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Project AQUADROP: Advancing Quality Utilization of Aquatic Droplets Vibration for Renewable Optimization of Power

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Abstract

Project AQUADROP explores an innovative method for converting water vibrations into electrical energy, presenting a potential solution for sustainable power generation. The study examines the system's efficiency in vibration frequency and output voltage, as well as its adaptability to varying rainfall conditions. Results demonstrate a positive correlation between vibration frequency and average output voltage, increasing from 0.66 V at 10 Hz to 5.38 V at 100 Hz, with peak efficiency achieved at 100 Hz. This suggests that optimizing operational frequencies could significantly enhance energy conversion. The system's performance across different rainfall intensities also shows a direct relationship between rainfall and energy output, with average voltage rising from 0.35 V in light rain to 0.64 V in heavy rain. While ANOVA analysis indicated that differences in output voltage across rainfall conditions were not statistically significant (p-value = 0.641), the dataset offers a foundation for future research on factors influencing energy capture. Additionally, the system's capability to power small electronic devices highlights its practical viability. These findings underscore Project AQUADROP's potential as a renewable energy solution, especially under conditions of higher vibration frequencies and varying rainfall. Further research is essential to refine the system's design and expand its applications in real-world scenarios.

Keywords: *aquatic, water vibrations, renewable energy, frequency*

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1. Introduction

Increasing reliance on renewable sources has become a need in the world to decrease the burning of fossil fuels and change the repercussions of climate change. Renewable sources have substantial economic and environmental benefits, including lower levels of carbon emissions, reduced air pollution, and increased possibilities of lower energy costs (Horobet et al., 2022; Soni et al., 2022). It has been established that using such power sources greatly impacts the comfort, safety, and robustness of electric grids while harnessing natural energy in a sustainable but environmentally savvy way (Zakariazadeh et al., 2024; Kabel & Bassim, 2019). For instance, solar, wind, and hydropower have been at the forefront of this renewed struggle towards a renewable energy shift. Diversification and optimization of these renewable energy sources will be achieved to a greater extent through continuous research and innovation (Ang et al., 2022; Siddika et al., 2025; Gitelman et al., 2023; Yu et al., 2025).

A notable advancement in this field is Vibro-Hydro Power (VHP), a technology that captures kinetic energy from water vibrations and transforms it into usable electrical energy. This method offers a unique strategy for harnessing previously unexploited energy generated by minor water movements, including waves, currents, or vibrations resulting from the interplay between infrastructure and water. In light of the ubiquitous presence of water bodies throughout the world, VHP could potentially become a significant player in the renewable energy space across various environmental landscapes. It is founded on the principle that vibration energy can be transformed into electrical energy using complex systems of mechanical and electromechanical construction. These vibration-generating technologies for energy are intended to detect and take advantage even of slight, periodic vibrations available in water, either in natural water bodies or regulated environments. The integration of VHP systems with existing structures of water management and energy generation could be a way of generating electricity sustainably, reducing environmental impacts.

Research by Doria (2019) highlights advancements in vibration-based energy harvesting, particularly focusing on the design and efficiency of piezoelectric devices in raindrop harvesting systems. These studies have explored such devices' structural and electrical configurations, often using prototypes to test various layouts, with piezoelectric cantilevers as a common design standard. In addition, Palomba (2022) analyzed the energy dynamics arising when raindrops hit a sufficiently thick layer of water that would generate the appearance of crown formation and surface ripples, where energy could be captured. Such research aspects point towards as-yet-unexploited potential in the transformation of water-induced vibrations into a sustainable source of energy.

This study, Project AQUADROP will investigate the feasibility, technological requirements, and potential uses of vibro-hydro power as a new renewable energy source. This will also investigate the scientific bases that underpin the conversion of water oscillations into electricity, acknowledge the technical advancements necessary to achieve efficient energy harvesting, and assess the environmental and economic impacts tied to this approach. Additionally, this research methodically reviews the potential input of VHP to future international efforts focused on attaining a greener and cleaner energy future.

