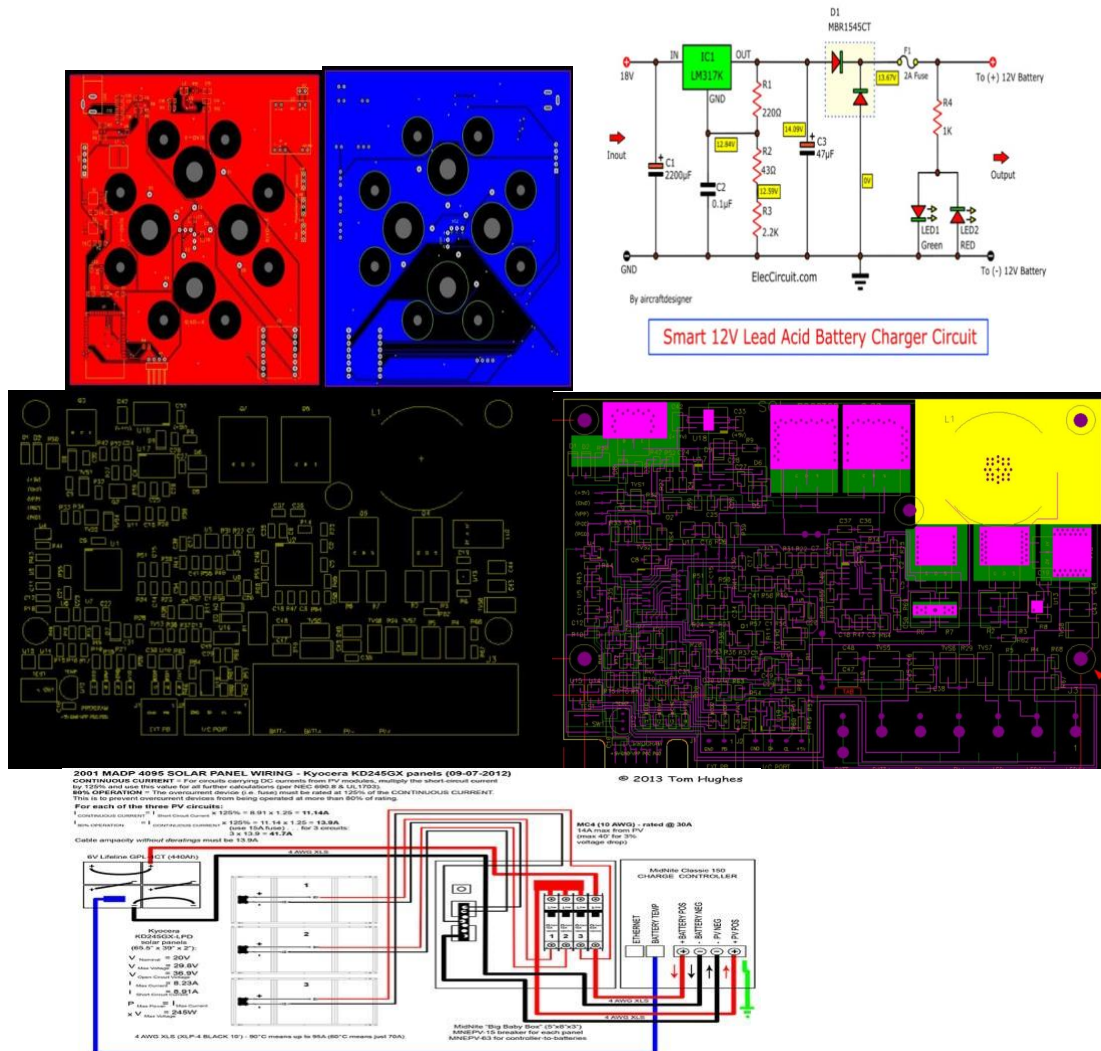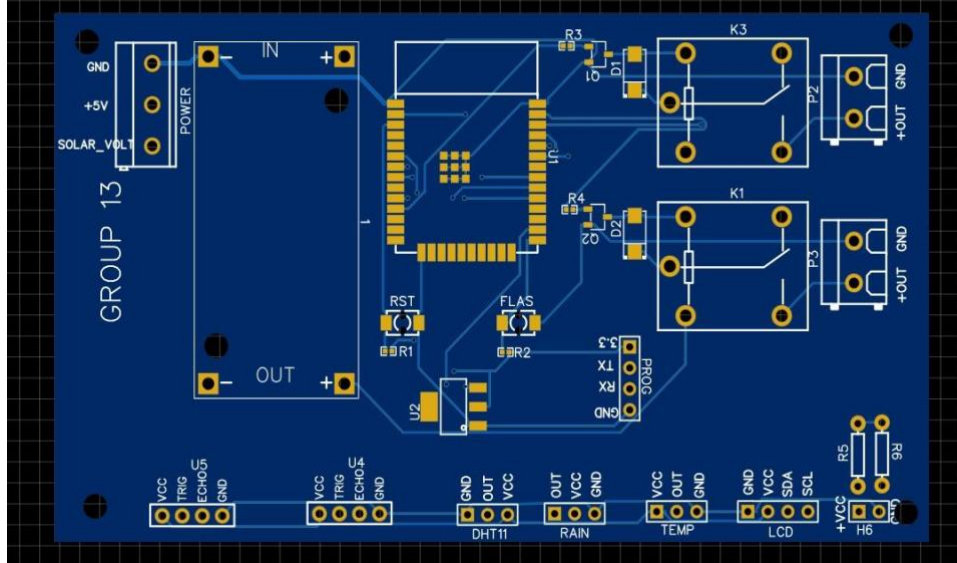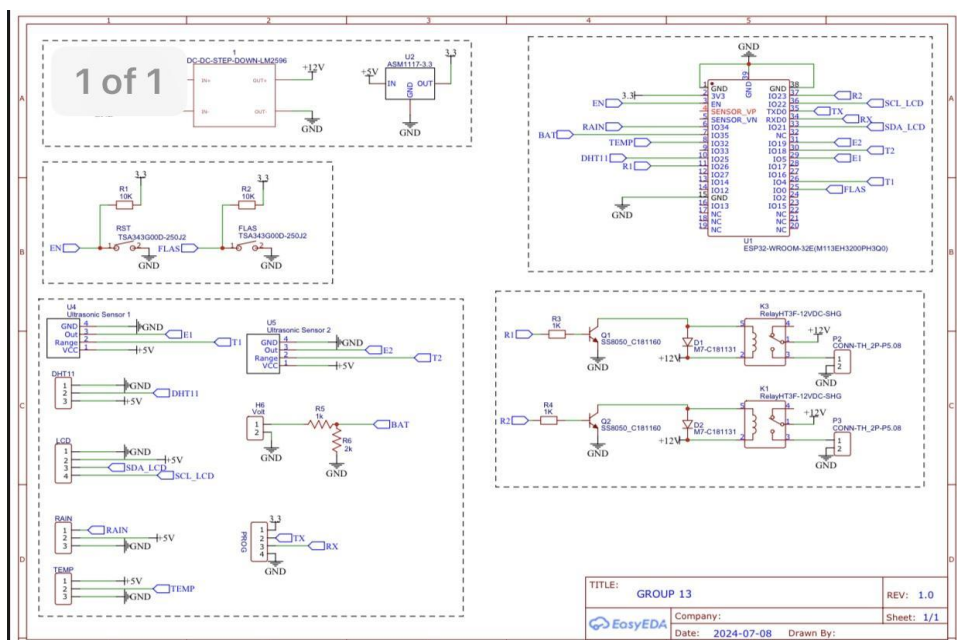