A STUDY ON VIBRATION SENSORS FOR WATER PIPELINE LEAKAGE APPLICATION

[1]Pusparini Dewi Abd Aziz, [2]Mohd Fauzan Mhod Anuar, [3]Norhafiza Mohamad, [4]Mohd Ismifaizul Mohd Ismail
[1]Universiti Kuala Lumpur British Malaysian Institute, Bt. 8, Jalan Sungai Pusu, 53100 Gombak, Selangor, Malaysia
[4]Universiti Teknologi Malaysia, Jalan Semarak, 54100 Kuala Lumpur, Malaysia.
For Correspondence; pusparini@unikl.edu.my

ABSTRACT: *Water leakage is a common problem that often results in water waste, damages, and hazards to public health. The water industry has invested in equipment to detect and localize leaks along the water distribution system. The experience of water distribution companies shows that the reduction of leakage and the preservation of a low leakage level can be achieved with a strategy that requires loss analysis followed by leak detection. This research addresses this shortcoming by studying on vibration sensors for pipeline leakage. Two types of the vibration sensors that employ the triple axis accelerometer sensor are MMA7361 and ADXL335, however only MMA7361 is applied to detect the leakage along the pipeline. The experiment considers the various length of the pipeline with different water pressure conditions. The vibration is analysed using Arduino board. The vibration data captured by the sensor is transmitted via XBee network.*

1. INTRODUCTION

This research is the prior stage in creating a reliable system for detecting pipeline leakage using accelerometer sensor. The goal of this research is to build a working prototype of a measuring device in order to measure vibration when the pipeline is in normal condition and leak condition. The important element of this research is the three-dimensional accelerometer sensor [1] that functions in triple axis sensor x, y and z and being supported by an open source known as Arduino board [2]. The system includes physical sensor, signal processing unit and a display. The interface is done by Arduino. The signal from sensor is converted to digital in unit of g-unit (9.81 m/s^2). This sensor measures the static acceleration of gravity.

Nowadays, this sensor has widely been used in a various applications with different significance in performance and technologies [3-9]. An accelerometer instrument and measurement can be found in industrial systems like medical electronic, vehicles system and gaming system. Furthermore, this sensor also able to measure dynamic acceleration which resulting from shock, motion and vibration.

Today's water utility operators have various equipment and techniques to measure, analyze, monitor and reduce leakage in pipelines. In recent years, there has been such development of tools and equipment to support this task. However, there is still a big gap in such technologies, complementary technology and equipment for locating and pinpointing the leaks. Thus systematic detection methods are essential to reduce the amount of leakages. In this research, the application of the vibration sensor method is tested in two different conditions for comparison purposes: (1) no pipe leakage; and (2) pipe leakage. The parameters to be considered in this research are: (1) the detection distance which is the separation distance between leakage and sensor placement, and (2) the water pressure in the pipeline.

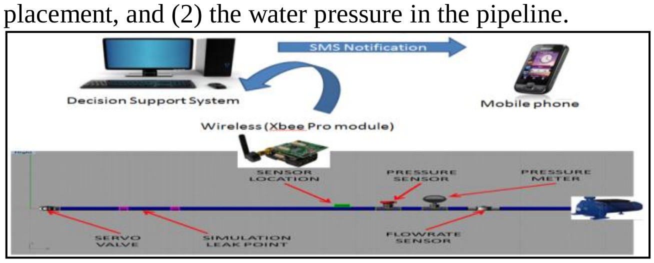

Fig.1 Overall detection system for testing method

Two types of the vibration sensor that has a triple axis accelerometer sensor are MMA7361 and ADXL335.

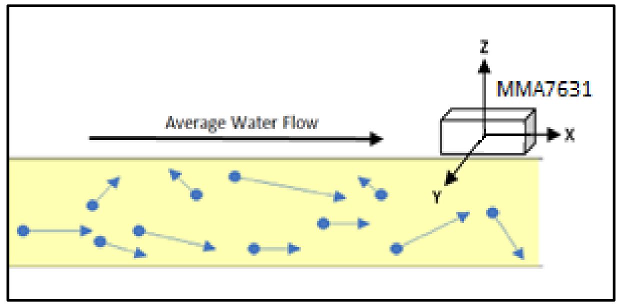

Fig.2 Microscopic view of the water flow in a pipeline with triple axis sensor.