2. Literature Review

There are four main types of renewable energy: wind, solar, hydroelectric, and bioelectric. Hydroelectric energy sources have been discussed through the use of dams or a diversion structure that enables them to generate power. However, one feature of hydroelectric energy has not been thoroughly discussed yet, which is the energy produced by water vibration. Droplets of water cause water waves to vibrate and this vibration has the potential to produce sufficient energy sources (Lin & Yang, 2024; Beacham et al., 2020; Trapuzzano et al., 2020). Most hydroelectric control plants have a supply of water, a door or valve to control how much water streams out of the supply, and an outlet or put where the water closes after streaming descending. Water picks up potential vitality fair some time recently it spills over the best of a dam or streams down a slope (Yanto et al., 2024). The plausibility of abusing the dynamic vitality of raindrops by implies of piezoelectric vibration vitality collectors has been analyzed since 2008.

Studies and research have contributed in the advancement of energy systems, in which the improvements have increased and risen globally due to its demand. The ultimate purpose of such renewable energy systems is to eliminate or decrease carbon emissions and emanations that are a high concern in environmental issues (Gunnarsdottir et al., 2021). Sustainable energy systems are feasible in comprehensive details under the umbrella of three important factors: economy, society, and the environment (Vezzoli et al., 2018; Halawa, 2024; Buchmayr et al., 2021). In this way, the development of sustainable energy systems plays an instrumental role in advancing financial development and social improvement, but most importantly, in fostering an eco-friendly way in producing energy that minimizes damage and negative environmental impact (Rangel-Martinez et al., 2021). One theoretical concept that provides innovative contribution to this aspect is Design Science Theory. This is a problem-solving paradigm which aims to enhance human skills and knowledge through creating innovative products that will contribute in advancing technology and science; and by this, several concepts and theories were also incorporated to accomplish this task (Brocke et al., 2020).

Most of the proposed raindrop gatherers arranges to produce electric vitality through the piezoelectric impact. Palomba (2022) also analyzed the effect of a raindrop on a dry strong surface creates spreading and sprinkling wonders, which disseminate a critical portion of the raindrops' active vitality. This study includes theoretical concepts that are instrumental in formulating hypotheses that will be considered as the basis of the study, and in processing certain ideas of how project AQUADROP's feasibility will be sufficient enough. One of the main key features of this study is the incorporation of piezoelectric transducers. Piezoelectric materials can specifically transduce electrical and mechanical vitality, making them alluring for applications such as sensors, actuators and vitality gathering gadgets (Smith et al., 2022).

The first law of thermodynamics applies the preservation of energy where heat and work are the strategies for exchanging energy into and out of systems. This states that the overall vitality of a framework remains steady, indeed in case it is converted from one frame to another. It can be utilized to portray how energy exchanged by heat is changed over and exchanged once more by work (Zohuri & Mcdaniel, 2019).

The piezoelectric theory depicts the transduction of electrical and mechanical energy. Between a stressed state of a material and the linear coupling with electrical polarization, the piezoelectric theory has produced energy through tapping or impact. The impact is intrinsically reversible; a polarization can be the result of the stress, or it can occur from a connected electric field. These are known as the coordinate and backhanded piezoelectric impacts, separately. The last mentioned is in some cases too alluded to as the converse piezoelectric impact (Maestri et al., 2023). Vibration energy harvesting is used by encompassing mechanical energy from the environment to convert it into reusable energy. This innovation is considered to be a generally unused strategy for providing sustainable energy to low-powered sensor systems and electronic gadgets. Different vibrational energy harvesters are incorporated in which their function has become known for research and studies and how these will contribute to further developments, this includes piezoelectric, electromagnetic, electrostatic, and triboelectric energy conversion instruments which were outlined and tested to achieve the goal (Zhou et al., 2022; Kokorus et al., 2014).

3. Methodology

This section outlines the materials and methodologies employed in the development and testing of the piezoelectric energy harvesting system under Project AQUADROP. Detailed descriptions of the materials, prototype design, circuit diagram, experimental setups, and procedures are provided to ensure reproducibility and to facilitate a comprehensive understanding of the processes involved in harnessing energy from water vibrations and rainwater. Through this systematic approach, we aim to evaluate the effectiveness and efficiency of the proposed energy generation system.

