Online Vibration Monitoring of a Water Pump Machine to Detect Its Malfunction Components Based on Artificial Neural Network

P Rahmawati, P Prajitno
Departemen Fisika, Fakultas Matematika & Ilmu Pengetahuan Alam, Universitas Indonesia, Kampus UI Depok, Depok 16424, Indonesia

Corresponding author’s e-mail: prawito@sci.ui.ac.id

Abstract. Vibration monitoring is a measurement instrument used to identify, predict, and prevent failures in machine instruments[6]. This is very needed in the industrial applications, cause any problem with the equipment or plant translates into economical loss and they are mostly monitored component off-line[2]. In this research, a system has been developed to detect the malfunction of the components of Shimizu PS-128BT water pump machine, such as capacitor, bearing and impeller by online measurements. The malfunction components are detected by taking vibration data using a Micro-Electro-Mechanical System(MEMS)-based accelerometer that are acquired by using Raspberry Pi microcomputer and then the data are converted into the form of Relative Power Ratio(RPR). In this form the signal acquired from different components conditions have different patterns. The collected RPR used as the base of classification process for recognizing the damage components of the water pump that are conducted by Artificial Neural Network(ANN). Finally, the damage test result will be sent via text message using GSM module that are connected to Raspberry Pi microcomputer. The results, with several measurement readings, with each reading in 10 minutes duration for each different component conditions, all cases yield 100% of accuracies while in the case of defective capacitor yields 90% of accuracy.

1. Introduction
Indonesia is a developing country that has many great natural resources. One of developments that Indonesia has been doing in industrial field is about how to use and manage natural resources effectively. Based on data from Ministry of Industry in 2015, non-petroleum refinement industrial sector have grown about 5.04 percent, which is higher than economic growth that have grown about 4.79 percent [9].

Indonesian industries have been using high technological machines to shorten the natural resources processing to become more effective. These machines may be broken because of their age or failure in use. Therefore, machine’s condition monitoring is needed, because it’s an important part of industrial processing maintenance. Sometimes a machine may break down unexpectedly from operating, it may cause relatively big financial loss and also may bring hazards that can harm work safety.

There are 2 ways that can be used to monitor the condition of machine, which are with vibration or lubricant. Vibration works by analyzing the damage through vibration from the machine, because every vibration from the machine indicates that there’s something broken in the machine. Lubricant is
a type of analysis that works by investigating the fluid from the inside of the machine such as lubricant.

Nowadays, there have been many researches that try to develop instruments to do vibration monitoring method, started from using wire to wireless, and each research also has used different sensor. Most of the researches use Micro-Electro-Mechanical System (MEMS) accelerometer and do processing data by applying Fast Fourier Transform (FFT). From the previous research of this year, a new instrument had been developed by using Field-Programmable Gate Array (FPGA) [1]-[6].

In this research, a system had been developed to detect any damage on water pump which happen to components that are bearing, capacitor and impeller by using MEMS accelerometer with data processing that uses Relative Power Ratio (RPR). And Artificial Neural Network (ANN) method is used to classify the malfunction. As for the result of this analysis will be transmitted by GSM network.

2. Methodology
The main component of this result consists of MEMS accelerometer, Raspberry Pi and GSM module. The type of MEMS accelerometer that is used in this research is MPU-6050 which has 3 axis. Then, the result data of MEMS accelerometer acquisition are sent by using I2C communication line which is located on Raspberry Pi and later on will be processed by using Power Spectral Density (PSD), Relative Power Ratio (RPR) and Artificial Neural Network (ANN) algorithms that are embedded on Raspberry Pi. The programming language that’s embedded on Raspberry Pi is Python programming language. The result of Raspberry Pi processing will be transmitted by GSM module as text message to cellular phone. USART is used for Raspberry Pi and GSM module interfacing. The overall system and work flow are shown as Figure 2.1, while the general flow diagram is shown by Figure 2.2.

![Figure 2.1 General System Diagram](image)

![Figure 2.2 The General Flow Diagram](image)
2.1. Vibration Data Acquisition
Sensor that’s used to take vibration data is MEMS accelerometer type MPU-6050 which is triaxial accelerometer with 16 bit output resolution in every axis and sampling rate frequency is 1000 Hz. In addition, measurement range of this accelerometer is ± 2g, so theoretically the resolution is $4g/2^{16} = 61.04 \mu g/\text{bit}$. MPU-6050 supports 400 kHz Fast Mode I2C serial interface for communication with other devices. Sensor is installed on the top surface of the water pump body by using rubber tape 3m.

The first vibration data taking is done to make it as training data on ANN with 5 minutes duration. Training data is data that consists of any malfunction on components which are bearing, impeller and capacitor. After that, training data will be processed to be training data on ANN which is embedded on Raspberry Pi.

