Experimental Study of Turbine Mechanism Using Cantilever PVDF Piezoelectric with Current Power on a Laboratory Scale

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***Abstract*— This research explores the integration of Internet of Things (IoT) technology with MEMS (Micro Electro Mechanical Systems) sensors and piezoelectric technology to enhance the efficiency and operational sustainability of devices. IoT connects physical devices to the internet to collect and exchange information and has become an integral part of Industry 4.0. The main components of IoT include physical objects, communication channels, software, operations, and data. In this study, IoT development focuses on the maritime sector with the application of MEMS sensors, piezoelectric technology, ocean current speed, and turbines. The use of piezoelectric technology allows devices to operate autonomously by harvesting energy from vibrations and pressure, further improving the efficiency of IoT devices. Experimental results show that in an open circuit, the highest average voltage at a speed of 1.1 m/s reached 0.019606 mV (capacitor) and 0.0056 mV (non-capacitor). In a closed circuit, with one non-capacitor piezoelectric, the average voltage was 14.762 mV and the average current was 0.0027 mA, producing a power output of 0.0398 mW. With four non-capacitor piezoelectrics, the average voltage reached 33.174 mV and the current was 0.0044 mA, producing a power output of 0.0146 mW. Meanwhile, with one capacitor piezoelectric, the average voltage was 4.947 mV and the current was 0.0023 mA, producing a power output of 0.01138 mW. With four capacitor piezoelectrics, the average voltage was 16.627 mV and the current was 0.0036 mA, producing a power output of 0.05986 mW. These results indicate that the piezoelectric turbine mechanism has significant potential as a reference for the development of future renewable energy technologies. The implementation of this technology allows IoT and MEMS devices to function autonomously and sustainably, supporting applications in various sectors including maritime and industry.**

Keywords— *Internet of Things (IoT), MEMS (Micro Electro Mechanical Systems), Ocean Current Speed, Piezoelectric Technology, Turbine*

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I. INTRODUCTION

The Internet of Things (IoT) and Micro Electro Mechanical Systems (MEMS) technologies have shown great potential in various fields. A book by [1] explains the application of IoT in multiple sectors such as libraries, intelligence, education, health, security, and privacy, as well as SMEs, demonstrating the significant benefits of this technology. These benefits include enhanced data management, improved efficiency, and more personalized user experiences. For instance, in libraries, IoT can streamline inventory management and improve user services by providing real-time data on book availability and usage patterns. In the context of maritime security, [2] reviews the role of IoT in eastern Indonesia, highlighting how intelligence gathering is less effective without the support of IoT technology. This includes the deployment of IoT devices for monitoring maritime activities, tracking vessel movements, and ensuring the safety of maritime operations. On the other hand, [3] emphasizes how IoT will revolutionize the economy and digital business by integrating information and communication technology, and restructuring industries and business models through big data utilization. The integration of IoT with big data allows for the collection and analysis of vast amounts of data, leading to more informed decision-making and the development of innovative business strategies.

Alongside the development of IoT, the application of MEMS in various sectors is also expanding. [4] describe the use of MEMS in smart devices and other micro systems, highlighting their role in enhancing device functionality and performance. MEMS technology enables the creation of smaller, more efficient sensors and actuators, which can be used in a wide range of applications from consumer electronics to industrial automation. A recent study by [5] shows that the development of IoT with MEMS sensors can accurately measure bridge structure vibrations, providing a clear picture of the importance of this technology combination in infrastructure monitoring. This is crucial for ensuring the safety and longevity of bridges, as continuous monitoring can detect early signs of structural weaknesses and prevent catastrophic failures.

In the field of ocean energy, research on the Ocean Wave Energy Harvester mechanism using the cantilever

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piezoelectric method has shown promising results on a laboratory scale. Research by [6] found that the largest electric power, amounting to 3.476 x 10^-7 watts, was obtained at a wave amplitude of 4.7 cm and with three piezoelectrics. This demonstrates the potential of piezoelectric materials in converting ocean wave energy into usable electrical power. In another scenario, [7] analyzed the utilization of sound energy based on piezoelectric materials in the Losari Beach area, producing an output of 0.7 volts when the material was not connected in series and 1.9 volts when connected in series. This study highlights the versatility of piezoelectric materials in harvesting different forms of ambient energy.

