Development of Water Pipelines Energy Harvesting System

H F Liew\textsuperscript{1}, Abd R Rosemizi\textsuperscript{2}, M I Fahmi Romli\textsuperscript{3}, M. T. Nuraidah\textsuperscript{1}

\textsuperscript{1} Faculty of Engineering Technology, University Malaysia Perlis, Sungai Chuchuh, 02100 Padang Besar (U), Perlis, Malaysia.
\textsuperscript{2} School of Computer and Communication Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600, Arau, Perlis, Malaysia.
\textsuperscript{3} School of Electrical System Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600, Arau, Perlis, Malaysia.

Abstract. Previously, the threats of negative effects caused from burning process of the fossil fuels is somewhat alarming which it may lead to acid rain, increasing greenhouse emissions and global warming. Based on the highlighted issue, this study aims to develop a system where the input power came from water pipes energy harvesting system. Water pipes harvesting system will be designed using polyvinyl chloride pipes and water turbines, to transform kinetic energy of a water flow into electrical energy and the energy performance will be monitored in a web-server using Arduino and ESP8266 Wi-Fi module as its processing centre. This research studies the feasibility of harvesting some energy from pipeline vibrations, and it is also observed that harvestable energy varies with harvesting location across a pipeline network as well as the pipe flow rate in the water-air and kinetic energy in the water pressure fluctuation. The water pipelines energy harvesting systems are modelled and then analyzed by using simulated data and real data using Arduino. Turbine generator are mounted on the pipeline surface at different locations to simultaneously collect vibrations-induced energy data from water pumping. The water flow rate energy harvester system and the water pressure fluctuation introduced in this research may be able to generate up to 6.8 mW's power. The output produced from the energy harvesting system is expected to be enough to light up a 3.8 V direct current light emitting diode bulb.

1. Introduction

Nowadays, the field of energy harvesting has experienced significant growth in recent years due to the growing desire to produce long-lasting mobile & wireless electronics [1]. In general, energy consumption is an advanced research and gain high interested in every year because of its different properties and characteristics. Currently, the wireless sensor to be located in a remote location, the sensor must be convenience accessible or user-friendly in order for the device to function for a long period of time. Previously, wireless devices and current portable had to be designed to include electrochemical batteries as their primary power source. However, the use of batteries can be troublesome due to the limited lifespan, which requires periodic replacement and results in drawbacks of required a high maintenance costs [2, 3]. To overcome the troublesome of all of these battery hurdles, alternative ideas for low-cost energy generation, high efficiency, availability and durability from existing environmental sources have been made to complement current technology sources has been has been fabricated to supplement the present technological without polluting and demanding the environment [4, 5].

Therefore, energy harvesting from human motion has attracted substantial research into its ability to replace conventional batteries for smart electronics. Energy harvesting module defined
as a relationship between an electronic device which used to generate energy and manage it for the operation of its sensors, processing units and communication units [6, 7]. This has led to a growing focus on energy harvesting (EH), a science which aims to capture energy from wind, rain, or other natural vibration, to transform it into another more useful energy form [8]. The solar cell [9, 10], piezoelectric [11, 12], electromagnet [13, 14], fuel cell [15, 16] and thermoelectric are also categories as energy harvesting method which suitable for water monitoring. Certainly, with environmental concerns and the global energy crisis, several free energy include bio-energy, hydro-power, geothermal energy, solar energy, wind energy and ocean energy (tide and wave) [17, 18] are consider as types of renewable energy sources replenish without being depleted in the Earth can be considered to generate power [19, 20]. The decision of energy harvesting method is based on the type and location of the application. The differences are in the amount of energy produced and the costs in each method which involved into the harvesting techniques is presented in Table 1.

