



A NEW MECHANICAL APPLICATION FOR FLAT-ROOF WATER PONDING INDICATOR SYSTEM VIA XBEE PROTOCOL

M. F Abdullah¹, A. I. Che-Ani², S. Setumin³, N. M. Tawil⁴ and A. I. Che Ani⁵

^{1,2,3} Faculty of Electrical Engineering, University Teknologi MARA Pulau Pinang, Malaysia

^{4,5} Department of Architecture, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Malaysia

E-Mail: f.abdullah@ppinang.uitm.edu.my

ABSTRACT

The development of a new mechanical application for a flat-roof water ponding indicator system via Xbee protocol is presented in this paper. The mechanical application manipulates variable resistance, which is used as a sensor. The proposed system integrates hardware and software subsystems. The hardware system design involved sensor integration using a potentiometric transduction circuit and was used to develop an interface for an analog-to-digital converter. The water ponding indicator system, a software subsystem, was developed using a programmable integrated circuit by converting the output from potentiometric circuit into water level using a look-up table, which helps convert digital data into the desired reading. The data are displayed through a computer using Xbee protocol. A prototype of the new mechanical application for flat-roof water ponding indicator system via the XBee Protocol was successfully developed. The mechanical sensor application reported changes in water level. The linearity and peak voltage of the output voltage for experimental result for output voltage is at 99%. This system offers possibilities for building surveyor practitioners to continuously monitor flat roofs for water ponding.

Keywords: mechanical application; flat roof; water ponding; potentiometric circuit; xbee protocol.

INTRODUCTION

The roof is the main protector of buildings against natural effects such as rain and sunrays. Roof profiles in Malaysia can be classified into two: pitched and flat. Exposure to weather makes the roof the most defect-prone part of a building. This study focuses on water ponding problem of flat roofs. Water ponding is one of the leading causes of moisture problems in buildings. It triggers problems such as structural damage and unideal breeding habitat for plants, algae, and fungi [1]. Moreover, moisture exposure lessens the strength of building materials [2] and is the main cause of building defects [1].

The mechanical application used in this project manipulates variable resistance, which is used as a sensor. It provides a resistive output that is proportional to water level, that is, a low water level corresponds to low output resistance. The detection method for mechanical application is a potentiometric transduction circuit. Physical measure and is detected in the first stage of the potentiometric indicator system, which consists of a sensor and the transduction stage.

Potentiometric transduction circuit is widely utilized in engineering [3–5]. An advantage is that its supply parameters do not affect its metrological characteristics [6]. This study used MPLAB Integrated Development Environment software, a Windows program package that facilitates simple program writing and development. This software runs on personal computers to develop applications for microchip microcontrollers. It is called an IDE because it provides a single integrated environment for code development for embedded microcontrollers. A PIC 18F26K22 microcontroller is used for the development of a microcontroller-based mechanical application for flat-roof water ponding indicator system. It offers the advantages of all PIC18

microcontrollers, which include a Flash program memory, high computational performance, and high endurance at an economical price. It also introduces design enhancements that make these microcontrollers a logical choice for many high-performance, power-sensitive applications.

The applications of wireless sensor network have been widely used in collecting signals from stand-alone or remote sensors [7]. They also have great potential in medical and health applications. Research on the use of sensor networks to monitor real-time signals has grown recently. The limitations on the existing wireless communication technologies, such as cost and power consumption, can be improved using an Xbee wireless sensor network. Xbee offers efficient low-power connectivity and the ability to connect a large number of devices into a single network.

The present study intends to develop new mechanical applications for a flat-roof water ponding indicator system via Xbee protocol. The mechanical system is placed in a specific location on a flat roof surface (i.e., gutter) where water ponding could occur. The mechanical system is connected to a computerized system using Xbee protocol that sends out alerts when water ponding occurs. Using the mechanical system placed in specific locations can provide complete and accurate information.

SYSTEM DESCRIPTION

The conceptual view of the system is illustrated in Figure-1. Water ponding on a flat roof is collected using mechanical applications by manipulating variable resistance. The data can be transmitted to a remote computer through a network of XBees.