Another study by [8] examined the model of the Ocean Wave Power Plant (PLTGL) using the small-scale cylindrical float method. The results showed that a cylindrical float with a length of 30 cm, volume of 3114.5 cm³, arm length of 30 cm, and moment of inertia of 49.7400 kg.cm² produced maximum and continuous electric energy with an rms value of 0.28 volts and 0.014826 watts. This method provides a viable solution for harnessing ocean wave energy, offering a renewable source of power that can be used in coastal and remote areas. Furthermore, a more comprehensive study by [9] provided an atlas of 85 piezoelectric energy harvester designs in ocean applications, categorizing designs based on configuration and providing detailed information on materials, coupling modes, locations, and their power ranges. This atlas serves as a valuable resource for researchers and engineers looking to develop efficient and effective energy harvesting systems for marine environments.

Following these technological developments, [10] developed a highly flexible piezoelectric energy device (FPED) to harvest vibrations caused by flow, using piezoelectric layers such as PVDF and elastomeric materials such as rubber or silicone to achieve high electrical performance. The flexible nature of these materials allows the device to adapt to varying environmental conditions and maintain high energy conversion efficiency. The EFHAS ocean power plant concept was also proposed by [11], consisting of floating modules and hanging modules with FPED to generate electric power from ocean energy. This innovative approach combines multiple energy harvesting mechanisms to maximize power output. Another study by [12] explored the impact of key factors such as water depth and wave inclination on the output voltage generated by FPED, providing insights into the optimization of these devices for different marine environments

Complementing the study of ocean energy, [13] analyzed the potential of ocean currents in the Alas Strait as a source of renewable energy, considering underwater topography and tides. This study underscores the importance of understanding local environmental conditions to effectively harness marine energy. [14] emphasized the importance of natural frequency in improving the electrical performance of piezoelectric generator devices for ocean energy harvesting, showing that resonance between vibration frequency and the natural frequency of the device is crucial. Finally, research by [15] demonstrated the potential of PVDF piezoelectric materials in generating electric energy from rainwater pressure to reduce household electricity usage. This innovative application extends the use of piezoelectric materials beyond marine environments, showcasing their versatility and potential for widespread adoption in sustainable energy solutions.

II. Method

A. Problem Identification

This research focuses on the utilization of ocean energy as a potential renewable alternative energy source. This study will design and build a laboratory-scale mechanism to thoroughly test the concept. The mechanism used is a turbine with a cantilever piezoelectric approach. Currently, the research is at the stage of selecting the inputs to be varied. The two main variations chosen are wave variations and ocean current variations. These variations are expected to provide in-depth insights into their effects on the performance of the mechanism and overall system optimization.

B. Literature Study

This section is a material for studying reference materials from various journals as a final assignment reference. From the references or references, we get the wave theory in which there are wave frequency, amplitude, wave speed, and wave slope. Then there is also the theory of ocean currents which explains that there are several factors that have an influence such as wind friction, gravity, and temperature differences. The current itself has several types such as wind currents, geostrophic currents, and tidal currents. At the end there is also a discussion of piezoelectric from its general understanding to what affects the power generated by piezoelectric such as Piezoelectric Charge Constant, Piezoelectric Voltage Constant, Permittivity, and Electromechanical Coupling Factor.

C. Mechanism Modeling

In this study, a laboratory-scale piezoelectric turbine design was carried out to obtain generated power and use variations in waves and current speed. In designing the circuit, there will be steps in the process.

D. Data Collecting

Data collection regarding the magnitude of voltage that can be produced by the piezoelectric energy harvesting mechanism using this turbine mechanism.

1. Flume Tank

The mechanism that has been modeled and designed will be tested in a laboratory scale test pool, the pool used is a Flume Tank type pool in figure 1.

Figure. 1. Flume Tank

2. Piezoelectric

In Figure 2, it is known that the dimensions of the piezoelectric PVDF used are 25x13x1mm. Piezoelectric PVDF is used to generate an electric charge in response to mechanical pressure or stress. PVDF is often used in various applications because of its highly sensitive and reliable piezoelectric properties.