However, only one of the sensors is used to measure the vibration occurred along the pipelines. This is due to MMA7361 has more advantages compared to ADXL335 as refer to Table 1 [10, 11]. Based on the experiment and data analysis, there is different in data between normal pipe and leakage pipe when applying MMA7361 sensor at 0.5m, 1m, 1.5m and 2m from the location of the leakage. The water pressure varies at 0.6kgf/cm^2, 0.8kgf/cm^2, 1.0kgf/cm^2, 1.2kgf/cm^2, 1.4kgf/cm^2 and 1.6kgf/cm2 at each distance mentioned. The vibration data is analysed using Arduino board. Data collected from vibration sensor then transmitted via XBee network.

Table: 1 Advantages and disadvantages between ADXL335 and MMA7361

Sensor	Advantages	Disadvantages
ADXL335	• Analog interface-easy to use • 3-axis accelerometer • Low cost • Low current consumption	• Low range • Supply voltage only 3.6V
MMA736	• 3-axis accelerometer • Very low cost • Flexibility in measuring the range because of g-select • MMA7361 has 0g detection interrupt (free-fall sensing) • Easy analogue interface • Sleep pin-save power	• MMA7361 does not offer quite as much flexibility as its processor • Complex to running but still quite easy to get up and running (need extra wires)

2. MATERIAL AND METHODS

2.1 Sensor Selection

There are various types of accelerometer sensors in the market. However, the selection for a suitable sensor to apply in this research requires some factors to be considered [11].

A. Full Scale Range

One of the characteristics that stand out the most is the accelerometer's full-scale range is the upper and lower limits of what the accelerometer can measure. In most cases, a smaller full-scale range means a more sensitive output; therefore more precise reading can be obtained from accelerometer with a low full-scale range.

B. Interface

Accelerometer has three types of interfacing which are analogue, pulse-width modulation and digital. Accelerometers with an analogue output produces a voltage that is directly proportional to the acceleration sense. At 0g, the analogue output resides at about the middle of the supplied voltage (e.g. 1.65V for a 3.3V sensor). Generally this interface is the easiest to work with, as analogue-to-digital converters (ADCs) are implemented in most microcontrollers. For pulse-width modulation (PWM), it produces fixed frequency in square wave although the duty cycle of pulse varies with acceleration sensing. Besides, for the digital interface, it might difficult to integrate with the microcontroller.

C. Number of Axes to Measure

Accelerometer can sense three axis which are X, Y and Z.

D. Bandwidth

This bandwidth requirement depends on the application of the sensing device. The bandwidth range usually within 50 up to 100Hz.

E. Power Usage

Consideration of sensor power consumptions. This sensor has sleeps function to conserve energy when not used.

F. Additional Features

Includes measuring range, 0-g detection and tap sensing.

There are two types of accelerometer sensor that need to be investigated. Table 1 classifies the advantages and the disadvantages between the both sensor features that have been studied [10, 11].

From the various types of the accelerometer sensor, the sensor that been choose is MMA7361 sensor.

2.2 MMA7361 Sensor

MMA7361 is a device consists of a surface micro machine capacitive sensing cell (g-cell) and a signal conditioning for Application Specific Integrated Circuit (ASIC) contains in a single package. The sensing element is sealed at the water level using a bulk micro machine cap wafer. The sensor requires a very low amount of power and has a g-select input which switches the accelerometer between ±1.5g and ±6g measurement ranges. Other features include sleep mode, signal conditioning, a 1-pole low pass filter, temperature compensation, self-test, and 0g-detect which detects linear freefall. Zero-g offset and sensitivity are factory set and require no external devices.

Mechanism of MMA7361 is based on a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modelled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to the acceleration. As the beams attached to the central mass move, the distance from them to the fixed beams on one side increases by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration. The g-cell beams form two back-to-back capacitors. As the center beam moves with acceleration, the distance between the beams changes and each capacitor's value will change ($C = A\varepsilon/D$). Where A is the area of the beam, ε is the dielectric constant, and D is the distance between the beams. The ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratio metric and proportional to acceleration. MMA7361 accelerometer also have built in special features, there are [11]:

A. Filtering

The three axis accelerometer contains an on board single-pole switched capacitor filter. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

B. Ratiometricity

Ratiometricity simply means the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as supply voltage is increased, the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analogue to digital conversion process.