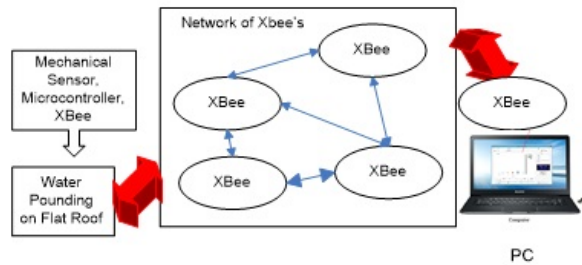


Figure-1. Conceptual view of the system.

The system consists of a signal conditioning circuit, a microcontroller, wireless mechanical applications for collecting data, and an Xbee module that transmits data to a remote PC.

a) Mechanical sensor design

The mechanical sensor was designed using a potentiometer Figure-2. The potentiometer was built with a shaft that can be turned clockwise or counterclockwise to alter the resistance. The range of resistance was from 0 to 10 kΩ. The potentiometer was integrated with a jig Figure-3 that was designed with a potentiometer in the middle. The shaft of the potentiometer was aligned with the jig arm, which was light-weight, minimizing friction at the potentiometer. A ball was installed at the edge of the jig arm to aid floating effect when in water. The top of the jig had a circuitry box that stored system circuitry. When water ponding occurs, the displacement of the jig arm alters the resistance of the potentiometer.



Figure-2. Variable resistor.

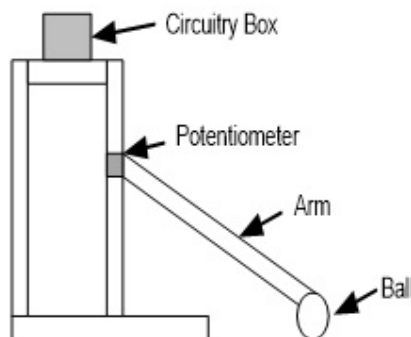


Figure-3. Mechanical sensor applications.

Resistance value alteration was deployed into a voltage value using a voltage divider circuit Figure-4. The potentiometer was used as a voltage-dividing component, and its shaft functioned as a wiper. The other two sides of the potentiometer were each connected to VCC and GND of the circuit. The resistance between GND and the wiper of the potentiometer was R2, and the resistance between the wiper and VCC was R1. Thus, R1 and R2 were in a series. The voltage across resistor R2 can be written as Equation. (1).

$$\text{Voltage across R2 resistor} = \frac{E \times R2}{R1 + R2} \quad (1)$$

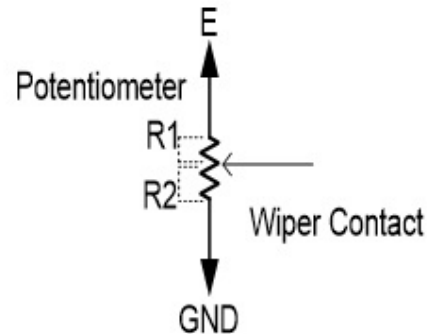


Figure-4. Potentiometric transduction circuit.

b) XBee wireless network

The XBee and XBee-PRO RF Modules meet IEEE 802.15.4 standards and support the unique needs of low-cost, low-power wireless sensor networks. The modules require minimal power and reliably transfer data between devices. They operate within the ISM 2.4 GHz frequency band. The devices are pin-for-pin compatible with each other. The XBee/XBee-PRO RF modules interface host devices through a logic-level asynchronous serial port, through which modules can communicate with any serial device using a logic and voltage compatible UART or a level translator. Figure-5 shows the XbeePro used in this project.



Figure-5. Xbee pro.

The XBee/XBee-PRO RF module was designed to be mounted onto a receptacle; thus, it did not require soldering. The XBee development kits contain RS-232 and USB interface boards that use two 20-pin receptacles to receive modules. Each XBee radio can directly gather sensor data and transmit them without using an external microcontroller. Therefore, XBee offers simple output



functions; thus, basic actuations can also take place without an external microcontroller.

However, XBee has a limitation: the stand-alone XBee radio does not allow access to any kind of logic, that is, no decisions can be made on the local device and no stand-alone operations can be performed besides transmitting data. A solution is to send serial data to an end device that is connected to the PIC16F26K22 microcontroller.

c) Development of microcontroller-based mechanical application for flat-roof water ponding indicator system

Figure-6 shows the PIC18F26K22 pin layout with the Xbee circuit of the developed microcontroller-based mechanical application for the flat-roof water ponding indicator system. The microcontroller performs analog-to-digital conversion, and processes and sends data to an Xbee module that in turn transmits the data to a remote PC. The PC displays the water level based on the mechanical system located on the flat roof.

