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Hybrid Power for Energy Harvesting Design and Applied to Quadcopter System

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Abstract: Quadcopter cannot fly for longer time even though the battery capacity is bigger. The suggested solution to this problem is to harvest energy from the surroundings and the system. This project is to study and designed a power system that uses surrounding energy to charge the battery of the quad-copter. The system requires a stable input charging to the battery from the harvester; a power controller is used to steady the input charging power. There are some limitations to the system where different harvester had different output power, which in turn difficult to choose a harvester to power the system. Thus, a hybrid power system is considered as a solution to generate a certain power from the harvester to the required system.

Keywords: piezoelectric; thermoelectric; quadcopter.

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1. INTRODUCTION

Quad-copter had been quite popular among people to take pictures at a high and unreachable place. This can be seen in many documentary films about wildlife or scientific research projects. It can be used as a surveillance drone in many fields of aspect and transportation uses, especially in difficult to reach terrains or hill tops and cliffs. Quad-copter is a multi-rotor helicopter that is lifted and propelled by four rotors. Quad-copter generally uses two pairs of identical fixed propellers; two clockwise (CW) and two counter-clockwise (CCW) [1]. Quad-copter is a useful tool for university researchers to test and evaluate innovative ideas in a number of different fields, including flight control theory, navigation, real-time systems, and robotics [2]. In this project, the power system of the quad-copter used has a limited power supply, which in turn causes less flight time performance. Thus, this project is to study and design a power system that uses surrounding energy to charge the battery of the quad-copter. The system requires a stable input charging to the battery from the harvester, a power controller is used to steady the input charging power. There are some limitations to the system where different harvester has different output power, which in turn is difficult to choose a harvester to power the system. Thus, a hybrid power system is considered as a solution to generate a certain power from the harvester to the required system [3].

This project will study the power output of each of the harvester and choose the two most suitable harvesters for the quad-copter system. The conditions of the quad-copter are taken into considerations for choosing the harvester used. There is a list of harvesters that can use in the quad-copter, solar panel, thermal transducer, and piezoelectric transducer (vibrations). These are considered as an approach for energy efficiency strategies in generating expansion planning. However, due to the high investment cost, great uncertainty of each energy resource, and the uncertainty of each supportive policy, these energies are not so popular among people [4]. Each of these harvesters has its own pro and cons; for example, the wind generator is able to generate power for most appliance but it may produce more vibration for the quad-copter. The micro power generation using vibration energy sources appears to be attractive due to its applicability in many situations and environmental conditions [5]. The electrostatic energy harvester has various advantages over piezoelectric and electromagnetic systems, such as the reduction in fabrication process complexity and cost.

Since the invention of power storage, batteries have been the source of energy for most mobile, embedded and remote system applications [6]. Today, with ubiquitous computing requirements in the fields of embedded systems,

wireless sensor networks and low power electronics such as MEMS devices, an alternative source of energy is required [7]. Also, with the limited capacity of finite power sources and the need for supplying energy for a lifetime of a system, there is a requirement for self-powered devices. The process of harvesting energy from the surrounding environment is termed as energy harvesting. There are various forms of energy that can be scavenged, like thermal, mechanical, solar, acoustic, wind, and wave [8].

The energy harvesting sources can be used to increase the lifetime and capability of the devices by either replacing or augmenting the battery usage. There is an increasingly volume of research carried out on energy harvesting. There are two energy harvesters selected to compare the pro and cons of each harvester and the compatibility to the quad-copter. Namely, thermoelectric generator (TEG) and piezoelectric transducer. Each parameter value and the characteristics of the harvesters explained in this chapter are taken from various previous research paper [2], [6], [9].

Recently, thermoelectric generator (TEG) devices have emerged as a viable alternative for certain power generating applications. Interest has grown in the TEG energy due to its ability to produce power from low grade or waste heat leading to advancements in the growing field of Green Technologies. This new field of technology involves producing less waste by using renewable resources for power generation while creating and producing sustainable energy resources. TEGs can reduce or eliminate use of batteries in applications where a heat source exists. Since batteries have a limited lifetime before having to be replaced or recharged, TEG devices give the ability to produce uninterrupted power by charging or replacing batteries [10]. A notable progress in the development of TEG devices is their recent use in the automotive industry. TEGs are also being developed for effective recovery of a vehicle's waste heat to enhance fuel efficiency and reduce greenhouse gas emissions.