3.1. Prototype Design

Figure 1. *Main frame*

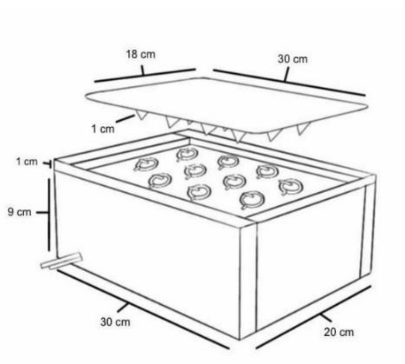


Figure 2. *Storage hardware*

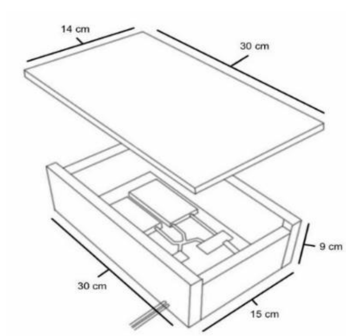


Figure 3: *Top view*

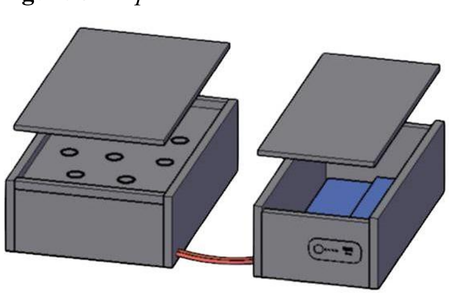


Figure 4: *Top view*

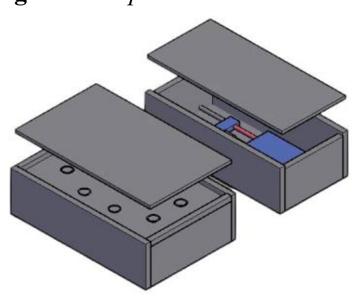


Figure 5: *Side view*

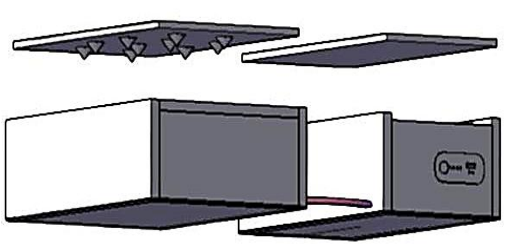
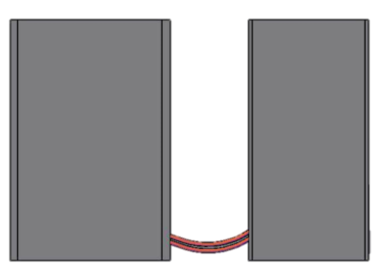
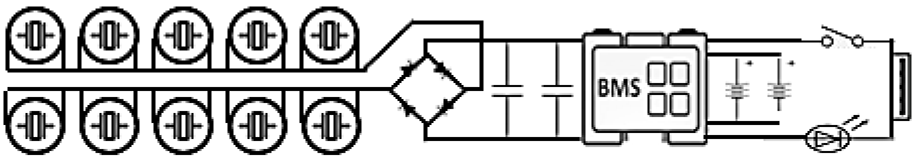


Figure 6: *Bottom view*

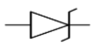
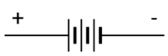
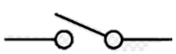
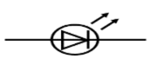


3.2. Circuit Diagram

Figure 7: *Circuit diagram of project AQUADROP*



Legend:

	Piezoelectric transducer
	Rectifier diode
	Capacitor
	Battery Management System
	Battery
	Switch
	LED Light Indicator
	USB Charging Module

3.3. Actual Product

Figure 8

Main frame

Main Frame

Main Frame with Vibrating Plate

Top view

Top view with vibrating plate

Side view (Left)

Side view (Right)

Figure 9

Storage hardware

Top view

Top view of the circuit

Side view (Left) Side view (Right)

