DEVELOPMENT OF PIEZOELECTRIC HARVESTING SYSTEM AS AN ALTERNATIVE RENEWABLE ENERGY FOR AUTOMATED STREET LIGHT IN MALAYSIA

M.I.F. Kamardan[1], A.Z. Annuar[2], H.A. Zakaria[2], W. Ahmed[3] and W.H. Wan Hassan[2]

[1]Malaysia-Japan International Institute of Technology,
Universiti Teknologi Malaysia, 54100
Kuala Lumpur, Malaysia.

[2]Faculty of Ocean Engineering Technology and Informatics,
Universiti Malaysia Terengganu, 21030 Kuala Nerus,
Terengganu, Malaysia.

[3]Pakistan Institute of Engineering and Applied Sciences,
Nilore, 44000 Islamabad,
Pakistan.

Corresponding Author's Email: [2]whafiza@umt.edu.my

Article History: Received 10 December 2020; Revised 7 April 2021;
Accepted 17 August 2021

ABSTRACT: In the past few decades, energy consumption for commercial purposes in Malaysia has increased by 100-fold due to escalating development in most states in Malaysia. The intrinsic ability of piezoelectricity to detect mechanical energy and convert it to electrical energy seems to be a promising solution to provide energy for low-power applications of electronic devices, including street lights. It is observed that the street light operation is not effectively managed and consequently caused energy waste. Therefore, this paper aims to exploit the potential of piezoelectric material as an alternative energy supply for automatic street light application. This work consists of three phases, including developing an energy harvesting system, a street light system, and a combination of both systems. A modified piezoelectric design was proposed by sandwiching elastic materials between piezoelectric sensors to increase the mechanical capacity. The result shows that the modified design produced 3.50 V, 30% higher than the commercial piezoelectric design, and capable of supplying low current to the automated street light system. Findings from this study might reduce energy consumption by a street light and indirectly provide a more sustainable way to supply electricity to street lamps.

KEYWORDS: *Piezoelectric; Renewable Energy; Harvesting System; Automated Street Light*

1.0 INTRODUCTION

The electrical energy demand in Peninsular Malaysia is expected to increase to 84% by 2020, with an increment rate of 1.8% annually [1]. This energy usage includes street light consumption as part of the commercial section besides industrial and residential areas. Energy can be reduced by lowering the energy consumption of street lights using a vehicle detection method that will turn off when no vehicle is detected [2]. Apart from the standard light and dark detection using a light-dependent resistor (LDR), the street light's energy supply can be altered from the grid to using ambient renewable energy collected by vibration possessed in a piezoelectric material that will convert vibration energy to electrical energy from human footsteps.

A recent study has demonstrated that humans can use piezoelectric energy to generate electricity only by walking [3]. A comparison between lead zirconate titanate (PZT) and polyvinyl flouride (PVDF). structures implanted in a shoe with a switching circuit was established in a previous study [3]. The highest power generated by the PZT unimorph structure was four times higher than the PVDF film that produced 80 mW and 20 mW of power, respectively. In any case, the highest voltage by the frequency generator was observed to be just 0.25 mW, which is unsuitable for controlling a radio frequency transmitter. [3]. The DC-DC converter was connected to the energy storage to supply a radio frequency mounting on the shoe. The test demonstrated that the switching converter circuit produced electrical energy more productively, about twice as much as the first direct controller circuit. The entire set-up was effective to power low-need electronic gadgets as the switching circuit gave continuous power when walking. Hence, piezoelectric could provide a sustainable solution to recycle energy [4].

