Development of renewable energy system for low power underwater devices

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ABSTRACT

Underwater sensor networks (UWSNs) are an emerging field in the research area as they have potential applications starting from pollution monitoring to defense and ocean exploration. Ocean monitoring is of great importance in marine scientific research. However, battery-operated devices utilized in such systems have limited power and maintenance is difficult. So, devices used underwater suffer from many research challenges and energy issues. Apart from all the problems, harvesting energy underwater is the main limiting factor. Nonrenewable energies come from sources that may not be replenished in our lifetime. Hence, it is very much essential to use renewable energy sources. Ocean has an unlimited amount of energy like wind energy, solar power, and tidal energy. Obtaining sufficient energy is sort of difficult since devices are underwater. Researchers are continuously working on it. Water energy is quite environmentally friendly, and it is a sustainable solution for a secure energy system. This paper implements a renewable energy system using piezoelectric (PZT) sensor, which generates sufficient power for low-power underwater devices by employing two stage amplifier circuits. Experimental outcome shows the proposed energy harvesting system can generate a maximum voltage of 10.6 V and current of 10.1 mA which is sufficient to run low power underwater device.

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1. INTRODUCTION

With the growth of electronics, technologies have aided in reducing the power needed to run sensor devices and thereby increasing its autonomy [1]. The network lifetime of sensor device can be improved using simple renewable energy resource [2]. Energy harvesting is an evolving idea in maintaining sensor networks, whereby each sensor device is independent in terms of energy, reducing operation and battery expenditures. In dealing the UWSNs environment and other comparable applications, autonomous energy harvesters must be developed. To supply energy to the sensor, many forms of power generation were investigated, with its own set of operating concepts and components, each of which has set of benefits and drawbacks [3]. The renewable power generators are classified into two types [4]: semi-submerged devices, which generally operates on the surface of ocean; and fully submerged devices, which operates under the surface of ocean. An example of an underwater sensor network is shown in Figure 1.

The assertiveness nature of ocean (for example, the influence of fauna, weather condition, navigation, and waves) and the issues created by microbes, an occurrence comprised of micro and macro-organisms growing on the hardware interfaces, seem to be two significant hurdles towards the proper functioning of power sources in ocean environments. Bacterial contamination has a major impact on structural integrity, lowering device lifespan and efficiency. The benefits of employing a device on the surface of sea include its ease of use, low operational cost and offers wide range of technical alternatives, such as using piezoelectric (PZT) energy, wind and solar. The downsides include that the devices are prone to tidal effects, and can disrupt marine movement (a restricted zone, a farm, are required for such devices), aquatic creatures may destroy these equipment's, as well as being susceptible to contamination [5], [6].

The significant benefits of underwater devices are that they are not exposed to sunlight and will not be subjected to the influence of the waves. The downsides are that they can't make utilization of wind and solar energy; there could be seaweed formation inside the equipment; the device could be harmed via fishing lines; and membrane fouling concerns are indeed prevalent. Considering their various purposes, these systems can utilize universal harvesting technologies [6], [7]. In next section different energy harvesting method used in underwater scenarios are studied and identified its benefit and limitation. This paper aimed at addressing the limitation of existing energy harvesting system [8] using piezoelectric sensors [9], [10] by introducing a two-stage amplification enabled piezoelectric sensors-based energy harvesting system.

The significance of research work is as follows. The proposed piezoelectric energy harvesting system uses a two-stage amplification model to generate higher voltage and current. Our two-stage energy harvesting model is very efficient in powering underwater sensors. The proposed energy harvesting model power generation efficiency is analyzed by varying the depth of PZT sensors.

The paper is arranged as follows. In section 2, the paper studies various existing energy harvesting systems. In section 3, the limitation of water turbine and proposed two-stage energy harvesting system is presented. In section 4, the power generated using the proposed energy harvesting model is studied. In section 5, the significance of the proposed energy harvesting system and its future direction are discussed.