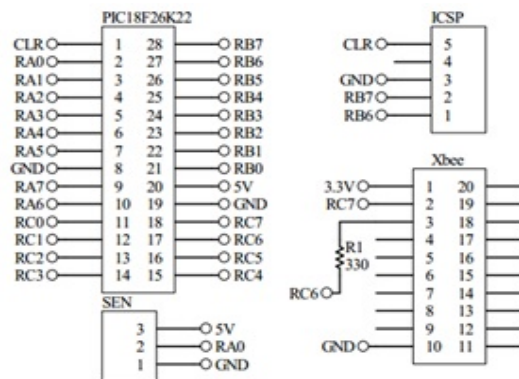


Figure-6. PIC18F26K22 pin layout with Xbee circuit

d) Power source

This study used commonly used lithium-ion (Li-ion) batteries as power source. These batteries are developed from Li-ion technology and used in most sensitive electronic devices [7] such as military and battery electric vehicles and aerospace applications. Li-ion batteries are among the most popular types of rechargeable batteries for portable electronics because of their high energy density, absence of adverse memory effect, and energy efficiency. Li-ion batteries are operated safely within the designated operating voltages. However, they may become unstable if they are charged to higher than specified voltage or reach very low discharge.

RESULTS AND DISCUSSIONS

A prototype of a new mechanical application for flat-roof water ponding indicator system via XBee protocol was successfully developed. A number of experiments and tests on both hardware and software were performed during the development stage. The prototype was tested by slowly pouring the water into a container, allowing the system to detect the differences in water levels.

a) Mechanical sensor design

The sensor design at transduction stage is summarized in Table-1. The linearity and peak voltage of the output voltage for experimental result for V_{out} were at 99% and approximately 1.197 V, respectively. The sensitivity of the output voltage for the experimental results for V_{out} was at 0.0943 V/ Ω . According to Figure-7, the output voltage for experimental testing V_{out} increased from 0.816 V to 1.197 V; likewise, the water level increased from 2 cm to 10 cm. The interposed buffer amplifier prevented the second circuit from loading. The first circuit was interfered with its desired operation.

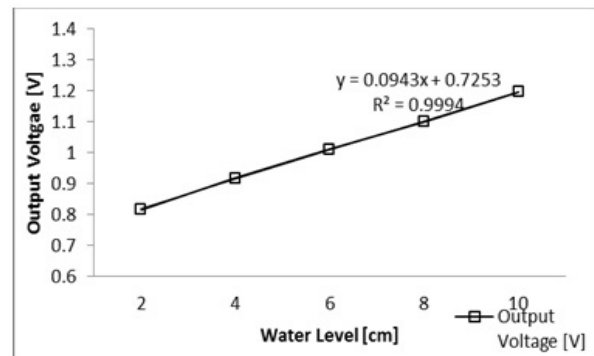


Figure-7. Output voltage (V) versus water level (cm)

Once the overall system for mechanical sensor design was completed, it was integrated with the microcontroller system for data acquisition. The XBee protocol was used to display the required characteristics to indicate the water level based on analog-signal input from the variation of mechanical sensor design. Table-2 shows the range of water level in centimeters based on the output voltage for experimental testing. The output voltage value increased with the increased range of water level. It provides a resistive output proportional to the water level, that is, a lower water level corresponds to a lower output resistance or vice versa.

Table-2. Mechanical sensor design.

Input		Output
Water Level (cm)	Resistance (k Ω)	Output Voltage
2	1.63	0.816
4	1.84	0.918
6	2.02	1.011
8	2.20	1.099
10	2.40	1.197

b) Development of microcontroller-based mechanical sensor application for flat-roof water ponding indicator system

The development of a microcontroller-based mechanical sensor application for flat-roof water ponding indicator system consists of a potentiometric circuit, a microcontroller, wireless mechanical applications to collect the data, and an Xbee module to transmit the data



to a remote PC. The system reliably detects the level of water ponding on the flat roof and can transmit real-time data for display on a PC. Figure-8-9 show the XBee water-level display for 4 cm and 10 cm, respectively.