It was reported that classic street light consumes 1/5 of the overall energy usage in India, which is relatively high in comparison with automated street light [5]. The system deployed several sensors to control the lamp's energy usage, including LDR, Wi-Fi module, and ultrasonic sensor. While the energy source itself is from the grid, the system is expected to give additional renewable energy to recycle the ambient vibration released by the crowd's movement. Implementing an infrared sensor to control the street light based on traffic density at the nearest pole was proposed, and it was proven to reduce the energy consumption by 70% as the traffic density is sparser at night [6]. The street light is turned off during the idle period as the infrared sensor detects no object movement. This method is yet to be implemented in Malaysia as the current conventional system using the timer is still practiced [6]. A similar study was conducted, in which a piezoelectric material was generated and salvaged on demand to power up street lights based on the traffic density [7]. Piezoelectric generation on the highway for street light electrification produces 1.5 kWh output per day [8]. Sensor technology has been utilized to minimize the light output and piezoelectric materials to control and deliver a power source to the street light system [9]. In common, these works [7-9] did not attempt to modify piezoelectric materials to maximize the output power.

Hence, this paper aims to enhance the piezoelectric design to obtain the maximum output power. An automatic street light system powered by a piezoelectric energy harvesting system is proposed. The proposed system uses a deficient dropout voltage device compatible with the piezoelectric element's low current output.

2.0 METHODOLOGY

This study was carried out in three phases. The first phase consists of developing a piezoelectric energy harvesting circuit, the second phase comprises fabricating an automatic street light system, and the third phase featured both the piezoelectric energy harvesting circuit and the automatic street light system. In phase 1, the process started by experimenting to validate that piezoelectric can generate electricity. Next, a suitable piezoelectric material for the energy harvesting system was selected. Finally, the output produced from system was maximized through the modified design of piezoelectric material.

2.1 Development of Piezoelectric Energy Harvesting System

Figure 1 illustrates the first phase of the methodology. The validation process was initiated to confirm the capability of piezoelectric material as an energy generator. An essential circuit connection of a piezoelectric disc using PZT material was connected with a bridge rectifier circuit to convert AC to DC from a piezoelectric material and then connected with a light-emitting diode (LED), as shown in Figure 3. The piezoelectric material selection process between PZT and PVDF was conducted to differentiate each material's output voltage. The connection between the PZT also needs to be connected in parallel to increase the piezoelectric element's current output. The development of the piezoelectric energy harvesting system used lower dropout electronic devices to reduce power loss during transmission. A DF40M AC-to-DC converter diode was used to convert the current from AC to DC, which is similar to four IN4007 diodes. The voltage regulator

LM2936 is practically suitable for this system because the low quiescent device that can take the input of current as low as 20 μA at 100 μA load is significantly compatible with the low current produced by a piezoelectric device.

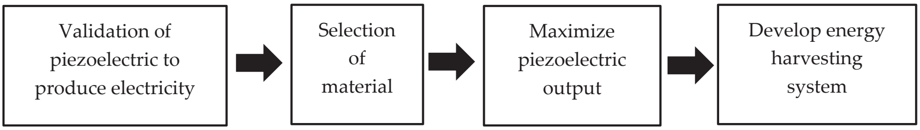

Figure 1: Methodology for phase 1

2.2 Development of Automatic Street Light System

The second phase developed an automatic street light system that used the LDR and (Infrared) IR as the primary input for sensors to detect light and vehicles. The input is executed at the microcontroller unit PIC16F877A, resulting in an LED output that resembled the street light. The operation of the system is illustrated in the flow chart shown in Figure 2. The system used the IR LED and IR receiver through the LM358 integrated circuit that converts the analog signal from the IR into the digital output that can be read at the digital input from a PIC microcontroller. As the input is binary, input one is considered a positive input to trigger a signal as a vehicle passed is detected. If the LDR sense no light, the LED output is turned, while if there is no vehicle passed or the LDR detects the presence of light, the LED is turned off. The condition is only satisfied if both sensors are in a positive state.

2.3 Combination of Both Systems

Finally, both systems were connected according to the schematic diagram in Figure 3. Transistor 2N3904 was proposed to switch between the piezoelectric system and the output LED on PIC 16F877A. When the output signal is one from the PIC microcontroller, the transistor's automatic switch activated the circuit's connection; therefore, the LED can be turned on. The circuit was also tested on the breadboard, and the LED output was observed after applying the condition of the sensor and the input energy from the piezoelectric power source. Therefore, after passing the voltage regulator circuit LM2936, the current is stored temporarily at the 100 μF capacitor before being supplied to the LED. The LED turns on after any vehicle approaches, and the LDR does not detect light, which gives an output signal of 5 V from the PIC microcontroller. Thus, it activates the base current that requires a minimum current of 0.5 mA to operate the switch between the piezoelectric generator and the LED.