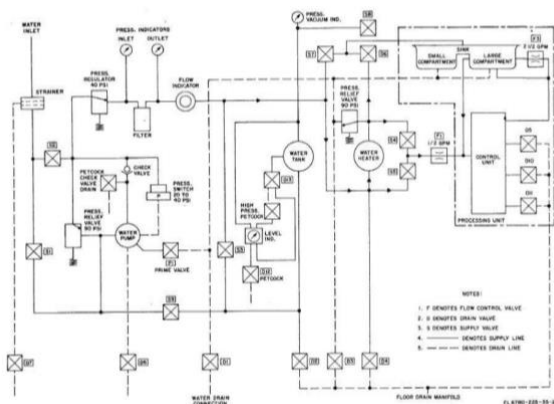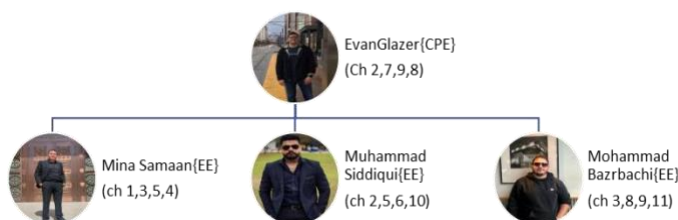
10.0 Administrative Content