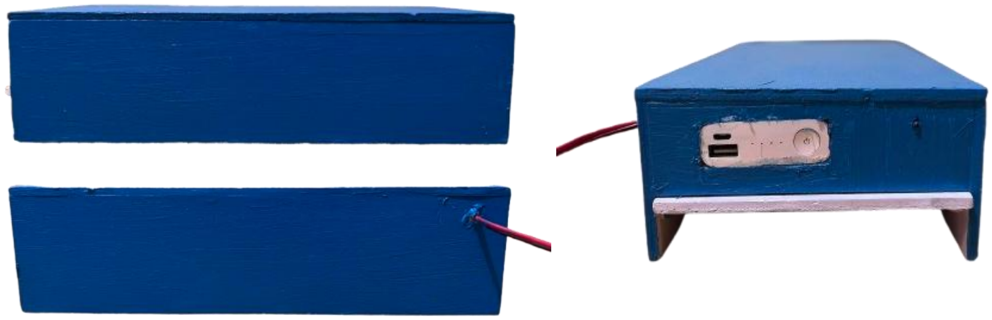


Figure 10

Final product

With Vibrating Plate Without Vibrating Plate

Table 1

Materials used

Quantity	Size	Materials
3	12x24 inches	Sintra Board
2	7V and 12V	Lithium-ion Battery
10	3-12V	Piezoelectric Transducer
1	12V	Dual USB 2.4A Micro/Type-C USB Mobile Power Bank 18650 Charging Module Lithium Battery Charger Board Circuit
4	5V	Rectifier diode
2	50V	Capacitor
2	0.22 mm² 3m (each)	Copper wire
1	30.48 cm	Ruler
1	1 m	Solder core wire

Quantity	Size	Materials
1	50x50cm	Flat Aluminum sheet
1	91.44 cm	Plastic cover
1	6x6 mm	Micro tact push button switch 0.5A/ 50V
2	225x275mm	Sandpaper no. 60 grit
1	15x13x2cm	Glue gun
5	20cmx12mm	Glue stick
1	-	Scissor for paper
1	-	Cutter
1	-	Electrical tape
1	-	Cobbler glue
1	-	Blow dryer
1	-	Scissor for metal
1	-	Multimeter

3.4. Procedures

Gather materials. Collect all necessary components, including Sintra board, piezoelectric transducers, cobbler glue, stranded wires, a soldering iron, rectifier diodes, a capacitor, a lithium battery charger board circuit, a lithium battery, and a USB port.

Creating the frames.

Cut sintra board for box 1(main frame): Cut the Sintra board into parts to create a rectangular box with dimensions of 32 cm (length) × 20 cm (width) × 10 cm (height).

Cut sintra board for box 2 (storage hardware): For the second box, cut the board into parts with dimensions of 30 cm (length) × 20 cm (width) × 15 cm (height).

Assemble the boxes: Use cobbler glue to securely join the cut parts of the Sintra board, forming the two rectangular boxes.

Putting drainage system: Cut small holes on each side of box 2 to be used for drainage once the product becomes operational.

Create the Circuit.

Place the piezoelectric transducers: Position 10 piezoelectric transducers evenly on the top surface of the main frame box.

Attach the transducers: Use a glue gun to affix each transducer to the board, applying glue to the side of each transducer.

Prepare for wiring: Create a hole next to each transducer using a multimeter tip. Insert two stranded wires into each hole, one for each terminal.

Solder the wires: Use a soldering iron to attach the wires to the terminals of the piezoelectric transducers, ensuring secure connections.

Organize the wires: Neatly arrange the wires on the back of the Sintra board, using glue to secure them. Trim any excess wire.

Combine the wires: Solder the wires from each transducer together, merging them into a single output wire.

Insulate the connections: Wrap the soldered connections with electrical tape to insulate and protect the wires.

Build the rectifier circuit: Construct a rectifier bridge using four rectifier diodes to convert AC to DC. Solder the diodes in place.

Add capacitor and charging module: Solder a capacitor to stabilize the output voltage, then connect the lithium battery charging module to the circuit.

Connect the battery: Solder the lithium battery to the charging board, ensuring proper polarity.

Complete the wiring: Attach a switch to the circuit for easy operation.

Creating the tapper.

Cutting the aluminum plate: Cut the aluminum flat sheet to dimensions of 38 cm in height and 25 cm in width.

Cutting the strips: From the remaining aluminum sheet, cut 10 strips, each measuring 3.3 cm in length and 1.0 cm in width.

Forming the tappers: Fold each aluminum strip into a “W” shape, ensuring that the fold has a height of 1.0 cm.