Table 1. Variety of Corresponding Power Densities involved into Energy-Harvesting Sources [19, 20]

| Energy source | Types                  | Energy harvesting method          | Power density       |
|---------------|------------------------|-----------------------------------|---------------------|
| Radiant       | Solar                  | Solar cells (indoors)             | < 10 µW/cm²         |
|               |                        | Solar cells (outdoors, sunny day) | 15 mW/cm²           |
|               | RF                     | Electromagnetic conversion        | 0.1 µW/cm² (GSM)    |
|               |                        | Electromagnetic conversion        | 0.01 µW/cm² (wifi)  |
| Mechanical    | Wind flow and hydro    | Electromagnetic conversion        | 16.2 µW/cm²         |
|               |                        | Acoustic noise                    | 960 nW/cm²          |
|               |                        | Motion                            | 330 µW/cm²          |
| Thermal       | Body heat              | Thermoelectric                    | 40 µW/cm²           |

2. Review of Previous Harvesting Energy from Water in -pipe

In previous review work, several turbine designs have been proposed for the in-pipe hydro system [21, 22]. The performance of the proposed designs was compared by implementing them in a real prototype that mimics the in-pipe system with gravity fed structure. The generated power depends on converting the extra water pressure in the in-pipe system to green power which can be used later to feed secondary applications such as lighting or any other loads [23]. Six turbines were proposed and investigated, and they have been implemented using SolidWorks software and a 3D printer. The design factors, which have been addressed in this work phase, were the number of blades, the angle of attack and the thickness of the blade. Each turbine was tested separately to determine the pressure drop and the generated output power. According to the experimental results, the spherical turbine design presented better performance in comparison with the Hybrid H-Egg designs since the blades had larger frontal area [24, 25].

Hence, more water streamlines were hitting the blades which leads to higher rotational speed. The output power of 16 W was obtained from the four blades spherical turbine, which is a good result from a small prototype. The proposed designs are recommended for implementation in-pipe hydro system [26], and mainly they can be used in the locations of that require pressure reduction as an alternative for pressure control valves. Moreover, a case study was conducted to investigate the benefit of the proposed system in the water network in Amman-Jordan. It is found that the system can be installed in several locations and it can produce up to 26 kW. Finally, the system is expected to provide higher energy and to occupy less area in contrast to the PV system and wind turbines [27, 28].
From Hoffmann et al. 2014 [29] have demonstrated that energy harvesting through fluid flow from water pipes which using principal of rotational energy harvester, a radial-flux combining with three-phase generation system. The generation of energy is existing for transforming energy from water flow into domestic water pipelines. The energy harvesting supply system is independent of the external power supply or depleting batteries and is connected with a power management circuit, which consisting of energy storage is used to backup power a smart metering system. The used of standard component included housing and impeller is enabling the water flow of meter and as a conventional mechanical method for design of radial-flux energy harvester is adapter to the housing. The output result of energy harvester when using flow rate of 20 l/min (fully opened water tab) can produce up 720 mW. When in minimum flow rate of 3 l/min, the energy harvester is in initial stage to generate output of 2 mW is reachable. Therefore, especially the mechanical structure, optimization is required for impeller and magnetic circuit the threshold flow rate can be further reduced.

Casini in 2015 [30] explained that divided in-pipe hydro power system in two main categories which are internal system and external system and which the runner is wholly inside the pipe section and only the generator protrudes from the conduit have the advantage of a more compact size, making it more suitable for smaller applications, but not constrained. The output varies from 5-10 Watt to 100 KW for more energy-intensive applications, which are sufficient to provide self-powered water metering or monitoring systems. On the other hand, external system where a secondary conduit that circumvents the main conduit contains a runner do not depend on pipe size as purely as the runner is in a specially designed tube and enables much greater flexibility.

Muhsen et al. 2019 [30] described that investigating the impact of the utilized turbine design on the harvested energy from in-pipe systems. Four turbine designs are involved in this study which includes the spherical turbine and the Helical (Egg Beater) with three blades, four blades, and five blades. The proposed turbines are designed and they have been implemented in a prototype to determine the performance of each design. The study presents design procedures and the design requirements of each employed turbine before the implementation phase. The next step is to collect the produced torque, rotational speed, pressure drop, and output power for each turbine experimentally. The results have been analyzed and compared to show the design impact on these parameters. Finally, a case study is carried out on the major water distribution network in Amman the capital of Jordan to determine the possible locations, which are benefited from the implementation of the in-pipe system with the examined turbines.