In this chapter, we outline our project management strategy, focusing on two crucial aspects: resource management and time allocation. The financial segment will be divided into two sections. The first section will delve into the budget and funding, featuring a chart illustrating the estimated budget alongside our funding plan. Following this, the bill of materials will itemize all individual costs associated with the components to be utilized in Senior Design. Similarly, the temporal dimension will also be divided into two parts. The initial part will present a table elucidating our benchmarks and underscoring the importance of adhering to strict timelines in Senior Design. The subsequent section will elaborate on the distribution of tasks during the Senior Design phase.
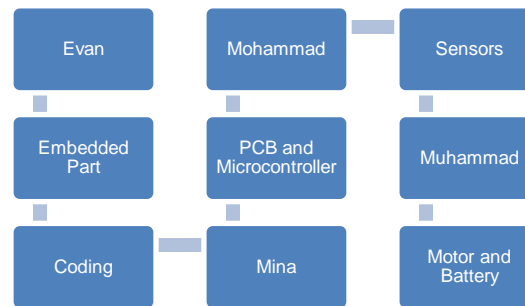
10.1 Work Distribution

In our team of four electrical engineers, each member contributed equally to the project's workload. Collaboration was integral to our approach, particularly in hardware-related tasks such as creating the bill of materials (B.O.M.), designing schematics, developing PCBs, and carrying out assembly. Similarly, a cooperative approach was adopted for software-related activities, including finalizing code, drafting pseudocode, project development, and management. This collaborative ethos fosters a sense of mutual support and trust, ensuring that each team member feels empowered to contribute effectively. While individuals have specific responsibilities, collective input is sought to ensure the most optimal decisions are made at every stage of the project. Moreover, we maintain an open-door policy, readily offering assistance and guidance to one another whenever uncertainties arise regarding our designs.

Our four-member electrical engineer team tackled this project with a collaborative spirit, recognizing its importance for success. This wasn't a one-man show; instead, we divided the workload evenly. Hardware tasks, like crafting the bill of materials, designing schematics, and building the PCBs, all benefited from this teamwork. Software development mirrored this approach, with collaboration on finalizing code, pseudocode, and overall project management. This cooperative spirit fostered a supportive and trusting environment where every member felt empowered to contribute. Our approach wasn't simply dividing tasks; it involved seeking collective input throughout the process to ensure optimal decision-making at every stage. By maintaining an open-door policy, we readily offered assistance and guidance whenever uncertainties surfaced in our designs, solidifying a collaborative triumph

SD2 Work distribution

Evan	Mohammad	Sensors
Embedded Part	PCB and Microcontroller	Muhammad
Coding	Mina	Motor and Battery

10.2 Initial Project Milestones/Timeline

In our project journey, milestones serve as crucial markers that demand careful attention and planning. Establishing clear objectives and deadlines is paramount to our team's efficiency as it streamlines workflow and helps prevent issues such as delayed part orders or missed submissions. Key milestones during Senior Design One include the submission of the first paper section, acquisition of test parts, placement of the PCB order, and completion of the paper submission. Each achieved milestone not only progresses the project but also instills a sense of achievement, driving us forward. However, maintaining some degree of deadline flexibility is essential as unforeseen challenges may arise during the semester, necessitating swift resolution. Ultimately, milestones provide the roadmap we need to navigate our project journey as a cohesive team.

Our Senior Design One project thrives on a foundation of meticulously planned milestones. These crucial checkpoints demand our focus and strategic planning. Establishing clear objectives and deadlines forms the cornerstone of our team's efficiency. This approach streamlines workflow, ensuring everything runs smoothly and averting potential roadblocks like delayed part orders or missed project submissions.

Throughout Senior Design One, key milestones serve as guiding lights. From submitting the initial paper section to acquiring test parts, placing the PCB order, and finally completing the final paper submission, each achieved milestone marks not just progress but also a sense of accomplishment, propelling us forward with renewed motivation. However, we understand that unforeseen challenges can emerge during the semester. Maintaining some degree of flexibility within our deadlines allows us to adapt and address these issues swiftly, ensuring we stay on track. In essence, milestones are our roadmap to success, guiding our team on a collaborative journey towards achieving our project goals.