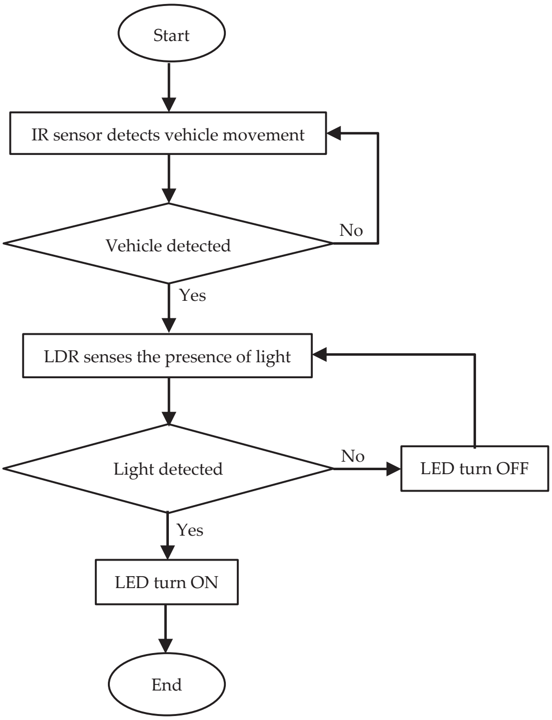

Figure 2: A flow chart of phase 2

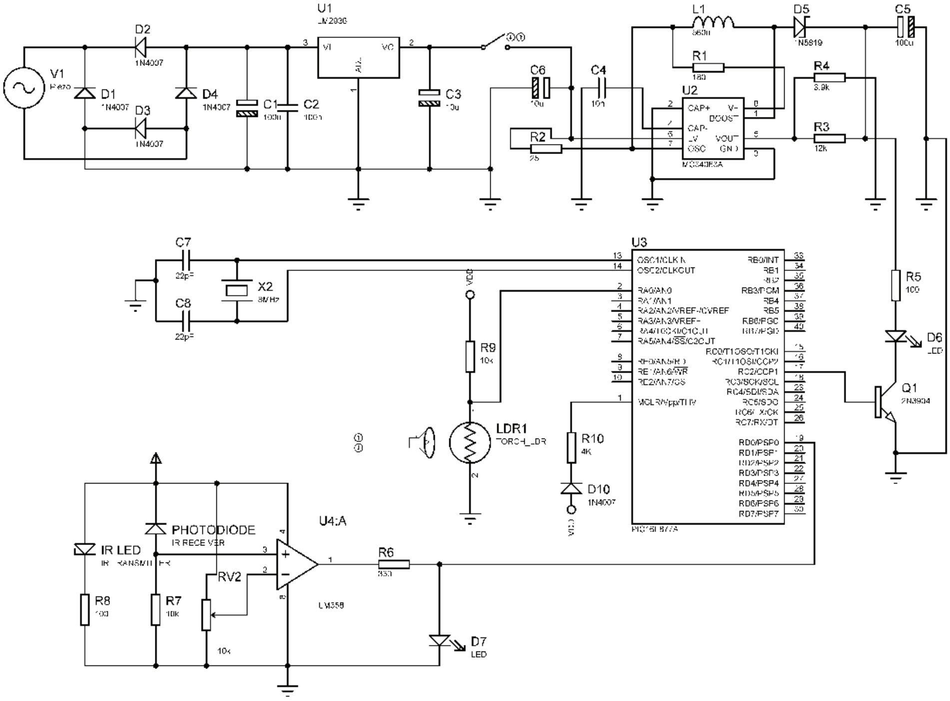

Figure 3: Schematic diagram of both systems

3.0 RESULTS AND DISCUSSION

The difference shows that PZT produced 80% higher voltage than the PVDF material and concludes that PZT is a more suitable material for a piezoelectric generator. The piezoelectric output can be maximized using the proposed design, as shown in Figure 4. The voltage reading in PZT is higher when the inner diameter is more extensive due to the more significant amount of PZT material that is white in color. Therefore, the force received tends to be higher compared to another lower inner diameter of PZT materials. The amount of force applied is similar because there is no change in the experiment's height. While replicating the experiment, significant differences in readings show the inconsistencies of direct current produced by piezoelectric materials, which need to be controlled using a low dropout electronic device. The hole between two mounted piezoelectric materials can increase the amount of strain received during the impact of the footstep. Therefore, the output voltage produced is higher than a commercial piezoelectric design [7-9, 14-15].

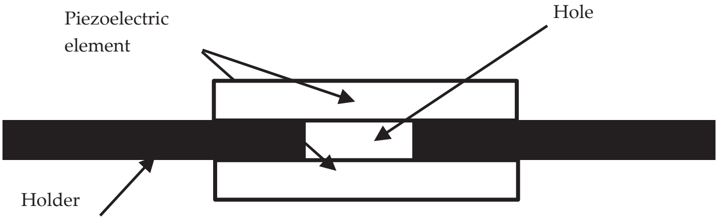

Figure 4: Diagram of piezoelectric design

The results tabulated in Table 1 show an increment of 30% output voltage than a typical piezoelectric element, validating that the modified design (Figure 4) can increase the PZT material's strain when vibration is applied. The work in [10] proposed to stack multiple piezoelectric transducers in order to increase the electrical output. The harvested energy is stored in the temporary storage of a 100 μF capacitor before it is transferred to a long-term energy storage and other loads to ensure that the DC power is filtered and ready to be used by the end-user. The current measured was 0.15 mA on a normal piezoelectric design, which is slightly lower than 0.28 mA of a modified piezoelectric design. Therefore, the output power of the modified PZT is 0.98 mW, which is a slight increase from the output power of a normal piezoelectric material such as 0.52 mW. This value is considered higher than another study in [11] that achieved 0.37 mW. Some studies also recorded the same power output for a normal piezoelectric material of 0.53 mW [12]. The power output from the footfall alone is higher, up to 150–675 mW [13]. Although the output power is higher, it dissipated much faster.