Thermoelectric effect is due to the phenomenon of two different temperature wire connected and produce electrical energy at the joint. This effect is based on the temperature difference of the semiconductor and an electromagnetic field is produced and gives out electricity [11]. This effect conversely produces two different temperatures on two different surfaces when electricity is applied. Thermoelectric effect is a two-way effect on the thermoelectric devices. On the atomic structure, when there is temperature difference, the atoms of either electrons or hole are diffused to the cooler side of the plate and move away from the hotter side. This causes a flow of electrons and holes in the semiconductor and thus produce electricity [12].

Thermoelectric devices are used to measure temperature, to heat or cool object, and to generate electricity due to this convenient effect where the devices can apply electricity to produce cold and hot sides, and generate electricity due to the temperature difference. This effect has three identified effect known as Seebeck effect, Thomson effect, and the Peltier effect. The commonly known is the Peltier-Seebeck effect due to the thermoelectric devices which can generate and produce two temperatures on the devices. Seebeck effect is the conversion to electricity by involving the difference in temperature. German physicist Thomas Johann Seebeck discover that in a closed loop of two metal of two different temperature joined at the junction, there is a deflection on the compass [13]. This is due to the atomic structure of the metal which react differently on the difference of temperature in a single contact, creating a current loop that produces magnetic field around it. The heat source on the semiconductor creates a flow of electrons and holes moving to the cooler side of the semiconductor. This flow creates current and emf voltage, flowing out to the load creating a complete close loop for electricity to flow [14]. According to Seebeck, the coefficient of the generated voltage at room temperature is of 41 μVolt per Kelvin.

Piezoelectric transducer is a type of vibrating devices that converts mechanical strain energy into electricity. The word "piezoelectric" means the electricity produced by pressure [15]. Originally, the quartz crystals were used as a material for piezoelectric crystal transducers. In the early 1950s, quartz crystals began to give way to piezoelectric ceramic as the primary transducer material due to ceramic's ability to be manufactured into variety of shapes and sizes, its capability of operating efficiently at low voltage, and its ability to function at temperatures up to 300 degrees Celsius [16].

The piezoelectric effect is used in various applications that involve detection and production of sound, and electronic frequency generation [8]. It is used as ignition source for fire lighter and used in force, pressure, sonar, microphone, and displacement measurement. It is also used in restaurants or airports where when a person steps near the door, the door opens automatically. In this, the concept used is when a person is near the door a pressure is exerted by the person's weight on the sensors due to which the electric effect is produced and the door opens automatically.

There are some advantages and disadvantages of using a piezoelectric transducer. The advantage is there are no need of external forces to produce electricity, just a small vibrations or pressure will produce electricity. It is easy to handle and use as it has a variety of size and shapes. Besides that, it also has high frequency responses and is sensitive. However, it is not suitable to take measurement in a static condition, foe it is easily affected by surrounding temperature, and the output power produces is low and needs external circuit attached to it [17].

Piezoelectric material are materials that can produce electricity due to mechanical stress, such as compression. When electricity applied, these materials will deform or vibrate. These materials are non-conductive and are of crystal and ceramic form. Example of materials are barium titanate, lead zinconate titanate (PZT), and lithium niobate, which are better than quartz to produce electricity. Where the quartz is the first known nonconductive material that generate electricity through pressure.

The PZT can produce more voltages than the quartz and the reverse effect also greater [18-19]. PZT is the combination of lead and zirconium element produced under high temperature and combined with titanate. This PZT are used in ultrasound transducer, actuators, ceramic

capacitor, and other sensors. Barium titanate and lithium niobate are ferroelectric ceramic materials that are used more commonly than the PZT. Barium titanate has the chemical formula of BaTiO3 and it is discovered during the World War II. Lithium niobate is the combination of lithium, niobium, and oxygen. The chemical formula is LiNbO3.