Ye and Soga in 2012 [31] recommended that used to monitor water distribution systems in the water supply industry in the field of energy harvesting. Due to harvesting renewable energy from a water or environmental distribution system would be an attractive option, water sensors have been installed into areas where power supply is lacking and drawbacks difficulties replacement of batteries or problem limited lifespan. The water distribution systems into energy harvesting systems are analyzed, compared and modelled using simulation data and real data [31, 32]. The result of this research introduced by hydrothermal energy harvesters and water pressure fluctuations is likely to produce range in mW power. Overall, this work reported that on the possibility of energy harvesting in a water distribution system from hydraulic energy in bypass water pipes, thermal energy in water-air temperature gradient, and kinetic energy in water pressure fluctuations.

This work is discuss about the energy harvesting system in current water pipelines which monitor and control water quality sensor based on Arduino platform and generate energy into smart metering application. This research also describe some key ideas into enhancement amount of energy produced by energy harvesting depends of power output, water pressure, flow rate, material pipe and structure of the pipelines and controlling by Arduino software. The variation of energy harvesting potential across locations closer to the bends based on water flow rate of the pipelines have various experimental configurations were used and experienced.

3. Methodology
The water pipeline system are can be divided into two main part design, included that internal system and external system. In internal system about the monitoring and controlling performance are determine by using Arduino software, and external system which inside pipe section, water flow and generator is protrudes from the conduits.

A block diagram of water pipelines energy harvesting in Figure 1 is describe fundamental method used to develop and setup hardware or software systems as well as represent the work flows and processes of project. A system to generate hydroelectric power from water pipeline is designed using Arduino Uno as the center of processor to obtain all the data and parameters required and display it onto the LCD screen for monitoring parameter.

In this water pipeline system consists of two arduino and two LCD screen used in the system to display different parameters from the source. The first Arduino and LCD is work as screen to collect and display data from the hydroelectric generator. Then the second arduino and LCD screen is used to collect and display data from the water flow sensor. At the same time, power generated from the hydroelectric generator will directly function as to light up a LED bulb. Also, parameters measured which are included current, voltage and power from the generator will be displayed on the LCD screen with an Arduino Uno board as the processor. From the source, water will flow through the water flow sensor to measure the water flow rate. Water flow rate will also be displayed on the LCD screen with an Arduino Uno as the processor. Finally, with the ESP8266 Wi-Fi module as the processor, all the parameters obtained should be displayed on the web-server for the monitoring system purposes.

![Block diagram of the water pipeline system](image)

**Figure 1. Block diagram of the water pipeline system**

### 3.1. Proteus Software Design

The first and foremost, designing the structure of the energy harvesting system is important as design will be the base of the project. All the simulation circuit in the project is designed and tested in Proteus software. Simulation of circuit is fundamental before proceeding to the hardware as all the components and equipment to use into hardware prototype can be decided. The Arduino Integrated Development Environment (IDE) is the software used to write and upload Arduino’s programme coding. Figure 2 shows the simulation circuit for displaying the value of voltage and current generated from the hydroelectric generator on the 16x2 liquid crystal display (LCD) screen. Voltage
supply B1 indicate the generator used in this project to generate electricity. Meanwhile the red-coloured LED indicate the load used which is a 3.8 V DC LED bulb.