Therefore, our study observed that it is crucial to regulate the power output so that it can be controlled to produce constant power for automatic street lights. On another note, compared to the PZT material, the power output for the PVDF material is much lower (0.012 mW). This result is in contrast with the reported power output in other PVDF studies [14-15] of 1.1–1.3 mW. However, this argument is justified because they stacked many PVDF materials to achieve high power output values. A PVDF sheet provides more contact area as the shape is relatively easy to rearrange. Compared to circle-shaped PZT and a more brittle material if contacted with high force, PVDF is more flexible. Therefore, it is better to stack many films to produce more power output [14-15].

Table 1: Comparison of the output voltage from PZT, PVDF materials and modified design

Type of Materials	Variable						
	Diameter (mm)		Value	Reading (V)			
	Outer	Inner		1	2	3	Mean
PZT	27	21	Min	0.88	0.27	0.25	0.47
			Max	1.51	4.65	1.25	2.47
	20	19	Min	0.02	0.03	0.03	0.03
			Max	0.64	0.41	0.41	0.48
	19	17	Min	0.74	0.41	0.15	0.43
			Max	1.74	0.60	1.64	1.32
	19	18	Min	0.30	0.35	0.05	0.23
			Max	1.36	0.77	0.45	0.86
PVDF	N/A		Min	0.03	0.02	0.03	0.03
			Max	0.06	0.09	0.09	0.08
Modified design	N/A		Max	3.31	3.27	3.92	3.50

The use of low dropout components is also essential to prevent current losses due to impedance. The harvesting system was tested with a voltage regulator commonly used in household electrical appliances

(L7805CV) and a low dropout voltage regulator (LM2936) based on the power supply datasheet's reference value. The output voltage of L7805CV showed 0.0 V (Table 2), indicating that the conventional regulator circuit is incapable of maintaining the low current resulted in a piezoelectric energy harvester. In contrast, LM2936 has a promising result as it maintained 6.0 V, similar to the reference voltage by the power supply. LM2936 has a minimum of 15 μA of current to operate, while L7805CV, like any other device, has the same minimum of 1.5 mA to operate. A piezoelectric harvester produces 0.1 mA, which explains 0.0 V produced for L7805CV as it does not meet the minimum requirement to operate the devices. Therefore, LM2936 is the best regulator to operate with an ambient piezoelectric energy harvester.