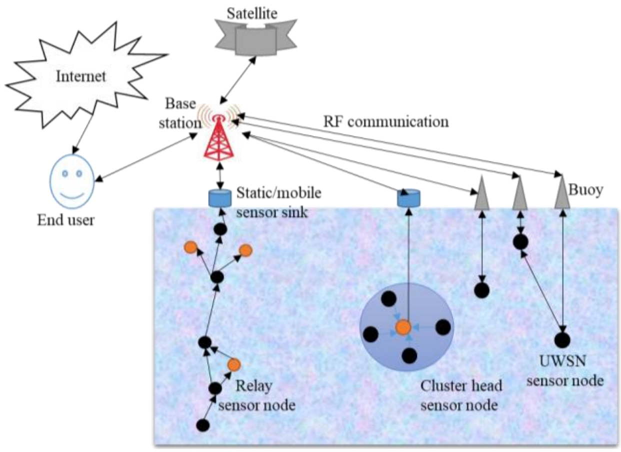

Figure 1. Architecture of an underwater sensor network [6]

2. LITERATURE SURVEY

This section presents a survey of various recent energy harvesting methodologies designed for underwater wireless sensor networks environment. Rigourd *et al.* [11], designed an electromechanical energy transducer in an oceanic environment using commercially available piezoelectric sensor components. They harvested the energy but did not use any amplification circuit and did not apply it to any underwater device. Zou *et al.* [12] designed an energy harvesting system in underwater system using mechanical energy of human motion through bionic stretchable nanogenerator; the model used both electrostatic induction principles and triboelectrification effects induced through flowing liquid. The system generated a maximum voltage of 10 volts in open circuit. Diab *et al.* [13] using tiny sphere-shaped piezoelectric transducer designed a low-cost energy harvesting system. The model is implemented through simulation with stored voltage result of 3 volt is measured; however, no experimental work is done using actual device.

Jang and adib [14] designed an energy harvesting system using piezoelectric sensor, where acoustic waves are transmitted toward piezoelectric sensor which induce vibration and resultant electrical charge are stored; the model can generate around 1.8 V. Abdellatif *et al.* [15] used solar charged device for charging RF modem and used for low-cost underwater data sensing; however, device covers only a small underwater area. Wei *et al.* [16], used dynamic induction method for charging autonomous vehicle and the device used for Underwater data collection; however, the model works for very small communication range.

Filho *et al.* [17] designed a self-powered internet of underwater things for provisioning video streaming application in underwater; however, consumes more power compared to depth. Geréb *et al.* [18] discussed about importance of reducing component size and power device through rechargeable battery for provisioning hydroacoustic communication application; nonetheless, the models don't produce any energy and emphasis is given for monitoring and reducing the current dissipation. Vu and Joyoong [19], for running underwater wearable applications designed a thin and waterproof high-efficient pressure sensors. The model generates 10 mW of power Suitable for underwater wearable applications; however, it works only within small communication range. Tiancong *et al.* [20], analyzed various methods of energy harvesting underwater and stated ocean kinetic energy harvester is the best method for harvesting energy and powering distributed sensors in ocean; Their method generates sufficient power to sensor device and LEDs. Yihan *et al.* [21] designed an autonomously powered triboelectric nanogenerator using piezoelectric sensors for monitoring mechanical motions, rescue, and search operation in oceanic environment. Kargar and Hao [22] for measuring wave period and wave height in ocean they designed using drifter-based piezoelectric sensor and tested in simulated environment. Faria *et al.* [23], designed havesting system using linear electromagnetic energy considering frequency ranging between 0.1-04 Hz. The model has potentiality to generate 7.77 milli joule per second considering frequency of 0.4 Hertz. Zhou *et al.* [24], a designed a model for measuring acoustic pressure gradient using scandium-doped aluminum nitride piezoelectric higher frequency microelectromechanical system hydrophone with larger operational data rates for underwater environment. The model is predominately focused on studying and monitors the dolphins' calls aiding its conservation. Similarly, the researchers [25], [26], showed that in underwater environment the output relies on depth of seabed and power generated is less near the seabed in comparison with surface; they generated a voltage of 1.5 V and produce 5.8 mW current. The significant benefit of using piezoelectric-based energy sensor for different application purposes [27] in underwater scenario motivates the proposed model to adopt an energy harvesting system [28] using piezoelectric sensors [29]. However, an extensive survey studied on application and energy harvesting method studied in [30] shows the power generated using piezoelectric sensor can be improved by designing an effective amplification design; In next section such design is presented.