Piezoelectric effect is a physical property that exists in various materials. The piezoelectric materials are place in between two metal plates to obtain the electricity produced. When there is mechanical stress applied on the materials, the polarity of the crystal is polarized in one direction and the electricity is created [20]. Each crystal or piezoelectric materials are non-conductive materials that does not have a symmetrical center for the molecular structure. The polarity of the materials is at random direction and there have ends with more negatively charged and positively charged, called dipole [10], [20-22]. When pressure and stress are applied on the material, the polarity of the material moves to the direction of the stress.

From the both energy harvesters, basically the power consumption of the quad-copter depends on the load it can take, mostly is consumed on the motor at the propeller. These consumptions had depleted the battery capacity faster, causing limited power source to support longer flight time. The average flight time of a normal quad-copter is around an hour with the LiPo battery capacity of 1000mAH. The charging of the battery usually takes about 3-4 hours to be fully charged and it depends on the main power supply to charge.

The flight time of the quad-copter and its dependency on the main power supply is the main cause that most quad-copter has to shut down during the flight and sometimes it falls onto unknown or unreachable places, thus making it difficult to retrieve it and the lost can be expensive. So, it is essential to prolong the battery output power to increase the flight time of the quad-copter and charge the quad-copter to supply it enough for a flight back to base.

2. METHODOLOGY

This project is to find the suitable energy harvester to be applied to a quadcopter and charge the battery. Thus, a survey is conducted to compare and apply to a power system to choose the most suitable energy harvester. Based on the flow, the project starts by doing the survey through the use of a literature review to compare and analysis each suitable energy harvester. After the survey, a minimum of two or three energy harvesters is chosen to charge the battery.

A circuit is designed for the harvesters using Proteus Design Suite, and the circuits are simulated. The simulation has to be error-free and the output result is suitable to the use of charging the battery. Subsequently, if an error occurs, the circuits are designed again until the simulations are passed. The Proteus Design Suite software is able to design the PCB layout of the designed circuit. The designed PCB layout is fabricated and soldering is done.

The fabricated circuit will be tested on charging the battery. If a problem arises, troubleshooting works are done to check the functionality of the circuit and some corrections are done to the circuit. If there is no problem with the connections and circuit component, then another circuit are designed by changing some parameters. Figure 1 shows the basic block diagram of this project.

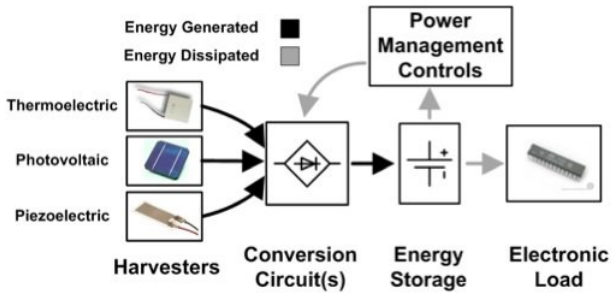

Figure 1. Block diagram of the energy harvesting power system

The project workflow and procedure of obtaining the expected result will state in this sub-topic. The first part is to explain workflow of analyzing each energy harvester by giving different conditions. Next, the process continues with the IC chip used on the power system and the requirement need to charge the battery using this IC chip.

2.1 Study of vibration from different source on piezoelectric transducer

The piezoelectric transducer is a 1.5cm in diameter thin plate shown to Figure 2.

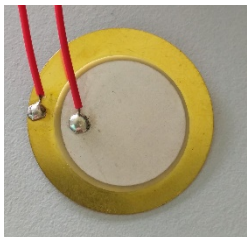

Figure 2. Piezoelectric Piece

The transducer is put on different condition to obtain the output voltage. There is hand tapping, bending, phone vibration, and lastly the motor vibration. The highest voltage output is when the piezoelectric is bend and released. It can reach up 30 volts only when the pressure is applied and released. The tapping on the piezoelectric transducer is based on the tapping strength [23-24].