Attaching the tappers: Secure the tappers to the aluminum plate, positioning each tapper so that it aligns with the center of a piezo element when the aluminum plate is placed over it.

***Assembly of the final product*.**

Waterproofing: Cover the main frame box with a plastic cover. Heat the cover with a blow dryer to stretch it, then use cobbler glue to attach it securely to the frame.

Assembling the unit: Position the vibrating aluminum plate on top of the main frame.

Testing: Verify that the tappers make contact with the piezo elements when the vibrating plate interacts with water.

3.5. Data Analysis

The data analysis for Project AQUADROP, a vibro-hydropower system designed to capture water vibrations and convert them into energy, focuses on evaluating the system's efficiency and its potential to generate voltage under varying conditions. The analysis addresses the following specific research questions:

Efficiency analysis of project AQUADROP. To quantify the efficiency of the vibro-hydropower system, the following steps were taken:

Data collection: Measure the output voltage (V) generated at different vibration frequencies (Hz), ranging from 10 Hz to 100 Hz, using a piezoelectric sensor. Conduct a minimum of 5 trials per frequency to ensure statistical significance

Efficiency formula: Calculate efficiency (%) using the formula:

$$\textbf{Efficiency} = (\textbf{Voltage} / \textbf{Maximum voltage}) \times 100$$

Voltage generation under different rainfall conditions. The system's ability to harness energy from rainfall was quantified by measuring the voltage output during light, moderate, and heavy rain conditions:

Data collection: Use a standardized setup to measure voltage output during:

Light rain: 0.1-2.5 mm/hour

Moderate rain: 2.6-7.6 mm/hour

Heavy rain: >7.6 mm/hour

Measurement process: Record each condition's voltage input (V) every 15 minutes to ensure consistency.

Average Output Calculation: Calculate the Average Output using the formula:

$$\textbf{Output}_{ave} = \textbf{Voltage output/ minutes of exposure}$$

Analysis of variance between the correlation among different rain intensities. The one-way ANOVA test was used to compare the average voltage output for light, moderate, and heavy rain.

Decision rule: If test statistic > critical value then reject the null hypothesis and conclude that the means of at least two groups are statistically significant.

Critical value: 0.05

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Value
Between Groups	$SSB = \Sigma n_j (\bar{X}_j - \bar{X})^2$	$df_1 = k - 1$	$MSB = SSB / (k - 1)$	$F = MSB / MSE$
Error	$SSE = \Sigma\Sigma (X - \bar{X}_j)^2$	$df_2 = N - k$	$MSE = SSE / (N - k)$	
Total	$SST = SSB + SSE$	$df_3 = N - 1$		

Analysis of compatible devices. To determine which devices can be powered by the system, the following quantitative analysis was performed:

Power calculation: Based on the measured voltage, calculate the power output (P) using the formula: $P=V^2/R$, where V is the output voltage and R is the resistance (Ω) of the load.

Device matching: Compare the calculated power output against the power requirements of various low-power devices: LED lights (3W, 5V); Mobile phone charger (5W, 5V); and Small fan (10W, 12V).

Duration of power supply: Estimate how long each device can be powered under different rainfall conditions using the formula: Duration=Energy/ Power requirement,

where Energy is the total energy generated over a time period during a given rainfall condition.

3.6. Ethical Considerations

The researchers are responsible for following research ethics to construct an ethical research study. Moreover, they obtained consent letters before the conduct of the study. The study also followed and reviewed the ISEF rules and guidelines by informing the parents and the adviser for the conduct of the study to guide the process of creation and investigation. By assessing the potential hazards that the participants might encounter during the conduct, the researchers ensured the safety of the investigators and assistants throughout the study. It minimized and mitigated the harm to the people involved in the project.

The researchers conducted the study with integrity and transparency, ensuring that the findings accurately reflected the results of the investigation. The results were validated by experts and the study adviser to ensure the trustworthiness of the paper. The researchers also avoided personal and financial conflicts of interest that could compromise the objectivity and integrity of the study. All cited literature and references used in the study were properly acknowledged to avoid plagiarism and maintain the originality of the project.