3. PROPOSED DESIGN AND IMPLEMENTATION

This section presents a two-stage energy harvesting system for UWSNs. Initially, the experiment was started with water turbine, but the energy generated using water turbine was less.i.e., 1 to 2 V and which not sufficient to run a low power underwater device [31], [32]. Further, the work introduces a piezoelectric sensor-based energy harvesting mechanism using two-stage amplification circuit to achieve higher voltage and current to power the underwater sensor device and enhance the lifetime of UWSNs [33].

3.1. Sensor output

The generation of energy using piezoelectric sensor is composed of following steps:

- The piezoelectric sensor [34] is used in proposed energy harvesting system for converting mechanical energy (pressure) into electrical energy.
- The piezoelectric sensor produces electricity when there is a pressure applied on its surface.
- A PZT sensor is just kept in water tank with some water pressure.
- When measured the voltage it was between 2 mv to 1 V.
- As the water movement or water pressure increases the voltage is increasing. Experiment is conducted for a depth of 5 meters in swimming pool.

3.2. Amplifier stage output

As the result suggests that sensor output was very low not able to run any underwater device, hence it is required to use amplifier circuits to give the required power to underwater device. The sensor output is analysed with the following aamplifier circuits such as a) instrumentation amplifier, b) transimpedance amplifier, and c) charge amplifier. After analysing the amplifier circuits, it is noticed that charge amplifier is simplest circuit of remaining amplifiers circuit as the circuit is simple to construct and provides enough power to charge an underwater device. The data suggests that using the amplified output voltage we can easily charge an underwater device as shown in Figure 2:

- The results are tabulated for 2 sets of sensors with 2 stages of amplification.
- The obtained output voltage was much satisfactory to meet requirement of underwater device.

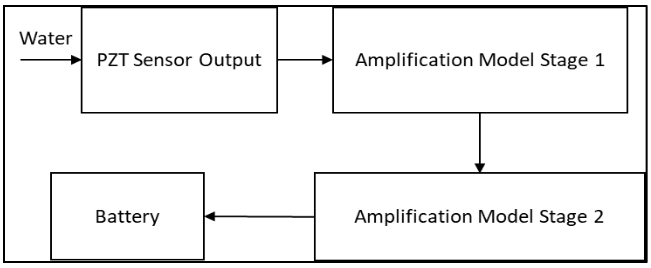

Figure 2. Block diagram of amplification stage

3.3. Block diagram of implementation module

The block diagram of proposed energy harvesting system is shown in Figure 3.

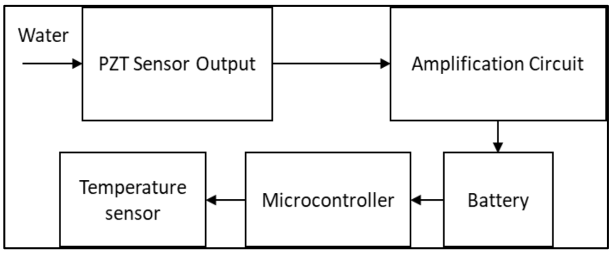

Figure 3. Block diagram of implementation module

Stage 1:

$$Gain = 1 + \frac{R_f}{R_1} \quad (1)$$

$$V_0 = V_{in} * Gain \quad (2)$$

$$= V_{in} * \left(1 + \frac{R_f}{R_1}\right) \quad (3)$$

then,

$$V_0 = V_{in}(1 + 100) = V_{in} * 101\ V,\ when\ R_f = 100\ K\Omega\ \&\ R_1 = 1\ K\Omega \quad (4)$$

Stage 2:

$$take\ R_{f1} = 10K\Omega\ \&\ R_1 = 1K\Omega$$

in the next section the implementation details of hardware and corresponding outcomes of energy harvesting efficiency of proposed design is studied.