As for the vibration of the phone, the piezoelectric is applied on the phone and cover it using the phone cover. When the phone rang, the phone vibrates and the piezoelectric convert the vibration to electrical energy. The maximum voltage of the vibration is not more than 300mV

2.2 Study of thermal on the TEG transducer

As general knowledge, most system create or produce heat energy. Cars, engines, computer, laptop, smartphone, and so on are the commonly used devices in the surrounding. Heat energy from these devices can convert to electrical energy to support back the system. Thermoelectric generator is used to collect and harvest the heat energy that are available in the surrounding, either from the device system or the heat from the sun. Thermal energy harvester

is based on the temperature difference of the transducer on each side of the plate and generate electricity through the semiconductor. The effect of thermoelectric is due to the atomic structure and performance inside the petltier. This effect is called the Seebeck effect or Petltier-Seebeck effect [25].

The TEG is placed under a laptop where most laptop produce more heat when it did heavy processing. This replaces the quadcopter system as laptop processing system produces more heat than the quadcopter system, but this is equally due to the fan in the laptop which has cool down most of the heat produced inside of the laptop.

The heat produced are slightly higher than the room temperature, around 3-5 □ difference. The heat sink is used to dissipate the heat and cool down the TEG faster to give a higher temperature difference. The voltage produce is around 40 mV at room temperature. Figure 3 shows the TEG Setup.

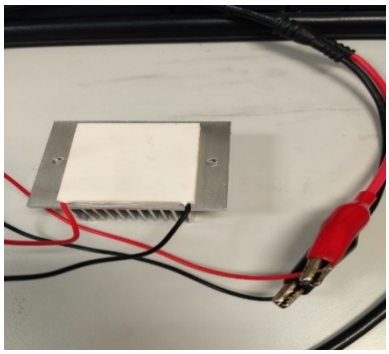

Figure 3. TEG Setup

2.3 Characteristic of Maxim IC chip MAX17710

Maxim Integrated has introduced an energy harvesting charger and protector devices for power management function in harvesting energy and charging while protecting a micro-energy cells (MECs). It can manage uncertain regulated input that most energy harvester device gives the output power ranging from 1µW to 100mW. Figure 4 shows the MAX 17710 Integrated Chip.

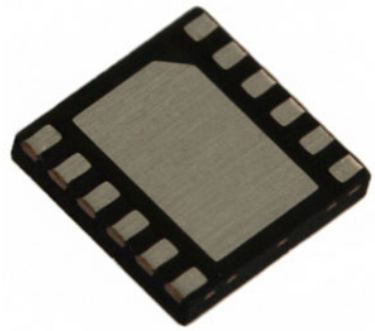

Figure 4. MAX 17710 Integrated Chip

3. RESULTS AND DISCUSSION

3.1 Comparison between the piezoelectric and the Thermoelectric Generator (TEG)

Table 1 shows the comparison between the piezoelectric and the Thermoelectric Generator (TEG) in terms of size, output power, and voltage from the experiment's setup. It can be seen that the TEG generates more power even though the temperature difference is less. The piezoelectric transducer generates high voltage up to 40V when bending it. However, the current production is less than the TEG, and the output power is around 400µW. There are some extra considerations when the TEG needs a heatsink to dissipate the heat and this adds an extra load to the quadcopter. The more loads the quadcopter has, the more power it needs to fly up. Thus, the extra load adds extra power consumption for the quadcopter to fly up.

Table 1. Comparison of Piezoelectric and TEG

Energy Harvester	**Piezoelectric Transducer**	**Thermoelectric Generator (TEG)**
Condition for conversion to electricity	Mechanical stress or pressure	Difference in temperature at the metal junction
Dimension	1.5 cm in diameter	40mm x 40 mm
Generate Electricity	Alternating Current	Direct Current
Output Voltage	High, 25V-40V	Low, ~200mV
Output Current	Low, ~10µA	Normal, ~0.1A

3.2 Charging of the capacitor

The battery of the quadcopter is replaced by using a capacitor to show the charging and discharging of the capacitor when connected to the energy harvester. The capacitor is charged by using the piezoelectric and TEG that are connected to the designed circuit. The oscilloscope is used at the positive terminal of the capacitor to show the flow of the voltage.