![Figure 2. Circuit to display current and voltage on LCD](image_url)

### 3.2. Water pipelines system hardware construction

The built in voltage stabilizing circuit and one rechargeable battery able to support the micro hydro generator into pipes structure to produce more stable output voltage and output current. The generator together with regulator circuit inside make output generator can supply stable 5 VDC voltage and output current of 0-150 mA. In this research, a DB_168 hydroelectric generator is attached to the PVC pipe to generate the energy from the water that flow through the pipe shown in Figure 3. The generator will be connected to Arduino. Arduino programming is written to display the parameter measured using this generator and will be display it on the LCD and web server using the Wi-Fi module. The power generated from the generator also will directly use to light up the load which is LED bulb used in this research. When water flows across the pipeline, a turbine wheel with a magnet is placed in a plastic envelope and the effect sensor hall is placed. The turbine wheel is rotated by the turbine wheel and therefore the magnet flow interferes with the sensor hall. The rates of interference depend on the speed of water flux. In this research, sensor to be used is YF-S201 hall effect water flow sensor. This sensor is attached to the PVC water pipe to let the water flow through it to enable the sensor measure the flow rate and display the measurement on the LCD.

Besides that, with the water flow rate, velocity of water flowing through the pipe line is calculated using Equation (1);

\[ v = \frac{4Q}{\Pi d^2} \]  \hspace{1cm} (1)

Where :

- \( v \) = velocity of water (m/min)
- \( Q \) = water flow rate (L/min)
\[ d = \text{diameter of water pipe (m)} \]

Figure 3. Connection of generator, water flow sensor and Arduino

The Arduino Uno microcontroller board based on ATmega328 is used. The software consists of a standard programming language and the boot loader that runs running on an Arduino board. An Arduino hardware is programmed using Wiring-based languages (syntax and library), similar to C++ with a little simplification and modification, and processing-based IDEs. Arduino Uno can be powered via USB connection from a computer or from a 9 V battery. In this research, the Arduino Uno presented will be used to install with the hydroelectric generator shown in Figure 4, that is water flow sensor and the Wi-Fi module. The ESP8266NodeMCU module to be used in this project is a system central processing unit and is responsible for communications between digital power meters and gateway web servers to read meter parameters and results displayed on LCD and web servers for system power monitoring.

Figure 4. hydroelectric generator
4. Result and Discussion
This research highlights the analysis considerations for hydro energy harvesting systems such as; the relationship between water flow rate and energy generated. First, the experimental result of water flow rate and output voltage is shown to analyse the relationship between the two parameters. However, the main purpose of the system is to analyse and see how the condition water flow rate effect the energy harvested from the system.

4.1. Water pipelines system simulation parameter result
The parameter result voltage, current and power obtained from circuit will be displayed on the LCD screen as shown in the Figure 5. All the parameters result are to be obtained from the hydroelectric generator where the flowing water through the generator will produce these parameters, as the arduino is programmed to display the parameters on the LCD screen.

![Figure 5. Current, voltage and power displayed on LCD](image)

4.2. Water flow rate and water velocity
Using the Equation (1) and water flow rate measured by the water flow sensor, velocity of water flow through the PVC pipe is calculated and tabulated as shown in Table 2. The velocity of water depends on the area or diameter of the pipe that the liquid is moving through, and the flow rate of the liquid. Therefore, the diameter area of PVC pipe setting as constant value as size of pipe used in the system with the diameter value of 0.023 m. The calculated value for the velocity of water is prescribed in Table 2. The experiment is consider minimum water flow rate measured in the system is 3 L/min which affordable produced 7.22 m/min water velocity. As the water flow rate increased, water velocity also increased. Then maximum water flow rate recorded is 20 L/min and produced 48.14 m/min water velocity.

| Water flow rate (L/min) | Water velocity (m/min) |
|-------------------------|------------------------|
| 3                       | 7.22                   |
| 5                       | 12.03                  |
| 8                       | 19.26                  |
| 10                      | 24.07                  |
| 12                      | 28.88                  |
| 15                      | 36.10                  |
The water flow rate is the parameter to be obtained from the water flow sensor that is attached to the water pipe. The water acts as the main source for this energy harvesting system to flow through it, will activate the sensor to do work detect the flow of water. This parameter can be controlled by controlling the water pipe faucet. When opening the faucet bigger, the more water will flow through the water sensor. The second part of the circuit measured the water flow rate and displayed the value on the second LCD as shown in Figure 6.