3. Digital Oscilloscope Multimeter

In this study, a Digital Oscilloscope Multimeter was used to monitor and analyze the signals generated by the piezoelectric sensor on the flumetank turbine, helping to obtain accurate data on pressure and vibration responses and providing in-depth insights into the performance and efficiency of the turbine system. This tool enables real-time measurement and data storage, supporting further analysis and solution development. In addition, the Oscilloscope Multimeter was also used to measure the voltage and current generated by the piezoelectric sensor, which is important for knowing the magnitude of the electric charge generated by mechanical pressure on the sensor and analyzing the performance of the sensor under various operating conditions.

4. Breadboard

Breadboards are a very useful tool to help develop and test electronic circuits. They allow assembly without soldering, making them ideal for prototyping. Using a breadboard allows developers to quickly design, test, and modify circuits without having to make permanent changes.

5. Arduino

Arduino is an open-source electronics platform that combines hardware and software to make it easier to create interactive projects. Its function as a microcontroller allows control of various devices and sensors through simple and flexible programming. In this study, Arduino is used for voltage readings from piezoelectric sensors installed on the flumetank turbine

Figure. 2. Piezoelectric PVDF

E. Analysis and Discussion

This experiment was conducted to see the effect of variations in water flow speed and impact points on the voltage generated by piezoelectrics. Experiments with this circuit were also conducted by dividing them into two categories, namely testing without a capacitor and testing with a capacitor. This was done to see the impact of the capacitor as a temporary charge storage on the voltage generated the figure of the circuit can be seen on figure number 4 and 5.

III. Results and Discussion

A. Mechanism Modelling

In the process of making this piezoelectric mechanism model using the 3D Rhino 8 application. In making this turbine model, the parts made are the turbine part, the piezoelectric beater, and the placement of the piezoelectric. Figure 4 is an example of the results of the turbine design that will be printed and used as a mechanism. Table 1 is a detailed turbine design.

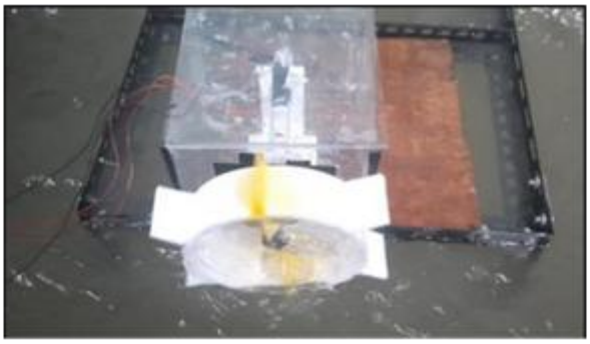


Figure. 3. Mechanism Design

TABLE 1.
DESIGN TABLE OF PIEZOELECTRIC TURBINE DESIGN

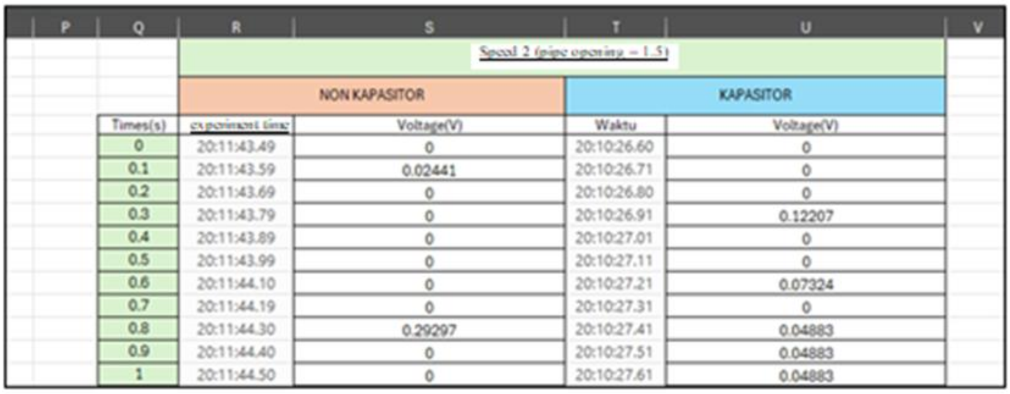
Number	Design Detail	Size		
		Lenght	Thickness	Height
1.	Diameter of The Inner Circle (Shaft Hole)	2,3 cm	0,5 cm	2 cm
2.	Diameter of The Outer Circle	15 cm	0,5 cm	4 cm
3.	Striker	3 cm	1 cm	4 cm
4.	Blade	4 cm	1 cm	4 cm

B. Experimental Data Result Retrieval

The data collection will be recorded in an Excel table as shown in Figure 5. The leftmost column includes time measurements in 100 ms intervals, the middle column provides the details of the data collection time, and the right column contains the voltage data generated by the piezoelectric device. Once the data table is completed, a data graph, like the example in Figure 5, Voltage Data Graph Example, can be produced.