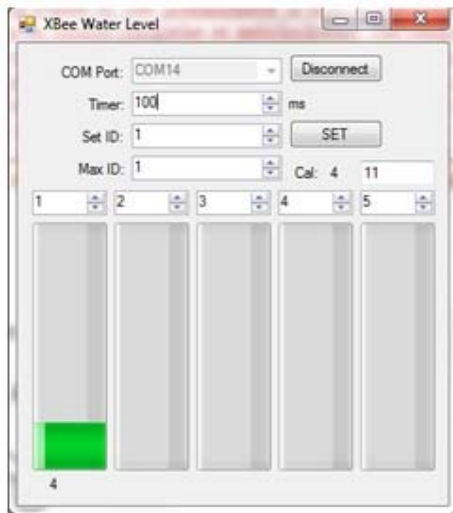


Figure-8. 4 cm Xbee water level.

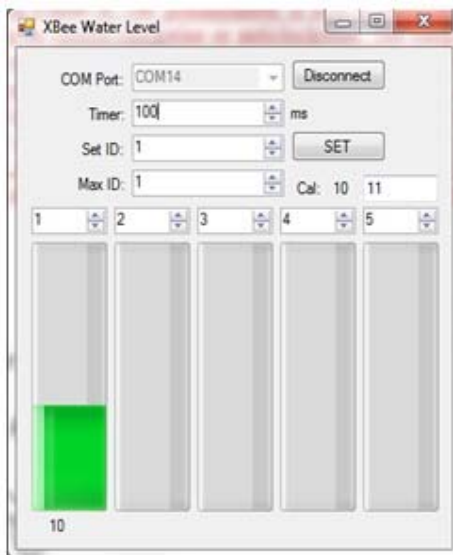


Figure-9. 10 cm Xbee water level.

CONCLUSIONS

A new mechanical application was successfully developed by manipulating a variable resistor that acts as a sensor to detect the level of water ponding on a flat roof. The experiment revealed that the mechanical sensor output varied according to the variable resistance values that were contributed by the different water levels. The linearity and peak voltage of the output voltage for experimental result for V_{out} were obtained at 99%. The hardware design consisted of a potentiometric circuit and a microcontroller with an interface that facilitated an Xbee module to

transmit data to a remote PC. The system can transmit real-time data that can be viewed on a PC. Building surveyors can use the continuous water-sensor system to monitor water ponding on flat roofs.

ACKNOWLEDGEMENT

This study was part of the project titled “The Development of Flat-roof Water Ponding Level Sensor for UKM Chancellery Building,” which is supported by the Universiti Kebangsaan Malaysia (UKM) under Geran Universiti Penyelidikan (GUP-2014-027) and Universiti Teknologi MARA Pulau Pinang (UiTMPP). The researchers are grateful for the financial support provided by these institutions.

REFERENCES

- [1] S. N. H. A. A. Halim, 2010, *Penyiasatan dan Diagnosis Kelembapan Bangunan Bangunan Bersejarah Pejabat Pos Lama*, Institut Pengurusan Penyelidikan, Universiti Teknologi Mara, Shah Alam, Ipoh, Perak.
- [2] H. J. Eldridge, 1976, *Common Defects in Buildings*. 1st. Ed. Great Britain: H.M. Stationery Off.
- [3] B. Wongkittisukka, C. Limsakul, P. Thavarungkul, P. Kanatharana, and P. Asawatreratanaku, 2003. A Conductimetric Transducer for Biosensor System, *NECTEC*, Vol. 4, pp. 369-374.
- [4] L. Jian-Yun, C. Yan-Ting, W. Te-Heng, C. Hong-Si, and L. Jui-Lin. 2007. Biosensor Integrated with Transducer to Detect the Glucose. In: *Circuits and Systems ISCAS IEEE International Symposium*. pp. 2015-2018.
- [5] M.F. Abdullah, L.Y. Khuan, N.K Madzhi, M. Masrie, and A. Ahmad. 2009. Development of a Transduction Circuit for Piezoresistive MEMS Sensor for Biosensing. In: *IEEE Symposium on Industrial Electronics and Applications*, Kuala Lumpur. pp. 679-683
- [6] E. Sifuentes, O. Casas, F. Reverter, and R. Pallàs-Areny, 2008. Direct interface circuit to linearise resistive sensor bridges. *Sensors and Actuators A: Physical*, Vol. 147, pp. 210-215.
- [7] A. H. Kioumars and T. Liqiong. 2011. ATmega and XBee-based wireless sensing. In: *Automation, Robotics and Applications (ICARA), 5th International Conference*. pp. 351-356.