4. Findings and Discussion

This section presents the findings of Project AQUADROP's performance, focusing on its efficiency in terms of vibration frequency and voltage generation. It also explores the voltage output harnessed under varying rain conditions, light, moderate, and heavy. Additionally, the analysis identifies the range of devices that can be powered using the energy generated by Project AQUADROP, highlighting the system's practical applications and potential for sustainable energy solutions.

4.1. Efficiency of Project AQUADROP in terms of Vibration Frequency and Voltage

Table 1 summarizes the output voltage (V) measured at various vibration frequencies (Hz), along with the calculated average output voltage. Each frequency was tested with a minimum of 5 trials to ensure statistical significance.

Table 1

Efficiency of project AQUADROP

Vibration Frequency (Hz)	Average Output Voltage (V)	Efficiency (%)
10	0.66	12.27
20	1.21	22.49
30	1.36	25.28
40	1.63	30.30
50	2.13	39.59
60	2.67	49.63
70	2.76	51.30
80	3.70	68.77
90	4.47	83.09
100	5.38	100.00

Correlation between frequency and voltage output. The output voltage generally increased with higher vibration frequencies. At 10 Hz, the average voltage was 0.66V, while at 100 Hz, it peaked at 5.38V. This indicates that Project AQUADROP is more effective at converting higher-frequency vibrations into electrical energy.

Low efficiency at lower frequencies. At lower frequencies (10 Hz to 40 Hz), the efficiency was notably lower, possibly due to inadequate mechanical energy input from insufficient water vibrations. This emphasizes the importance of selecting the appropriate frequency range for maximum energy capture.

4.2. Voltage Output of Project AQUADROP under Different Rainfall Conditions

To evaluate Project AQUADROP's performance under varying rainfall conditions, voltage output was measured during light, moderate, and heavy rain events.

Table 2 outlines the voltage measurements recorded during exposure to light rain over 60 minutes.

Table 2

Voltage measurement during light rain exposure

Trials	Voltage input	Average Output Voltage (V)/ minute
0 minutes	0.00	0.00
15 minutes	1.25	0.08
30 minutes	13.31	0.44
45 minutes	19.07	0.42
60 minutes	24.90	0.46

At the start of the trial, with 0 minutes of exposure, both the voltage input and average output voltage were recorded at 0.00 V, indicating no energy generation. After 15 minutes, the input voltage increased to 1.25 V, yielding a low average output voltage of 0.08 V, reflecting minimal energy conversion efficiency. As the exposure continued, the input voltage significantly rose to 13.31 V at 30 minutes, resulting in an average output voltage of 0.44 V, suggesting improved energy capture. However, at the 45-minute mark, the input voltage was 19.07 V, and the average output voltage slightly decreased to 0.42 V, which may indicate fluctuations in efficiency. By the end of the 60-minute trial, the input voltage reached 24.90 V, with the average output voltage increasing to 0.46 V, demonstrating the system's capability to stabilize and enhance energy conversion over time.

Table 3 presents the voltage measurements obtained during moderate rain exposure, again over 60 minutes.

Table 3

Voltage measurement during moderate rain exposure

Trials	Voltage input	Average Output Voltage (V)
0 minutes	0	0.00
15 minutes	1.12	0.07
30 minutes	16.8	0.56
45 minutes	30.47	0.68
60 minutes	40.54	0.68

The trial began with an input voltage of 0, resulting in an average output voltage of 0.00 V. After 15 minutes, the input voltage increased to 1.12 V, leading to a minimal average output voltage of 0.07 V. At the 30-minute interval, the input voltage rose to 16.8 V, which corresponded to a significant increase in average output voltage to 0.56 V, indicating a more effective energy conversion process than observed in light rain conditions. By 45 minutes, the input voltage had further increased to 30.47 V, and the average output voltage reached 0.68 V, suggesting improved efficiency with prolonged exposure. Finally, at the 60-minute mark, the input voltage peaked at 40.54 V, while the average output voltage stabilized at 0.68 V, highlighting the system's consistent performance under moderate rainfall conditions.

Table 4 summarizes the voltage measurements during heavy rain exposure, again spanning a 60-minute duration.