Senior DesignI		
Task	Start Date	End Date
Brainstorm/ form group	1/10/2024	1/10/2024
Finalize Idea	1/25/2024	1/25/2024
Initial Document - D and C	2/2/2024	2/2/2024
Meet with Wei	2/7/2024	2/7/2024
Research and write	2/9/2024	2/9/2024
PCB Initial Design and Work	TBD	TBD
60 Page paper	3/29/2024	2/29/2024
Meet with committee	4/1/2024	4/1/2024
120 Page Paper	4/23/2024	4/23/2024
Finalize PCB Design	TBD	TBD
Order PCB	11/27/2024	12/5/2024
Senior DesignII		
Build Prototype	5/17/24	6/14/24
Meet with Wei	5/17/24	6/14/24
Test and Redesign	5/17/24	6/29/24
Finalize Design	5/17/24	7/18/24
Presentation	5/17/24	6/14/24
Final Report	5/17/24	7/23/24
Final Presentation	5/17/24	7/18/24

10.3 Budget Estimate

Each member of our team will contribute equally to the project's funding. The anticipated costs for the necessary components at this stage of our project are outlined in the table below. The Senior Design Lab on campus is equipped with all the necessary tools for testing and constructing the project, including power supplies, oscilloscopes, multimeters, 3D printers, and soldering irons.

Item	Quantity	Used for the project	Unit Cost	Total	Notes
Electrical Circuit Board	12	3	$10	$120	Multiple iterations are considered
Rain Water sensor	5	1	$1.48	$7.44	
Water level sensor	10	2	3.406	$34.06	
Water tanks	4	2	$10	$40	
Solar panel	1	1	$32	$32	
flexible water tube	1		$28.68	$28.68	
Battery	1	1	$24.48	$24.48	
Digital screen LCD 20x4	6	1	$5.68	34.06	
Water filter	1	1	$4.55	$4.55	
relay	7	1	$3.034	$21.24	
DHT11	5	1	$2.13	$10.64	
Green conector box	50	1	$0.34	$17.03	
Buck convertor	10	3	$1.34	13.41	
Water tempreature sensor	3	1	$4.61	$13.82	
ESP32	4	1	$10.11	$40.46	
Hose clamp	1	1	$2.64	$2.64	
Water pump	1	1	$94.2	$94.2	
Faucet pipe adapter	1	1	$9.72	$9.72	
Pla for 3d printer	2	2	13.83	27.67	
Components	1		$20	$20	1 box include (Capacitors, resistors, and other components)
AWS EC2 m5.large Instance	$0.096 per hour		$0 - Free Tier	$0	
AWS RDS (DB, S3)	$0.096 per hour		$0 - Free Tier	$0	
Domain, SSL	1		$10	$10	
IoT Devices	1		$50	$50	
IoT Sensors				$30	

	125	23	361.95	706.1	
	Total Estimated Value:		$361.95	Prices might get different depends on the components availability and when it will arrive	

Following a preliminary assessment of the costs associated with various components, we estimate that a budget of approximately $500 will be required for additional parts. This allocation accounts for unforeseen circumstances and ensures that we have the necessary resources to build at least two prototypes and the final product without any setbacks. After conducting a preliminary assessment of the costs associated with various components, we have estimated that an additional budget of approximately $500 will be required for purchasing additional parts. This allocation takes into account any unforeseen circumstances and ensures that we have the necessary resources to build at least two prototypes and the final product without encountering any setbacks.

By pooling our resources and carefully budgeting for our project, we are confident that we did have everything we need to successfully execute our plans and deliver a high-quality solution that meets our objectives. This approach not only demonstrates our commitment to the project but also ensures that we are prepared to overcome any challenges that may arise during the development process.

11.0 Conclusion

WaterSaver represents a beacon of hope and innovation in the face of one of the world's most pressing challenges: water scarcity. By harnessing the power of rainwater and integrating advanced technologies, WaterSaver offers a sustainable solution to communities, especially those in resource-constrained environments. Its mission to empower communities with access to clean water aligns with global efforts to ensure water for all and promote environmental sustainability. WaterSaver's user-centric design, incorporating rainwater sensors, solar power integration, and advanced filtration, not only addresses immediate water needs but also encourages mindful and sustainable practices among users.

Furthermore, WaterSaver goes beyond providing a practical solution; it embodies a commitment to environmental preservation and community engagement. By reducing reliance on conventional water sources, minimizing wastage, and mitigating flood risks, WaterSaver contributes to the broader goals of water conservation and climate resilience. Its vision of a future where sustainability and equity are intertwined serves as a catalyst for change, inspiring individuals and communities to rethink their relationship with the environment and adopt more responsible practices. As WaterSaver continues to expand its reach and impact, it sets a precedent for how technology and innovation can address critical global challenges and catalyze positive environmental and social change.