Before assembling the piezoelectric to the designed circuit, the piezoelectric has to be rectified first as the circuit are DC supplied. Piezoelectric as mention earlier is an AC output voltage energy harvester, so a diode is placed to rectified the positive waveform to pass through the circuit.

There are two energy harvesting input in the {MAX17710 circuit, low voltage input and high voltage input. The piezoelectric are placed on the high voltage input of the circuit. Figure 5 shows the connection of the piezoelectric transducer to the circuit board.

After the piezoelectric transducer is connected to the circuit board, the unregulated output is measured. The unregulated output voltage shown in Figure 6 is the yellow waveform and the green waveform is the input voltage from the piezoelectric transducer. There are some drop in voltage from the piezoelectric transducer to the unregulated output. This is due to the power consumption in the circuit that some voltage is dissipated as heat in the circuit.

The oscilloscope probe is place at the capacitor to measure the voltage of the capacitor. The capacitor act as the battery to show the charging of the energy harvester to the capacitor. Figure 7 shows the voltage charging to the capacitor when the stress is applied on the piezoelectric. There are voltage charging the capacitor when stress is applied and discharge when no stress is applied. The

discharge takes about 0.3s to discharge and take about 0.05s to charge the capacitor. The more voltage is charged, the longer the discharge of the capacitor. This graph shows the maximum voltage charged is 8.8V.

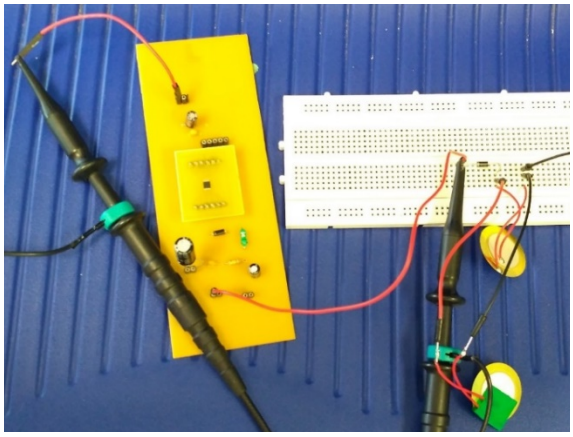

Figure 5. Connection of Piezoelectric to the Circuit

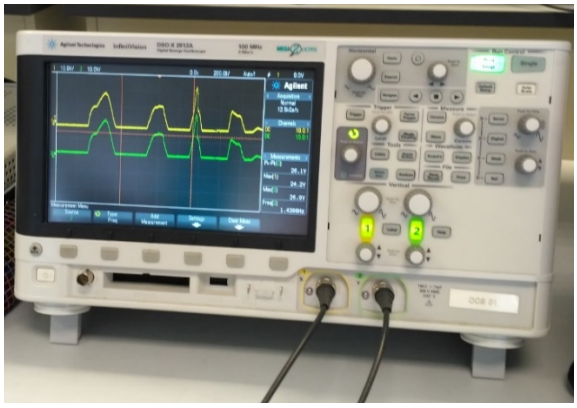

Figure 6. The Unregulated Output of Piezoelectric

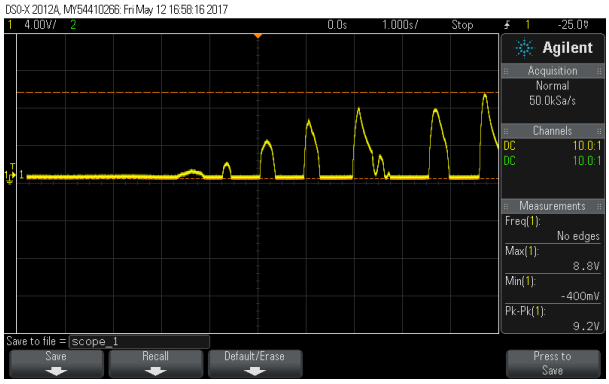

Figure 7. Capacitor Charging Using Piezoelectric

The TEG is connected to the circuit board together with the piezoelectric transducer. The TEG is heated and pressure is applied on the piezoelectric to obtain the combined charging of the capacitor. The selected waveform in Figure 8 is the charging of the piezoelectric transducer and the TEG. The TEG contribute around 100mV in charging the capacitor, and the others are from the piezoelectric transducer. The combined charging voltage is around 6V and can charge up to 20V depending on the piezoelectric condition shown in Figure 9.