Table 4

Voltage measurement during heavy rain exposure

Trials	Voltage input	Average Output Voltage (V)
0 minutes	0.00	0.00
15 minutes	2.23	0.15
30 minutes	20.67	0.69
45 minutes	38.05	0.85
60 minutes	50.98	0.85

The initial measurement at 0 minutes revealed both the input and output voltages at 0.00 V. After 15 minutes, the input voltage rose to 2.23 V, resulting in an average output voltage of 0.15 V. At the 30-minute mark, the input voltage significantly increased to 20.67 V, leading to a much higher average output voltage of 0.69 V, indicating enhanced performance under heavy rainfall. The input voltage continued to rise, reaching 38.05 V at 45 minutes, with the average output voltage further increasing to 0.85 V, showcasing the system's effectiveness in harnessing energy from strong water vibrations. By the end of the 60-minute trial, the input voltage peaked at 50.98 V, and the average output voltage remained stable at 0.85 V, reflecting a consistent energy conversion efficiency even at high input voltages.

Table 5 provides a summary of the average output voltage generated by the system under varying rainfall conditions.

Table 5

Average voltage output under different rainfall conditions

Rainfall Condition	Average Output Voltage (V) per minute
Light rain	0.35
Moderate rain	0.50
Heavy	0.64

The data reveals that the average output voltage during light rain is 0.35 V, indicating relatively low efficiency in energy capture compared to other conditions. As the intensity of rainfall increases to moderate, the average output voltage rises to 0.50 V, demonstrating better performance in energy conversion. The most significant improvement is observed under heavy rain conditions, where the average output voltage reaches 0.64 V, indicating optimal performance and efficiency during intense rainfall. This summary emphasizes the direct relationship between rainfall intensity and the system's energy generation capabilities, highlighting its effectiveness in harnessing energy from water vibrations under varying environmental conditions.

4.3. Significant Difference Among Voltages Based on Rain Intensity

The ANOVA results presented indicate an analysis conducted to explore differences in average output voltage across varying rainfall conditions (light, moderate, and heavy rain).

Table 6

ANOVA of the different rain intensities

	Sum of Squares	df	Mean Square	F	Significance
Between Groups	286.981	2	143.4391	.462	.641
Within Groups	3724.259	12	310.355		
Total	4011.240	14			

Sum of squares.

Between Groups (286.981). This value reflects the variation in average output voltage attributable to differences in rainfall conditions. It suggests that there is some variation between the groups, highlighting the potential for the system to respond differently to varying rainfall intensities.

Within Groups (3724.259). This value indicates the variability among individual observations within each rainfall condition. The considerable within-group variance shows that there are consistent performance levels across trials, offering insights into the reliability of the system under controlled conditions.

Total (4011.240). This figure represents the overall variance, incorporating both between-group and within-group variances. A high total variance indicates a rich dataset that can be analyzed for further insights.

Degrees of Freedom (df).

Between Groups (2). This indicates the number of conditions being compared. The inclusion of three distinct rainfall conditions allows for a comprehensive analysis of the system's performance.

Within Groups (12). The degrees of freedom within groups suggest a robust sample size, which adds to the reliability of the results.

Total (14). This total reflects a well-structured study design with multiple observations for each condition.

Mean Square.

Between Groups (143.491). This mean square value illustrates the average variance between the group means. It indicates that there is some difference in output voltage performance that could be further investigated.

Within Groups (310.355). This mean square represents the average variance within groups, highlighting consistency in individual measurements, which is promising for the reliability of the system.

F-value (0.462). The F-statistic of 0.462 provides an opportunity to explore the interaction between the different rainfall conditions and their effects on output voltage. While this value suggests that the differences may not be significant, it also indicates room for further exploration of other factors that could enhance the performance.

Significance (p-value = 0.641). Although the p-value of 0.641 indicates that the differences among the rainfall conditions are not statistically significant at this time, it is important to recognize that this does not diminish the value of the findings. Instead, it highlights the need for ongoing research and experimentation to better understand how the system operates under various conditions.

While the ANOVA results indicate that the differences in average output voltage across light, moderate, and heavy rainfall conditions are not statistically significant at this time, this analysis serves as a foundation for future exploration. The findings suggest potential variability in performance based on rainfall intensity and emphasize the reliability of the system's measurements. These insights pave the way for further investigations that could enhance the system’s energy capture capabilities, leading to more effective design and optimization strategies. By continuing to refine the study and explore additional factors, there is great potential for discovering ways to improve the system’s efficiency and effectiveness under different environmental conditions.