Table 2: Comparison of the output voltage and current from the voltage regulator and DC-DC boost

Type of Regulators	Reading				
	Variable	Input Voltage (V)	Output Voltage (V)	Input Current (A)	Output Current (A)
LM2936	Reference	12.00000	6.00000	1.50000	1.50000
	Piezo	13.60000	6.00000	0.00015	0.00015
L7805CV	Reference	12.00000	5.00000	1.50000	1.50000
	Piezo	12.80000	0.00000	0.00015	0.00015
DC-DC Boost	Simulation	3.700000	5.10000	1.50000	1.50000
	Actual	13.20000	0.70000	0.00015	0.00015

A comparison was made between the DC-DC converter with the DC input from the power supply generator and a piezoelectric source. The obtained results in Table 2 show that the output voltage is lower than the power supply that flows 1.5 A of current compared to 0.15 mA of current from a piezoelectric source (current readings are shown in Table 2). Although the input voltage is higher in the piezoelectric source, the current loss in approaching load is higher due to the impedance in passing every DC-DC circuit component. The only small voltage produced caused the function of MC34063A into buck converter operation. A recent study in [12] integrated low dropout voltage and resulted in an increase of efficiency up to 83.3%, in which the study had focused on both electronic and mechanical improvement of the piezoelectric and regulator itself.

In comparison with previous research, the power output obtained was 1.8 mW [14]. Meanwhile, another study reported the power output up to 8.4 mW [15]. The obtained output power of 1.98 mW in this study shows a considerable difference from other studies even using the same PZT. The low power output is mainly due to the low current output of the high impedance by electrical components, where not all the semiconductors used are low dropout devices. Some conventional capacitors also give high resistance that significantly reduces the current flow. It is suggested to carefully use low impedance semiconductors for the power supply circuit to achieve more efficient power output. Therefore, it can be concluded that the piezoelectric energy harvester requires a more efficient DC-DC boost converter that reduces energy loss by heat from the electronic devices.

By combining the street light and a piezoelectric energy harvester system, a short test on capacitor 100 μF was used, which acts as temporary storage with constantly increasing ten steps on the piezoelectric plate, as tabulated in Table 5. A voltage peak of 12.6 V was obtained with a discharge time of 1.2 s using a capacitor for ten walking steps with an average weight of 70 kg. The amount of voltage produced increased gradually with the step count. Although the discharge time is faster than the holding time, the capacitor used could only retain a short time of current that may be replaced with a charged battery alongside a DC inverter. This system also has a high chance of being implemented in a high-density population where people who use walking as a medium of movement, such as the university, pedestrian walkway of shopping lot, and hospitals in Kuala Terengganu.

4.0 CONCLUSION

The potential of piezoelectric material as an alternative energy supply for automatic street light application has been explored in this paper. The initial results show that the piezoelectric material in the designed system only managed to supply limited energy for a short time to the LED. This limited energy is known as ambient energy as it requires a continuous supply of mechanical strain to give constant power to electronic devices. Thus, the system has been modified and showed 30% higher voltage than the prior piezoelectric design and consequently managed to supply low current to our proposed automated street light system. As a result, the proposed automatic street light system is functioning as expected, where the system operates automatically based on the IR sensor and the LDR sensor working principle. In conclusion, this work can significantly reduce electrical consumption by a street light and consequently conserve energy. The proposed system can be further improved using a long-term energy storage to increase the capacity of current and provide a longer duration to turn on the LED. In the future, the power supply system can be replaced by a built-in low dropout integrated circuit consisting of a DC-DC converter to increase the system's efficiency and consequently reduce the current loss from the higher impedance of a bulky component.