| Water Flow Rate | Voltage (V) |
|----------------|-------------|
| 17 L/min       | 40.92       |
| 20 L/min       | 48.14       |

Figure 6. Water flow rate displaying on LCD

4.3 Water pipelines system measurement parameter result
This parameter lastly will be compared to the output voltage, current and power generated to analyse the effect of water flow rate to the energy harvesting system. All the recorded values tabulated in Figure 7 to analyse the relationship between water flow rate and voltage, current, and power generated from the system. In Figure 7, X-axis represent water flow rate as the independent variable or constant variable. Meanwhile y-axis presented by three parameters measured by hydroelectric generator, current (green line), voltage (red line) and power (purple line) as the dependent variable. It can be seen that the three parameters are directly proportional to the water flow rate. The experimental result explained that higher water flow rate needed to generate higher electricity power. Also, the equation used to calculate water velocity describes that bigger diameter or area of the channel for the water to flow, the lower velocity will be obtained.

Based on the Figure 7, it can be seen that the output voltage at y-axis is directly proportional to the water flow rate at x-axis. That explained as the water pipe faucet opened bigger, there will be more water flowing through the PVC pipe and water flow sensor. As the water flow rate increased, the voltage generated by the generator also increased. The voltage varies constantly from water flow rate range 3 - 12 L/min but at range 12 - 15 L/min, voltage experienced a raise and increase constantly at range 15 - 20 L/min. For water flow rate and output current produced from the energy harvesting system demonstrate that when more water flowing through it, more current will be produced. The result presents that water flow rate is controlled by controlling the water pipe faucet with 3 L/min recorded as the minimum water flow rate and 20 L/min recorded as the maximum water flow rate by the water flow sensor. When output current produced from the system increasing from 23 mA as the minimum value and 107 mA as the maximum value are recorded. The line in Figure 7 shows a constant increasing in the output power without any sudden rise or declination. Moreover for the relationship between water flow rate and output power...
generated by the system are proportionally, that is when minimum output power can be generated by the system is 9.2 mW and water flow rate is 3 L/min or the maximum power produced is 524.3 mW when water flow rate is at 20 L/min.

Figure 7. Relationship between water flow rate and several output generated

| Water flow rate (l/min) | Power (W) | Current (A) | Voltage (V) |
|------------------------|-----------|-------------|-------------|
|                        | 3         | 5           | 8           | 10          | 12          | 15          | 17          | 20          |
| 0.009                  | 0.030     | 0.052       | 0.086       | 0.136       | 0.256       | 0.365       | 0.524       |
| 0.023                  | 0.033     | 0.040       | 0.048       | 0.062       | 0.071       | 0.089       | 0.107       |
| 0.4                    | 0.9       | 1.3         | 1.8         | 2.2         | 3.6         | 4.1         | 4.9         |

5. Conclusion
This research has explored about the generated free electrical from water pipeline energy harvesting system from hydraulic energy power bypass water pipes using generator is developed. This work is focused on the basic operation, controlling and analysis of energy harvesters. Using a bypass water pipelines in water flow is the most direct way to produce energy. Instead, the output power generated from the system is even with small in capacity of the equipment used in the system is small scale but managed to light up the LED bulb. However, the system used a small-scale hydroelectric generator which to generate maximum voltage 5 V DC and use the power to light up a 3.8 V LED bulb. With water as its main source of energy, this project able to create an energy harvesting system with clean and most promising sustainability of the source. In future work, using IoT mechanism in monitoring system did a great job in providing an easier method which is used to monitor for water quality in real time to carry out active pollution control measures. Water quality is a serious factor that affects the health of the economy. In addition, piezoelectric mechanism also widely used to replace generator to produce energy as it has lot of advantages and easy to implemented as relevant information provided and enable real-time measurement for the users and it can be accessed anytime and anywhere. Another improvisation that can be done to the project in future is using bigger hydroelectric generator in order to generate more output power. As the generator used in this project can only generate maximum output voltage 5 V, the power is low and unable be used to supply bigger load. Finally, the use of the battery as a direct connection to the power Arduino for this purpose can cause other problems such as the need for regular battery replacement and the possibility of electrical shocks caused by water leakages situation. Therefore, with few suggestions and alternatives to provide supply in a safer for the system can be developed and improved.
6. References

[1] Lopes C M A and Gallo C A 2014 A review of piezoelectrical energy harvesting and applications. *IEEE 23rd International Symposium on Industrial Electronics (ISIE) Istanbul* pp 1284-1288.