2.3 System Architecture

The system consists of three main parts, which are sensor unit, monitor unit and water pipeline monitoring system. Sensor unit used Arduino UNO board as a microprocessor and connected wirelessly using XBEE Pro Module. The data are collected from the MMA7361 sensor. This sensor transmitted all the analogue data from the XBee Pro Module transmitter to the XBee Pro Module receiver, and then displayed on the hyper terminal [12]. All data are saved in the text file to be processed and analysed using excel. The transmitter has different address that need to be connected to the receiver. X-CTU software is used to setup this address so that the data will be transmitted to the receiver without having any problem.

The Arduino controller board sets the sensitivity for MMA7361 sensor. The sensitivity of the MMA7361 can be selected at 206mv/g or 800mv/g. The MMA7361 allows for the selection between two sensitivities. Depending on the logic input placed on pin 10, the device internal gain is changed allowing it to function with a 1.5g or 6g sensitivity. This feature is ideal when a product has applications requiring two different sensitivities for optimum performance. The sensitivity can be changed at any time during the operation. The g-Select pin can be left unconnected for applications requiring only 1.5g sensitivity as the device has an internal pull-down to keep it at that sensitivity (800mV/g). The final step is to analyse the data to identify the normal pipe as well as the pipe with leakage.

2.4 System Monitoring

The water pipeline monitoring test bed is built to analyse the water pipeline leakage. The measurement is to identify the normal pipe and also the leakage condition of the water pipeline system. In our prototype, PVC pipe is used. This pipe has length at 10 meters long.

Fig. 3 shows the prototype of the pipeline system comprises the water pump, flow rate meter, pressure meter, leaking pipes and two manual valves. The function of a water pump is to generate the water flow and the water pressure in the pipeline system. The water pump pressure is configured between 0.6 to 1.6kgf/cm^2. Pressure meter indicates the amount of pressure in the pipeline while flow meter is used to measure flow rate of water that passes through it. A valve is installed in the pipeline system for controlling the pressure and the water flow. The water system is designed to recycle the water intake during the experiments conducted. The distance between water pump and location of leakage is 7.8m.

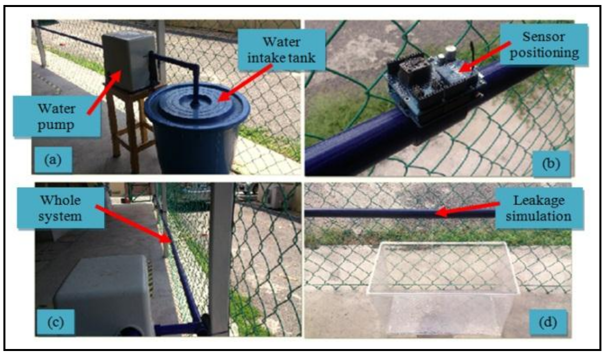

Fig.3 Real Simulation Pipe system for testing method

The vibration sensor is be placed from the location of leakage at 0.5m, 1m, 1.5m and 2m and at each distance the water pressure will different at 0.6 kgf/cm^2, 0.8kgf/cm^2, 1.0kgf/cm^2, 1.2kgf/cm^2, 1.4kgf/cm^2 and 1.6kgf/cm^2. All the data were recorded 3 times within 3 minutes.

2.5 Data Collection

All the data from the vibration sensor are collected at distance of 500mm, 1000mm, 1500mm and 2000mm with different water pressures applied; 0.6 kgf/cm^2, 0.8kgf/cm^2, 1.0kgf/cm^2, 1.2kgf/cm^2, 1.4kgf/cm^2 and 1.6kgf/cm^2 using Hyper-terminal software. The data obtained is saved in the computer using text file and used for the simulation in Excel using graph. To obtain the graph, data collected from the normal pipe, leak pipe and normal pipe without pump are subtracted with the data from the water pump.

The equations to obtain the data are shown below:

Data for normal pipeline condition:

Data water pump – (Data normal pipe – Data without water pump) (1)

Data for leak pipe:

Data water pump - (Data leak pipe – Data without pump)

Data from normal pipe and leak pipe are used to detect pipeline leakage and to measure sensor sensitivity.