ACKNOWLEDGMENT

This work is partially supported by UMT/TPM/68007/2016/76 and UMT1/2018/58902.

REFERENCES

[1] R. Ali, I. Daut and S. Taib, "A review on existing and future energy sources for electrical power generation in Malaysia," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 6, pp. 4047-4055, 2012.

[2] A. Ożadowicz, and J. Grela, "Energy saving in the street lighting control system—a new approach based on the EN-15232 standard", *Energy Efficiency*, vol. 10, no. 3, pp. 563-576, 2017.

[3] I. Izadgoshasb, Y. Y. Lim, N. Lake, L. Tang, R. V. Padilla, and T. Kashiwao, "Optimizing orientation of piezoelectric cantilever beam for harvesting energy from human walking," *Energy Conversion and Management*, vol. 161, pp. 66-73, 2018.

[4] M. S. Mazalan, R. Mohamad, M. Kassim, and S. Shahbudin, "Power harvesting using piezoelectric shoe for external power storage," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 9, no. 3, pp. 655-659, 2018.

[5] N. Subhalakshmi, A. Jayalakshmi, N. Janani, S. Induveni, and P. Dhivya Dharshini, "Automatic Street Lights Lightened by Piezoelectric Roads," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 6, no. 14, pp. 146-150. 2017.

[6] S. Digamber, J. Maruti, J. Amol, and M. Sachin, “Intelligent traffic light and automatic street lighting system according to traffic density,” *IJREAT International Journal of Research in Engineering & Advanced Technology*, vol. 3, no. 1, pp. 18-21, 2015.

[7] H. Ahmad, K. Naseer, M. Asif, and M. F. Alam, "Smart street light system powered by footsteps," in 7th International Conference on Green and Human Information Technology, Selangor, Malaysia, 2019, pp. 122-124.

[8] L. T. E. Nyamayoka, L. Zhang, and X. Xia, "Feasibility study of embedded piezoelectric generator system on a highway for street lights electrification," *Energy Procedia*, vol. 512, pp. 1015-1020, 2018.

[9] R. Abinaya, V. Varsha, and K. Hariharan, "An intelligent street light system based on piezoelectric sensor network," in 4th International Conference on Electronics and Communication Systems, Coimbatore, India, 2017, pp. 138-142.

[10] S. Maidin, A. S. Mohamed, S. B. Mohamed, J. H. U. Wong, and S. Sivarao, "Effect of Multiple Piezoelectric Transducer on Fused Deposition Modeling to Improve Parts Surface Finish," *Journal of Advanced Manufacturing Technology*, vol. 12, no. 1(2), pp. 101-116, 2018.

[11] S. Roundy and P. K. Wright, "A piezoelectric vibration based generator for wireless electronics," *Smart Materials and Structures*. vol. 13, no. 5, pp. 1131-1142, 2004.

[12] H. Kim, S. Priya, H. Stephanou and K. Uchino, "Consideration of Impedance Matching Techniques for Efficient Piezoelectric Energy Harvesting," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 54, no. 9, pp. 1851-1859, 2007.

[13] J. F. Antaki, G. E. Bertocci, E. C. Green, A. Nadeem, T. Rintoul, R. L. Kormos and B. P. Griffith, "A Gait-Powered Autologous Battery Charging System for Artificial Organs," *American Society for Artificial Internal Organs Journal*, vol. 41, no. 3, pp. M588-M595, 1995.

[14] J. Kymissis, C. Kendall, J. Paradiso and N. Gershenfeld, "Parasitic power harvesting in shoes," in Digest of Papers. Second International Symposium on Wearable Computers, Pennsylvania, USA, 1998, pp. 132-139.

[15] N. S. Shenck, and J. A. Paradiso, "Energy scavenging with shoe-mounted piezoelectrics," *IEEE Micro*, vol. 21, no. 3, pp. 30-42, 2001.