[2] In V and Palacios A 2018 Energy Harvesting. Symmetry in Complex Network Systems. *Understanding Complex Systems. Springer, Berlin, Heidelberg* pp 295-316.

[3] Lu X, Wang P, Niyato D, Kim D I and Han Z 2015 Wireless Networks With RF Energy Harvesting: A Contemporary Survey. *IEEE Communications Surveys & Tutorials* 17 2 pp 757-789.

[4] Ulukus S, Yener A, Erkip E, Simeone O, Zorzi M, Grover P and Huang K 2015 Energy Harvesting Wireless Communications: A Review of Recent Advances. *IEEE Journal on Selected Areas in Communications* 33 3 pp 360-381.

[5] Jamadar V, Pingle P and Karase S 2017 Possibility of harvesting Vibration energy from power producing devices: A review. In *International Conference on Automatic Control and Dynamic Optimization Techniques, ICACDOT 2016*. Pune pp 496-503.

[6] Zhang X, Pan H, Qi L, Zhang Z, Yuan Y and Liu Y 2017 A renewable energy harvesting system using a mechanical vibration rectifier (MVR) for railroads. *Applied Energy* 204 pp 1535-1543.

[7] Yang Z, Zhou S, Zu J and Inman D 2018 High-Performance Piezoelectric Energy Harvesters and Their Applications. *Joule* 300 p. 111634.

[8] Adu Manu, Kofi Adam, Nadir Tapparello, Cristiano Ayatollahi Hoda and Heinzelman Wendi 2018 Energy-harvesting wireless sensor networks (EH-WSNs) A review. *ACM Transactions on Sensor Networks*. 14 2 pp 1-50.

[9] Kabir E, Kumar P, Kumar S, Adelodun A A and Kim K H 2018 Solar energy: Potential and future prospects. *Renewable and Sustainable Energy Reviews*. 82 pp 894-900.

[10] Sharma H, Haque A and Jaffery Z A 2018 An Efficient Solar Energy Harvesting System for Wireless Sensor Nodes. 2018. *2nd IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES) Delhi India* pp 461-464.

[11] Yang Z, Zhou S, Zu J and Inman D 2018 High-Performance Piezoelectric Energy Harvesters and Their Applications. *Joule*. 2 pp 642-697.

[12] Li H, Tian C and Deng Z D 2014 Energy harvesting from low frequency applications using piezoelectric materials. *Applied Physics Reviews*. 1 4 pp 041301.

[13] Yang Z, Erturk A and Zu J 2017 On the efficiency of piezoelectric energy harvesters. *Extreme Mechanics Letters* 15 pp 26-37.

[14] Zibrov V, Zanina I, Molev M and Iliev A 2018 Piezoelectric Cantilever in the Device for Extraction Energy from the Water Flow. *2018 IEEE East-West Design & Test Symposium (EWDTS)*, Kazan, pp 1-4.

[15] Pragya N, Pandey K K and Sahoo P K 2013 A review on harvesting, oil extraction and biofuels production technologies from microalgae. *Renewable and Sustainable Energy Reviews*. 24 pp 159-171.