C. Experiment Result

In Table 2 it can be seen that the highest average voltage is obtained at 4 piezoelectrics with a speed of 1.1m/s. This pattern shows that the more the number of piezoelectrics and the faster the water flow, the higher the average voltage will be.



P	Q	R	S	T	U	V
		Speed 2 (pipe opening = 1.5)				
		NON KAPASITOR		KAPASITOR		
	Times(s)	experiment time	Voltage(V)	Waktu	Voltage(V)	
	0	20:11:43.49	0	20:10:26.60	0	
	0.1	20:11:43.59	0.02441	20:10:26.71	0	
	0.2	20:11:43.69	0	20:10:26.80	0	
	0.3	20:11:43.79	0	20:10:26.91	0.12207	
	0.4	20:11:43.89	0	20:10:27.01	0	
	0.5	20:11:43.99	0	20:10:27.11	0	
	0.6	20:11:44.10	0	20:10:27.21	0.07324	
	0.7	20:11:44.19	0	20:10:27.31	0	
	0.8	20:11:44.30	0.29297	20:10:27.41	0.04883	
	0.9	20:11:44.40	0	20:10:27.51	0.04883	
	1	20:11:44.50	0	20:10:27.61	0.04883	

Figure. 4. Excel Voltage Data Retrieval

TABLE 2.
AVERAGE OPEN CIRCUIT VOLTAGE

Non Capasitor				
Speed (m/s)	1 Piezo (v)	2 Piezo (v)	3 Piezo (v)	4 Piezo (v)
1,1	0,0191	0,0424	0,0591	0,0720
0,8	0,0145	0,0321	0,0496	0,0538
0,6	0,0117	0,0243	0,0419	0,0468
0,4	0,0086	0,0170	0,0342	0,0390

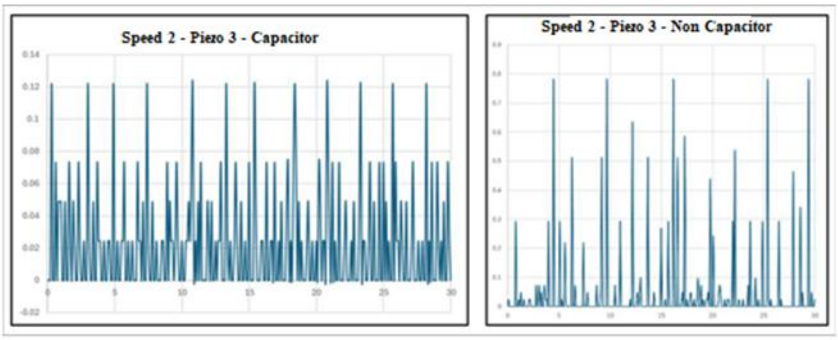


Figure. 5. Example of Voltage Data Graph

TABLE 3.
AVERAGE OPEN CIRCUIT VOLTAGE

		Capasitor		
Speed (m/s)	1 Piezo (v)	2 Piezo (v)	3 Piezo (v)	4 Piezo (v)
1,1	0,0056	0,0214	0,0382	0,0524
0,8	0,0042	0,0135	0,0223	0,0479
0,6	0,0035	0,0081	0,0122	0,0335
0,4	0,0020	0,0055	0,0077	0,0255