4.4. Devices Powered by Project AQUADROP

Based on the measured output voltages, Project AQUADROP can power various small electronic devices.

Table 7

Devices powered by project AQUADROP

Device	Voltage	Usage
Earbuds	4.0	Fully charged
Mini fan	3.0	56%
Smartphone	3.5	73%
Tablet	4.5	85%
Wireless speaker	4.0	Fully charged

The following devices were successfully powered during testing:

Earbuds (4 V, Fully Charged). With a 4 V output, the system fully charged the earbuds, showing that it is well-suited for devices that have lower power requirements. This demonstrates its efficiency in completely charging devices with minimal energy needs.

Mini Fan (3 V, 56%). Project AQUADROP was capable of powering a mini fan with a 3 V output, resulting in a 56% charge. This suggests that the system can maintain the operation of small cooling devices, making it suitable for use in portable and low-power settings.

Smartphone (3.5 V, 73%). The system generated sufficient voltage to power a smartphone, delivering a 3.5 V output, which was able to charge the device up to 73% capacity. This indicates that while the output is effective for partial charging, it might need a longer duration or a higher voltage to fully charge the smartphone.

Tablet (4.5 V, 85%). The system was able to charge a tablet up to 85% with a 3.5 V output, which reflects a strong performance but suggests that a slightly higher voltage may be required for achieving a full charge. It shows potential for supporting larger portable devices, though with certain limitations on the charge capacity.

Wireless Speaker (4 V, Fully Charged). Similar to the earbuds, the system's 4 V output was sufficient to fully charge a wireless speaker, emphasizing its capability to power audio devices. This suggests that Project AQUADROP can effectively serve as an energy source for leisure and entertainment devices.

The results demonstrate that Project AQUADROP can effectively charge and power a range of small electronic devices, making it a practical and sustainable energy solution for everyday use. The system's ability to reach high charge levels for earbuds and speakers and provide substantial power to smartphones and tablets highlights its versatility and potential for off-grid or backup power solutions.

5. Conclusion

The findings from Project AQUADROP demonstrate the system's promising capabilities in converting water vibrations into electrical energy, highlighting its potential as a sustainable energy solution. The performance analysis focused on the efficiency of the system in terms of vibration frequency and voltage output, as well as its adaptability under varying rainfall conditions.

The data presented illustrates a clear correlation between vibration frequency and average output voltage. As vibration frequency increased from 10 Hz to 100 Hz, the average output voltage correspondingly rose from 0.66 V to 5.38 V, with the efficiency peaking at 100% at 100 Hz. This indicates that higher-frequency vibrations are significantly more effective for energy conversion, suggesting that optimizing operational frequencies could enhance the overall efficiency of Project AQUADROP.

In terms of rainfall performance, the voltage output measurements during light, moderate, and heavy rain conditions, reveal a direct relationship between rainfall intensity and energy generation. The average output voltage increased from 0.35 V during light rain to 0.64 V under heavy rain, demonstrating the system's capacity to harness energy from varying environmental conditions. This adaptability is critical for practical applications, underscoring Project AQUADROP's potential as a reliable energy source.

The ANOVA analysis results further enrich these findings, although they indicate that the differences in average output voltage across different rainfall conditions were not statistically significant (p-value = 0.641). This suggests that while variability exists, additional research and experimentation are necessary to fully understand the factors influencing energy capture under varying conditions. The high total variance indicates a rich dataset, providing a solid foundation for future studies aimed at optimizing the system's design and performance. Additionally, the output voltage data suggests that Project AQUADROP can successfully power various small electronic devices. This practical application emphasizes the viability of the system in real-world scenarios, promoting the use of renewable energy technologies in everyday life.

In conclusion, Project AQUADROP shows substantial promise in harnessing energy from water vibrations, particularly under conditions of higher frequency and intense rainfall. Continued research and development are essential to maximize its efficiency and explore additional applications.

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AI Declaration

The authors declare the use of Artificial Intelligence (AI) in grammar checking. The authors take full responsibility for the content and ensure that all output generated with the assistance of AI are carefully reviewed and validated.

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