4. RESULTS AND DISCUSSION

This section conducts experiments for measuring the performance efficiency of the proposed energy harvesting system. The energy harvesting system is designed using 20 PZT sensors, amplifier, rechargeable lead acid battery, Arduino Eno microcontroller, and temperature sensors. The performance of the proposed two-stage energy harvesting system is measured in terms of voltage and current generated under varying depth. The testbed used for harvesting energy is shown in Figure 4. The piezoelectric sensor placed below underwater is shown in Figure 5. Measuring output voltage of PZT sensor is shown in Figure 6. The temperature sensor used for measuring temperature at different depths is shown in Figure 7. The proposed implemented module for harvesting energy using PZT sensors is shown in Figure 8. The observer temperature measured at different depth noticed is shown in Figure 9.

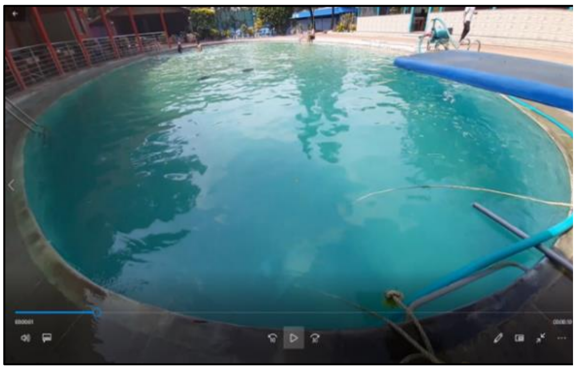

Figure 4. Testbed environment

Figure 5. PZT kept in underwater

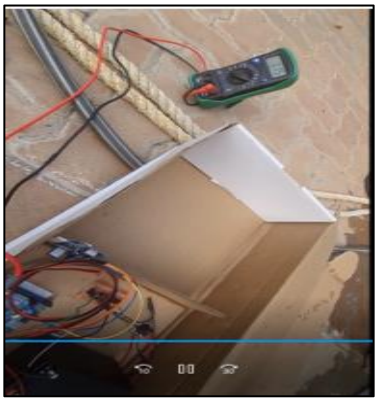

Figure 6. Measuring output voltage of PZT sensors

Figure 7. Temperature sensor to observe temperatures at different depths

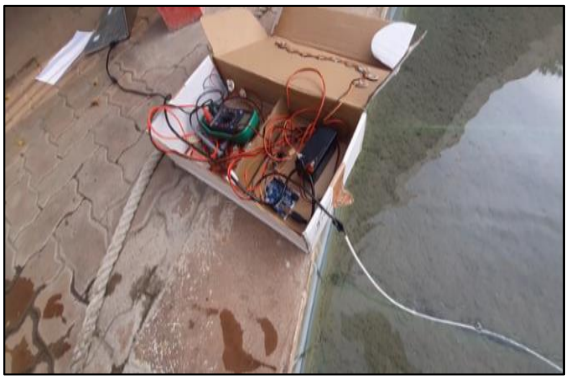

Figure 8. The proposed implemented module

Figure 9. Monitoring observed underwater temperature on PC

4.1. Power generation in stage 1

The amount of power generated using 20 PZT sensors using proposed energy harvesting system of stage 1 is graphically shown in Figures 10-12. The depth size varies from 1 to 5 meters. Figure 10 shows the graphical representation of output voltage (mV) measured at the different depth in stage 1. A minimum of 42 mV is experienced at depth of 1 meter and maximum of 74 mV is experienced at depth of 5 meters. The outcome obtained shows that as the depth of sensor placement increases the output voltage measured at stage 1 is increased. Figure 11 shows the graphical representation of amplification voltage output (V) measured at the different depth in stage 1. A minimum of 1.8 V is experienced at depth of 1 meter and maximum of 2.25 V is experienced at depth of 5 meters. The outcome obtained shows that as the depth of sensor placement increases the amplification voltage output measured at stage 1 is increased. Figure 12 shows the graphical representation of amplification current output (mA) measured at the different depths in stage 1. A minimum of 1.43 mA is experienced at depth of 1 meter and maximum of 2.13 mA is experienced at depth of 5 meters. The outcome obtained shows as the depth of sensor placement increase the amplification current output measured at stage 1 is increased.