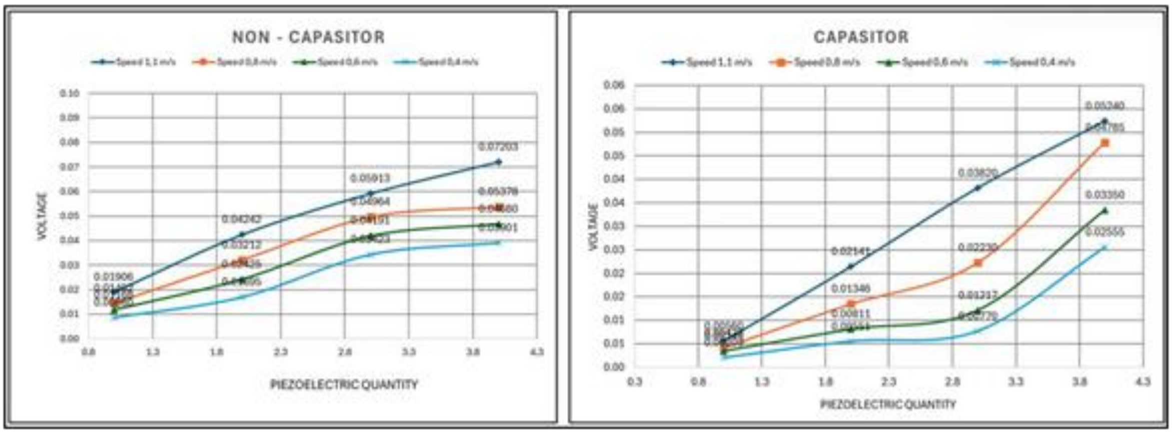


Figure. 7. Average Graph of Open Circuit with Capasitor (Right) and Non-Capasitor (Left)

Figure 7 shows the average voltage graph of the comparison results of the variation of the number of piezoelectrics and the variation of speed. In the figure, the highest average voltage is obtained at 4 piezoelectrics and a speed of 1.1 m/s, the average voltage reaches 0.07203 V (Non-Capacitor) and 0.0524 V (Capacitor). The use of capacitors tends to reduce the voltage produced by the piezoelectric, but makes the results more consistent, although the average voltage produced is lower when compared to non-capacitors.

TABLE 4.
CLOSED CIRCUIT POWER CALCULATION NON-CAPASITOR

	1 Piezoelectric			4 Piezoelectric		
Speed (m/s)	Voltage (mV)	Current (mA)	Power (mWatt)	Voltage (mV)	Current (mA)	Power (mWatt)
1,1	14,762	0,0027	0,0398	33,174	0,0044	0,1459
0,8	12,896	0,0018	0,0232	30,822	0,0041	0,1236
0,6	8,679	0,0017	0,0147	28,483	0,004	0,1139
0,4	5,759	0,0013	0,0075	24,901	0,0032	0,0797

TABLE 5.
CLOSED CIRCUIT POWER CALCULATION CAPASITOR

	1 Piezoelectric			4 Piezoelectric		
Speed (m/s)	Voltage (mV)	Current (mA)	Power (mWatt)	Voltage (mV)	Current (mA)	Power (mWatt)
1,1	4,947	0,0023	0,01134	16,627	0,0036	0,0598
0,8	3,974	0,0017	0,00675	11,192	0,0028	0,0313
0,6	2,839	0,0012	0,00341	7,543	0,0026	0,0196
0,4	2,352	0,0009	0,00212	4,461	0,0024	0,0107

In Table 4 and 5, it can be seen that the average voltage and average current at the number of 1 and 4 piezoelectrics are directly proportional to the increase in water current speed so that the power obtained is greater.

Figure 8 shows a comparison graph of the number of 1 piezoelectric (left) using a capacitor and non-capacitor with speed variations. The graph shows that the highest power is achieved at a speed of 1.1m/s of 0.0398mWatt (Non-Capacitor) and 0.01137mWatt (Capacitor). On shows a comparison graph of the number of 4 piezoelectric (right) using a capacitor and non-capacitor with speed variations. The graph shows that the highest power is achieved at a speed of 1.1m/s of 0.1459mWatt (Non-Capacitor) and 0.0598mWatt (Capacitor).