To sum up, our project aims to unite all group members to work collaboratively on a single project, not only to apply the knowledge gained through electrical and computer engineering degrees but also to ensure that each engineer can effectively work in a team. Most jobs require teamwork to accomplish tasks, unlike individual assignments and projects that evaluate team members based on their knowledge from individual courses. Collaborating as a team enhanced our teamwork skills and taught us valuable lessons, such as time management and the importance of regular meetings to ensure everyone is aligned and to minimize mistakes and missed deadlines. Additionally, teamwork enriched the final project by incorporating diverse perspectives from each team member's background. Through this collaborative effort, we developed the WaterSaver project, which addresses various challenges and serves multiple purposes, including car wash systems, dishwashing, toilet use, and watering plants and trees on dry days. Moreover, WaterSaver can be particularly beneficial in third-world countries where water conservation is vital. These regions often experience water shortages, leading to days without water, which can contribute to widespread disease and even fatalities.

The WaterSaver project comprises both hardware and software components, offering a self-contained system that users can also adjust via their web application to ensure it meets their specific needs. The hardware includes solar panels, rainwater sensors, water level sensors, two water tanks, tubes, a water filter, voltage controllers and regulators,

and a water valve. On the software side, the design focuses on creating a robust, flexible, and user-friendly solution using various technologies and architectural components. The project is built on Amazon Web Services (AWS), utilizing Elastic Compute Cloud (EC2) for scalable computing and Relational Database Service (RDS) for efficient data storage and retrieval. Security features are enhanced through AWS Certificate Manager, Route 53, and CloudFront to ensure secure and encrypted connections. Source code management is facilitated by GitHub SCM for collaborative development. The backend employs Docker, NGINX, and Python 3.11 for the Flask API, while the frontend utilizes libraries such as Axios, Material UI, and React Router to enhance functionality and user experience. The system also integrates SSL web domains using Lets Encrypt and TLS 1.2. Data management is conducted through a Postgres database with SQLAlchemy for constraints and validation, along with ORM relationships for managing notifications and product associations. Device events are handled via crontabs and Flask API webhooks, incorporating retry mechanisms for event payload transmissions. The user interface concept showcases a dashboard displaying metrics like battery level, water level, and temperature, as well as water storage calculations and event logs. In summary, the software aims to deliver a comprehensive and intuitive platform for efficient water management.

We used AI in our project because it can perform various tasks to enhance our 120 page document and support our project development. It helped generate new ideas to add to our project, provided hints on where to start, and corrected grammar mistakes to ensure our work is understandable to the reader as english is not the first language to most of us.

Our team was inspired to merge our expertise in electrical engineering and design throughout our project. Our objective was to create a solution that integrated knowledge from various courses into a real-world application. Collaborating as team members, we utilized our hardware and software implementation skills to showcase our commitment to applying classroom learning to practical situations. To ensure alignment between technical and marketing criteria, we employed the House of Quality methodology, guiding our design process to a successful outcome.
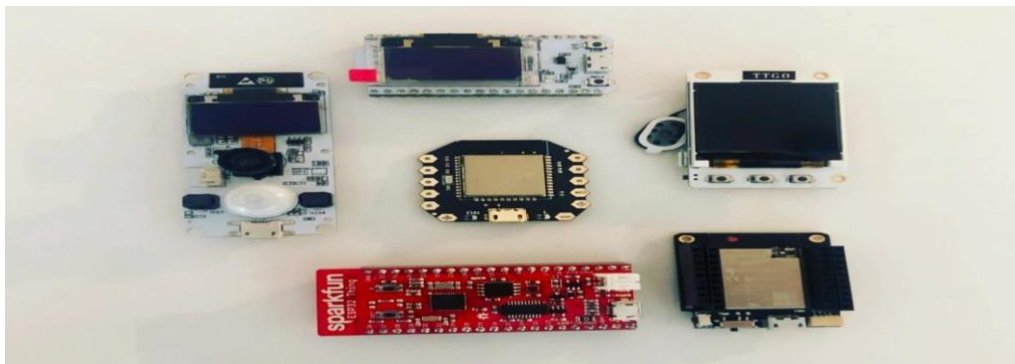
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