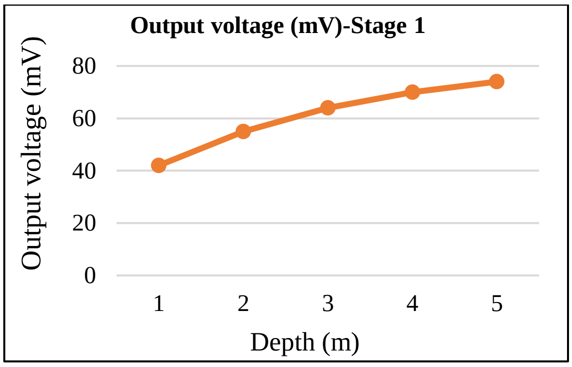

Figure 10. Output voltage of stage 1

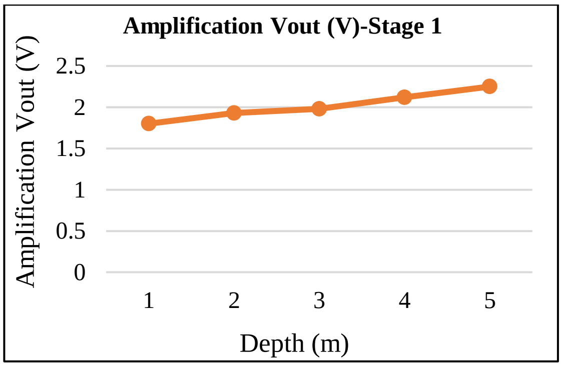

Figure 11. Amplification voltage output of stage 1

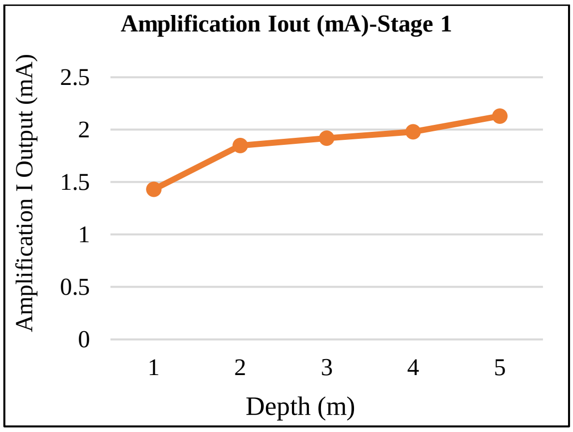

Figure 12. Amplification current output voltage of stage 1

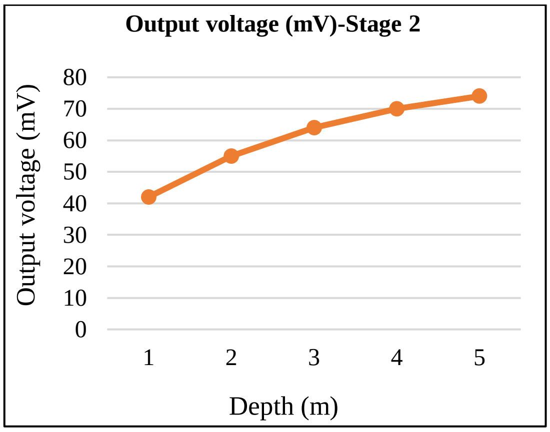

Figure 13. Output voltage of stage 2

4.2. Power generation in stage 2

The amount of power generated using 20 PZT sensors using proposed energy harvesting system of stage 2 is graphically shown in Figures 13-15. The depth size is varied from 1-5 meters. The Figure 13 shows the graphical representation of output voltage (mV) measured at the different depth in stage 2. A minimum of 42 mV is experienced at depth of 1 meter and maximum of 74 mV is experienced at depth of 5 meters. The outcome obtained shows as the depth of sensor placement increase the output voltage measured at stage 2 is increased. The Figure 14 shows the graphical representation of amplification voltage output (V) measured at the different depth in stage 2. A minimum of 7.6 V is experienced at depth of 1 meter and maximum of 10.6 V is experienced at depth of 5 meters. The outcome obtained shows as the depth of sensor placement increase the amplification voltage output measured at stage 2 is increased. The Figure 15 shows the graphical representation of amplification current output (mA) measured at the different depth in stage 2. A minimum of 6.8 mA is experienced at depth of 1 meter and maximum of 10.1 mA is experienced at depth of 5 meters. The outcome obtained shows as the depth of sensor placement increase the amplification current output measured at stage 2 is increased.