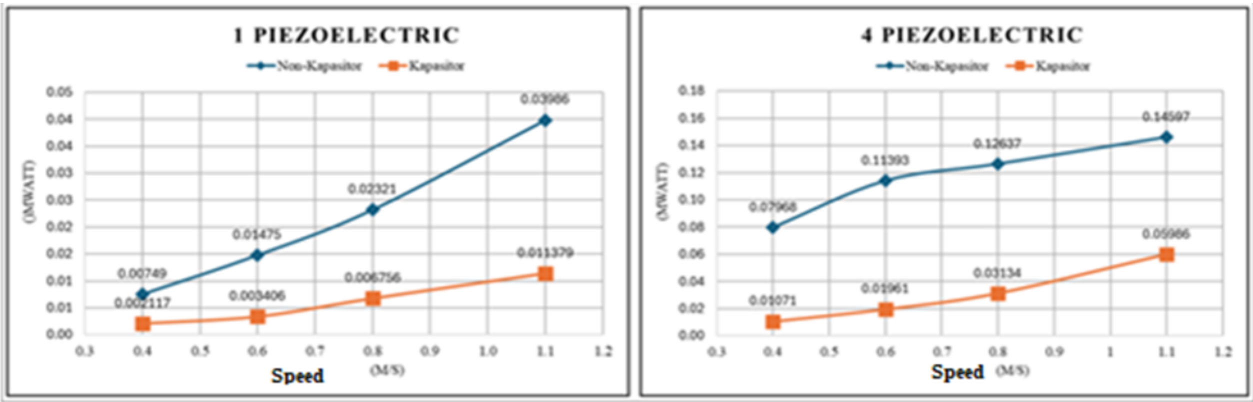


Figure. 8. Average Voltage Graph of Closed Circuit with 1 Piezoelectric (Left) and 4 Piezoelectric (Right).

	Crossbow MICAz [21, 59]	Intel Mote 2 [21, 59]	Jennie JN5139 [21, 60]
Radio standard	IEEE802.15.4/ZigBee	IEEE802.15.4	IEEE802.15.4/ZigBee
Typical range	100 m (outdoor), 30 m (indoor)	30 m	1 km
Data rate (kbps)	250 kbps	250 kbps	250 kbps
Sleep mode (deep sleep)	15 μA	390 μA	2.8 μA (1.6 μA)
Processor only	8 mA active mode	31–53 mA	2.7 + 0.325 mA/MHz
RX	19.7 mA	44 mA	34 mA
TX	17.4 mA (+0 dbm)	44 mA	34 mA (+3 dBm)
Supply voltage (minimum)	2.7 V	3.2 V	2.7 V
Average	2.8 mW	12 mW	3 mW

Figure. 9. Power Consumption of Some Commercial Wireless Sensor Nodes

D. Power Requirements Discussion

In the discussion of power requirements, Table 4.5 explains that each of these devices uses the IEEE 802.15.4/ZigBee radio standard and has various technical specifications such as range, data rate, power consumption in various modes, supply voltage, and average power consumption [16]. These devices are commonly used in wireless sensor network applications, which are often applied in various fields such as environmental monitoring, home automation systems, and health monitoring. The data that has been obtained will then be calculated and compared the amount of piezoelectric to supply the required power requirements, as follows:

The power used by 1 piezoelectric non-capacitor at a speed of 1.1m/s is 0.0398mWatt.

Power specifications required by the tool sensor

- Crossbow MICAz : 2.8 mW
- Intel Mote 2 : 12 mW
- Jennic JN5139 : 3 mW

Comparison of piezoelectric output power with the average power required by each device:

- Crossbow MICAz
- Required : 2,8 Mw
- Piezoelectric power : 0,0398 mW

Amount of piezoelectric required

$$\frac{2.8\square\square}{0,0398\square\square} = 70,35\ \square\square\square\square\square\square\square\square\square\square\square\square\square\square\square\square\square$$

- Intel Mote 2
  o needed : 12 mW

o piezoelectric power : 0,0398 mW
o amount needed:
12mW / 0,0398mW = 302 piezoelectric

- Jennic JN5139
  o needed : 3 mW
  o piezoelectric power : 0,0398 mW
  o amount needed:

$$\frac{3\ \text{mW}}{0.0398\text{mW}} = 76\ \text{piezoelectric}$$

The given piezo source has a current of 0.0027 mA, a voltage of 0.014 V, and a power of 0.0398 mW. When compared to the power required by the devices shown in the figure, namely the Crossbow MICAz (2.8 mW), Intel Mote 2 (12 mW), and Jennic JN5139 (3 mW), the output power of these piezos is much smaller. As a result, to supply these devices with sufficient power, a large number of piezos are required. Specifically, the Crossbow MICAz requires about 71 piezos, the Intel Mote 2 requires about 302 piezos, and the Jennic JN5139 requires about 76 piezos. Therefore, one piezo is not enough to supply these devices, but rather several piezos connected in series or parallel to achieve the required power.