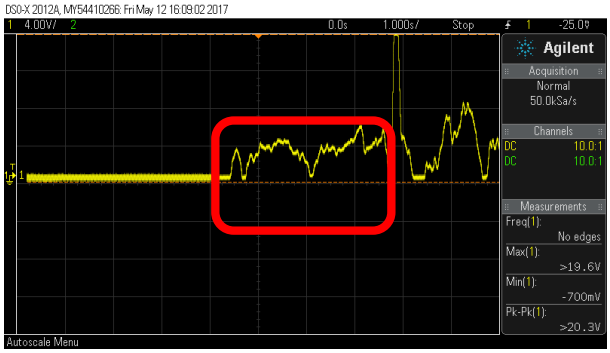

Figure 8. Charging Using Both Piezoelectric and TEG

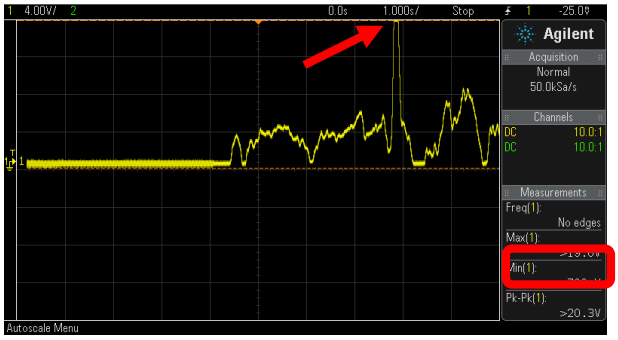

Figure 9. Maximum Voltage Charged

4. CONCLUSION

The energy harvesters are chosen to form a hybrid power system circuit for quadcopter to maintain air-born for a longer time. Two energy harvester namely piezoelectric transducer and thermoelectric generator is used to study the output power and its compatibility to the quadcopter.

In conclusion, the performance of each energy harvester is analyzed and compared. The piezoelectric transducer gives high voltage and low current when pressure is applied. This low current allows lower charging rate to the battery. While the TEG provides higher current than the piezoelectric, the output voltage are relatively low for 1□. A hybrid energy harvesting power system are designed using an energy harvesting charger and protector integrated chip from Maxim company. This hybrid power system combines this two-energy harvester together to charge the battery. Although the charging rate is lower than the discharging rate of the system, there are some addition charging to prolong the battery usage.

Overall, there still has space for improvement on this related topic as the charging power are not as expected to charge the battery for a longer time. The placement of the energy harvester also an important consideration to harvest the energy and convert to electrical energy to the battery storage.

The TEG creates low voltage for a degree Celsius difference which is not enough to charge the battery. A charge pump or a step-up converter can increase the voltage provided by the TEG. As for the piezoelectric transducer, the PZT piezoelectric can be used as it shows high efficiency of mechanical to electrical energy conversion. Other energy harvester can also be considered, for example solar panel and rotational energy harvester. There are new solar panel that are flexible enough to cover the quadcopter body and harvest the solar energy, and the rotational energy harvester is a new idea introduced by

Robert Sowah in 2015 in the paper *"Rotational Energy Harvesting to Prolong Flight Duration of Quadcopters"*. Besides that, the use of microcontroller in the circuit to indicate the performance of the power system is suggested. The MATLAB can provide the analyzed graph of the energy harvester in the quadcopter; thus, a microcontroller and a wireless node is suggested to include in the system for better analyzing graphs.

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