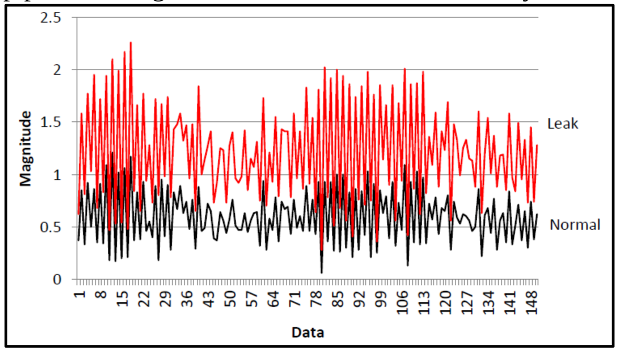

Fig.4 Data sample for non-leak and leak at 500mm

For each graph, 150 of data at each water pressure and distance are used to compare between each of them. All data are plotted in the graph to compare between magnitude and condensate of the normal pipe and leak pipe. With the aid of graph plotted in Microsoft Excel, all the data can now be interpret easily by any personnel. The main interpretation made to the graphs is basically to compare the normal pipe with the leak pipe.

3. RESULTS AND DISCUSSION

In this research, instead of using the actual piping used in water works, a PVC pipe is used to simulate actual behavior. The PVC pipe of 10 meters long was used to get the vibration when the pipe is with or without hole. Two experiments are conducted to investigate the vibration of the pipe. The first set up was during the water flow through a normal PVC pipe and the vibration activities is then been investigated. The second set up, the 1mm hole was drilled into the pipe to mimic water leakage condition. In this subsection, the data obtained is then tabulated according to the following criteria(s):

1. Different pressure to detect pipeline leakage
2. Separation distance to measure sensor sensitivity

All the data were presented in normal and leak conditions. This is for comparison purposes to detect the leakage in pipeline. By comparing between water pressure at normal and leak condition, it can be seen that the higher water pressure produce greater vibration magnitude. At this point, sound can be heard louder than usual with high in magnitude. Besides, it is found that normal pipe produced more vibration compared to leakage pipe. The increasing of water pressure increases the magnitude in both normal and leakage pipe. So, it can be said that the magnitude is directly proportional to the water pressure. The condensation of the signal from normal pipe is much higher than the leakage pipe. From graph shown in Fig. 5, vibration can be detected and compared between normal and leak pipe.

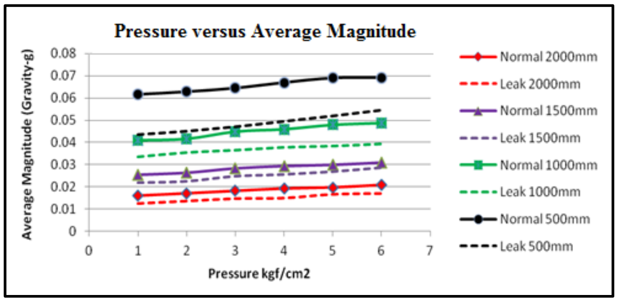

Fig.5 Pressure effect with leak and non-leak condition.

Ideally, with low water pressure is best applied to detect the pipeline leakage. The graph obtained that comprises of 150 at each water pressure is used to compare between each of the data. These data are used to obtain the average magnitude between the water pressures. By comparing the normal pipeline and leak pipeline at 0.6 water pressure, the pipeline leakage can be detected more easily compared to the other water pressure.

Accelerometers are placed at the distance of 500mm, 100mm, 1500mm and 2000mm from location of the leak to obtain the vibration motion of the pipeline. Ideally, accelerometers are placed at a certain distance. Since the pipe is about 10 meters long, the accelerometers are placed about 7.8 meters apart from the location of leak. It cannot be placed any nearer as it will collect vibration from the water pump itself because water pump produced lots of vibration. This will affect the vibration sample. Based on the graph above, the graphs show that at the distance 500mm, the vibration data produces higher magnitude than the distance 1000mm, 1500mm and 2000mm. Increase in distance, decreases the magnitude of the vibration. Therefore, the sensor will sense less vibration when increase in distance. Besides that, normal pipe also produced higher magnitude than leak pipe same with the data that collected when compared with the water pressure. When the water pressure reached 1.0 kgf/cm2, the different between normal graph and leak graph are slightly different because the water flow in the pipeline neglects the presence of the leak. Based on condense level, normal pipe produced more condense than the leak pipe.

The data consists of 150 data at each distance are used to compare between each of them. The data is used to get the average magnitude between the distances. The graph in Fig. 6 proves that all the analysis from graph shown in Fig. 5 is correct. At all distances in which accelerometers are placed, vibration can be detected. Accelerometers cannot be placed any further due to the short pipe length. The optimum distance at which accelerometers should be placed is probably at a distance of 2000mm from the location of the leak.