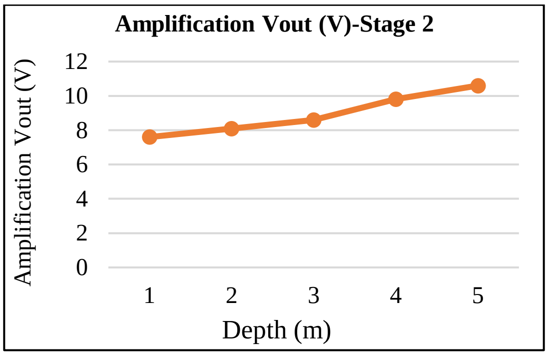

Figure 14. Amplification voltage output of stage 2

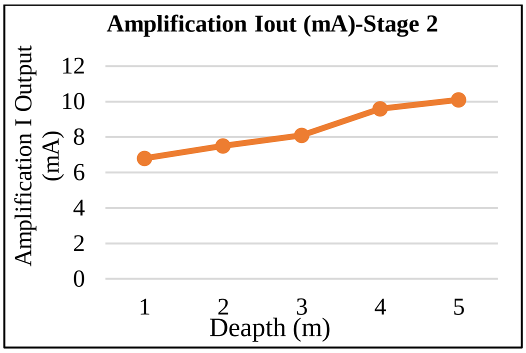

Figure 15. Amplification current output of stage 2

4.3. Temperature at different depth

In this work the temperature sensor is placed in the pool by, and temperature is measured. The Figure 16 shows the graphical representation of temperature measured at the different depth. The depth size is varied from 1-5 meters. A maximum temperature of 23.26 ºC is experienced at depth of 1 meters and minimum temperature of 24.44 ºC is experienced at depth of 5 meters. The outcome obtained shows as the depth of sensor placement increase the temperature measured is reduced.

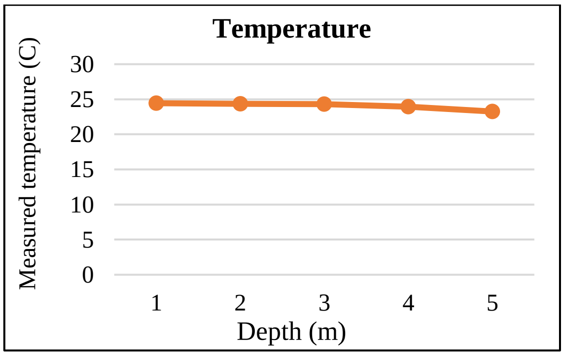

Figure 16. Temperature measure at different depth

5. CONCLUSION

This paper shows improving lifetime of underwater sensor network is very important. Designing efficient energy harvesting system plays a very important role in increasing network lifetime for provisioning future smart applications. Various energy harvesting methods such as wind, electromagnetic, solar, and piezoelectric energy. are used in designing energy harvesting system for underwater sensor network. In this paper initially explored generating energy using wind turbine; however, the voltage generated ranges between 1-2 volt which is vary less to run the device or charge the batteries/capacitors. In addressing this work designed a new energy harvesting system using piezoelectric sensors systems by incorporating a two-stage mechanism for amplification of voltage and current. Experiment outcome shows the proposed energy harvesting design can generate a maximum voltage and current of 10.6 V and 10.1 mA, respectively considering a maximum depth of 5 meters.The generated power is sufficient to run a low power underwater temperature sensor. In future work the water proofing mechanism will be designed and performance of proposed two stage energy harvesting system power generation efficiency will be tested considering different water sources, terrain, and depth.

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