[16] Nguyen C L, Tartakovsky B and Woodward L 2019 Harvesting Energy from Multiple Microbial Fuel Cells with a High-Conversion Efficiency Power Management System. *ACS omega*. 4 21 pp 18978-18986.
[17] Nabavi S F, Farshidianfar A, Afsharfar A and Khodaparast H H 2019 An ocean wave-based piezoelectric energy harvesting system using breaking wave force. *International Journal of Mechanical Sciences* 151 pp 498-507

[18] Wang L, Isberg J and Tedeschi E 2018 Review of control strategies for wave energy conversion systems and their validation: the wave-to-wire approach. *Renewable and Sustainable Energy Reviews* 81 1 pp 366-379

[19] Han F, Bandarkar A W and Sozer Y 2019 Energy Harvesting from Moving Vehicles on Highways. 2019 *IEEE Energy Conversion Congress and Exposition (ECCE)* Baltimore, MD, USA pp 974-978

[20] Krithika V, Chittal K., Nandhini M, Kumar M M, Balaji S and Kumar T R 2017 Design and fabrication of tidal energy harvester. 2017 *IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI)*, Chennai, pp 2542-2547

[21] Zibrov V A and Maltseva D A 2018 Device for Energy Extraction from the Water Flow for the Pipeline Network Monitoring System. 2018 *XIV International Scientific-Technical Conference on Actual Problems of Electronics Instrument Engineering (APEIE)*, Novosibirsk pp 509-512

[22] Rahmat R F, Satria I S, Siregar B and Budiarto R 2016 Water pipeline monitoring and leak detection using flow liquid meter sensor. In *International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)* 190 1 p. 012036

[23] Sadeghioon A M, Metje N, Chapman D N and Anthony C J 2014 Smart Pipes: Smart wireless sensor networks for leak detection in water pipelines. *Journal of Sensor and Actuator Networks* 3 pp 64-78

[24] Vieira A S, Beal C D, Ghisi E and Stewart R A 2014 Energy intensity of rainwater harvesting systems: A review. *Renewable and Sustainable Energy Reviews*. 34 pp 225-242

[25] Cho J Y, Choi J Y, Jeong S W, Ahn J H, Hwang W S, Yoo H H and Sung T H 2017 Design of hydro electromagnetic and piezoelectric energy harvesters for a smart water meter system. *Sensors and Actuators, A: Physical*. 261 pp 261-267

[26] Vitols A and Rankis I 2014 Harvesting electrical energy from rain by SPMS - Special pipe and micro-generator system. 2014 *55th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON)* Riga pp 105-110

[27] Dilao P J C and Agno K C 2019 Evaluation of a Direct Drive Motor as Generator Driven by Centrifugal Pump as Turbine Energy Harvester for Rural Water Distribution Pipelines. 2019 *IEEE PES GTD Grand International Conference and Exposition Asia (GTD Asia)*, Bangkok, Thailand, pp 848-853

[28] Hoffmann D, Willmann A, Göpfert R, Becker P, Folkmer B and Manoli Y 2013 Energy harvesting from fluid flow in water pipelines for smart metering applications. In *Journal of Physics: Conference Series*. 476 1 pp 2104-2110

[29] Casini M 2015 Harvesting energy from in-pipe hydro systems at urban and building scale. *International Journal of Smart Grid and Clean Energy*. 4 pp 316-327

[30] Muhsen H, Ibrahim M, Alsheikh A, Qanadilo M and Karadsheh A 2019 Turbine design and its impact on energy harvesting from in-pipe hydro systems. *International Journal of Mechanical Engineering and Robotics Research*. 8 5 pp 685-690

[31] Ye G and Soga K 2012 Energy harvesting from water distribution systems. *Journal of Energy Engineering*. 138 1 pp 7-17

[32] Shukla H, Desa H, Sorber J and Piratla K R 2018 Evaluation of Energy Harvesting Potential in Water Pipelines to Power Sustainable Monitoring Systems. In *Construction Research Congress 2018: Infrastructure and Facility Management - Selected Papers from the Construction Research*. p. 475

Acknowledgements
The authors would like to acknowledge University Malaysia Perlis and the School of Computer and Communication Engineering for providing the research grant scheme, which made this study possible to be conducted and successfully published.