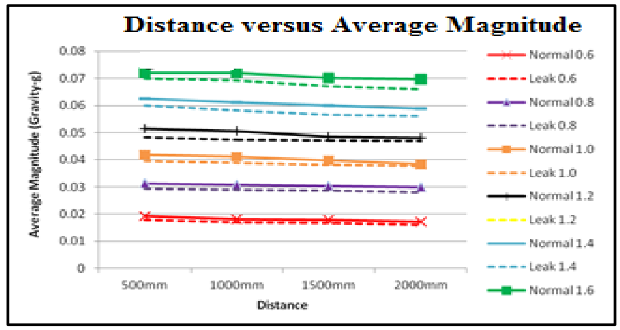

Fig.6 Distance versus Average Magnitude

4. CONCLUSION

With modern technology, vibration sensor technology was applied to monitor and detect leaks. The study of this research is divided into three sections which are sensor unit, monitor unit and water pipeline test bed. The sensor unit is all about how to design and construct the connection between the Arduino XBee Prototype board, Arduino Uno and XBee Pro Module. For the monitoring unit, it consists of XBee Pro Module receiver that connected to the laptop so that the data can be received and displayed on the hyper terminal. Water pipeline test bed has a 10m PVC pipe system was developed which included water pump, pressure gauge, flow rate meter and valve. The water pump was installed at the water intake to generate the water flow in the pipeline. The valve was installed at the edge of the pipeline system to control the pressure and water velocity in the pipeline. The wireless sensor is located on the pipeline with the range of 0.5m, 1m, 1.5m and 2m between the location of the leakage and the wireless sensor. The pipeline system was installed with the pressure meter and also with the flow rate meter to measure the pressure and the water flow respectively. The water pressure will different at 0.6 kgf/cm^2, 0.8kgf/cm^2, 1.0kgf/cm^2, 1.2kgf/cm^2, and 1.4kgf/cm^2 and 1.6kgf/cm^2 at each distance of the leak. All the data will be recorded 3 times within 3 minutes. The size of the leakage hole is 1mm.

The result shows the difference between output data from the normal pipe and pipe with leakage. Pipe with leakage produces less vibration compare to the normal pipe. The distance between the location of the leakage and the sensor also affected the output data. The furthest the distance between sensor and leakage, the less vibration can be sensed by the sensor. When the water pressure is increases, it causes vibration but when the water pressure reaches 1.0 kgf/cm^2. The vibration reduces the water flowrate in the pipeline increases and neglected the 1mm hole on the pipeline.

5. ACKNOWLEDGEMENT

The author would like to express sincere gratitude to the students and staffs of Universiti Kuala Lumpur British Malaysian Institute and Universiti Teknologi Malaysia for their effort to make this research happened.

6. REFERENCES

[1] Accelerometer Sensor, http://www.sensorwiki.org/doku.php/sensors/accelerometer, Feb, (2015).

[2] Arduino Uno, http://arduino.cc/en/Main/arduinoBoardUno, Feb, (2015).

[3] Fuchs, H. V. and Riehle, R., Ten Years of Experience with Leak Detection by Acoustic Signal Analysis, pp. 1-19, (1991).

[4] Seaford, H., Acoustic Leak Detection through Advanced Signal-Processing Technology, pp. 17-18, (1994).

[5] Schwendeman, T., Detecting Underground Piping Leaks, pp. 56-58, (1987).

[6] Hough, J. E., Leak Testing of Pipeline Uses Pressure and Acoustic Velocity, pp. 35-41, (1998).

[7] Megyesy, E. F., Pressure Vessel Handbook, Tulsa, UK, Pressure Vessel Publication, 1998.

[8] Williams, J. A., Kozak, S., and Rodenbaugh, T. J. Leak Location Methods for HV Underground Cables, IEEE Transactions on Power Apparatus and Systems, pp. 2029-2036, (1983).

[9] Paquin, F., Babineau, D.,Brissette, F., Leconte, R, Development of A Methodology for Locating Leaks in Water Lines pp. 151-159, (2000).

[10] ADXL 335 Datasheets, https://www.sparkfun.com/datasheets/Components/SMD/adxl335.pdf, Feb, (2015).

[11] MMA 7361 Sensor, https://www.sparkfun.com/products/retired/9652, Feb, (2015).

[12] XBee Datasheets, https://www.sparkfun.com/datasheets/Wireless/Zigbee/XBee-Datasheet.pdf, Feb (2015).