In Figure 9, it is known that the Crossbow MICAz sensor uses an average power of 2.8 mW, so the piezoelectric area required to operate the sensor can be compared, the calculation is as follows:

$$\text{Increase factor} = \frac{\text{Power required}}{\text{Current power}}$$

$$\text{Increase factor} = \frac{2{,}8\ \text{mW}}{2{,}4 \times 10^{-7}\ \text{mW}} = 1{,}167 \times 10^{10}$$

$$\text{Needed Area} = 0{,}000325 \times 1{,}167 \times 10^{10}\text{m}^2$$

$$\text{Needed Area} = 3{,}79 \times 10^{6}\text{m}^2$$

The power enhancement factor required to meet the requirement is about 1.167 × 10^{10} times the power currently available. As a result of this enhancement, the new piezoelectric area required to achieve this power is about 3.79 × 106 m².

- Voltage Calculation

$$V = \frac{td}{\epsilon} P$$

Where:

T	: 1 mm = 0,001 m
d	: 23 C/N
ϵ	: 12 F/m
P	: Ignored

$$V = \frac{0.001\text{m} \times 23\text{C}/N}{12\text{F/m}} = 0{,}000192\ \text{V}$$

- Capacity Calculation

$$Q = CV = \frac{\epsilon A}{t} V$$

Where :

V	: 0,000192 v
ϵ	: 12 F/m
A	: 0,000325 m^2
t	: 0,001 m

$$Q = \frac{12\text{F/m} \times 0{,}000325\ \text{m}^2}{0{,}001} 0{,}00192\text{v} = 0{,}00747C$$

- Stored Energy

$$W = \tfrac{1}{2} CV^2$$

$$C = \frac{\epsilon A}{t} = 3{,}9 \times 10^{-3}F$$

$$C = \frac{1}{2} 3{,}9 \times 10^{-3} \times (0{,}00192\ \square)^2 = 7{,}19\ \text{nJ}$$

$$= 7{,}19 \times 10^{-6}\ \text{mJ}$$

- Energy Power in 30 Seconds

$$P = \frac{W}{t} = \frac{7{,}19 \times 10^{-9}\ \text{J}}{30\ \text{s}} = 2{,}4 \times 10^{-10}\ \text{W}$$

$$P = 2{,}4 \times 10^{-7}\ \text{mW}$$

IV. CONCLUSION

Based on the data obtained after conducting the experiment, the following conclusions can be drawn:

1. The design was carried out by creating a water turbine design concept where the middle part was designed so that the piezoelectric was exposed to pressure or impact. The process began by using Rhino 8 software for detailed 3D design. Furthermore, if the design process is complete, the fabrication or 3D printing process will be carried out and in this section the material selection is carried out, namely PLA + (Polylactic Acid). After the fabrication is complete, the next step is to design the mechanism by arranging the turbine stand so that the water current can hit the blade perfectly. When all has been done, the final part ensures that the mechanism can work properly and data collection is carried out.
2. The effect of variations in current speed changes is directly proportional to the results obtained, if the current speed is greater, the voltage obtained will be greater and vice versa. For example, in an open circuit of 1 non-capacitor piezoelectric, the results are 0.01906V (current velocity 1.1 m/s), 0.0145V (current velocity 0.8m/s), 0.01168V (current velocity 0.6m/s), and 0.0086V (current velocity 0.4m/s). The results of this voltage also show a pattern like this for variations in closed circuits, for example in 1 non-capacitor piezoelectric 0.01476V (current velocity 1.1m/s), 0.0129V (current velocity

0.8m/s), 0.00868V (current velocity 0.6m/s), and 0.00576V (current velocity 0.4m/s).

3. The effect of variations in the number of piezoelectrics on the voltage obtained is directly proportional. In this case, the more piezoelectrics used, the higher the voltage obtained. An example of a non-capacitor open circuit at a current velocity of 1.1m/s is 0.01906V (1 piezoelectric), 0.04242V (2 piezoelectrics), 0.05913V (3 piezoelectrics), and 0.07203V (4 piezoelectrics). Then an example of a non-capacitor closed circuit at a current velocity of 1.1m/s is 0.01476V (1 piezoelectric) and 0.03317 V (2 piezoelectrics).

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