2.2. Data Processing by Using Relative Power Ratio (RPR) Method
Vibration data that is taken by using accelerometer has a relatively big number of data, so RPR method is needed to minimize the number of data to make training on ANN become easier. In this RPR method, vibration data are divided into 3000 data per one set of data. Every set of data is calculated by Power Spectral Density (PSD) algorithm, so the power value can be known in every frequency on every set of data. Then, with 10 Hz frequency band, the RPR value can be calculated by following equation:

$$ RPR(df) = \frac{\text{Power}(df)}{\text{Sum}(\text{PSD})} \quad (1) $$

with RPR(df) is the value of RPR on frequency band, Power(df) is the total power of frequency band and Sum(psd) is the overall total power on every frequency.

2.3. Malfunction Classification by Using Artificial Neural Network (ANN)
Artificial Neural Network (ANN) is an artificial intelligence that can analyze data by comparing data to other data which had been chosen as reference. On ANN, first thing that’s needed to be done is doing training by giving data which represent every component’s malfunction. ANN that’s used in this research is a type of feed-forward network with backpropagation training. On ANN, there are certain value of input nodes, hidden nodes and output nodes that have to be set. The chosen value of input nodes is 50 which is the data number of one data set, and the chosen value of hidden layer is 25 nodes and the chosen value of output nodes is 6 based on the number of malfunction that wants to be classified into several classes which are normal, broken capacitor, broken impeller, broken bearing, broken capacitor & impeller, and broken capacitor & bearing.

Besides training data on ANN, testing process is also conducted by taking real time and online data that later will be compared with the result of the training.

2.4. Result of Analysis Transmission using GSM Module
The result of analysis from ANN is transmitted through text message by using GSM Module. The result that will be transmitted is just the result of malfunction analysis. Text message transmission is done by every one minute with duration of 10 minutes.

3. Results

3.1. ANN Training
Data taking to get ANN training data is conducted for about 5 minutes to every malfunction case on water pump. So the number of data which is 300,000 data is obtained from sampling rate of MEMS accelerometer MPU 6050 is 1 kHz. Then, data from every malfunction is converted into the form of set of data with value of 3000 data per set of data. From this data set, RPR calculation is conducted in frequency band with value of 10 Hz which later will be projected into a graphic like in Figure 3.1.

On Figure 3.1., there’s RPR graphic from every case where each case has different pattern. The graphic from broken impeller and broken capacitor case show that RPR value is almost the same in every frequency band but RPR from broken impeller is bigger than RPR from broken capacitor. However, graphic from broken bearing case shows that the RPR value is smaller, so there’s a visible bold line in the lower part. The case that gives the biggest value of RPR is the broken capacitor and impeller case.

From these different patterns of malfunction, by using human’s visual skill, the malfunction of water pump component can be known, but it takes a long time. Therefore, ANN training is needed to be done by giving the result of RPR data to ANN. The chosen ANN is the feed-forward network type and backpropagation trainer with hidden layer which value is 25 and activation function that uses Tanh layer and Softmax Layer.
3.2. Testing
Testing for each case is conducted in every minute for about 10 minutes where test data is taken by online. Then the result of analysis will be transmitted by using GSM module through text message. The result from testing system shows that there’s a match between the analyzed case and there is an error on the 4th minute on capacitor testing (based on Figure 3.2).

4. Conclusion
From the result of component’s malfunction testing on water pump that’s conducted by the artificial system, it can be concluded that vibration monitoring system can be built by acquisitioning vibration data through MEMS MPU-6050 accelerometer by using Raspberry Pi microcomputer. This microcomputer had been embedded with Artificial Neural Network (ANN) that uses feed-forward dan backpropagation. The training uses hidden layer that uses Tanh Layer and also uses Softmax Layer as the output with the chosen value of hidden layer is 25. The result of testing data for every case shows that there’s a match between the result of test and types of cases that has been testing, except for capacitor case that has 1 error from 10 times of testing. This result may give simplicity for industrial workers to know the machine malfunctions fastly in certain period remotely.

Suggestions for further research are the data taking for training data and testing data must taken in same electrical condition because the different voltage source used will change the vibration pattern of each case and it is also necessary to vary the experimental conditions, for example the duration of the use of the water pump machine should be more than 30 minutes and then taking training data for each case.
Acknowledgments
This research is a final assignment research under the support of the Instrumentation Physics Division at the Department of Physics of the Universitas Indonesia.

References
[1] Bengherbia B, Zmirli M O, Toubal A, & Guessoum A 2017 FPGA- based wireless sensor nodes for vibration monitoring system and fault diagnosis Measurement 101 81-92.
[2] Chikuruwo M N, Maregedze L, & Gankayi T 2016 Design of an Automated Vibration Monitoring System for Condition Based Maintenance of a Lathe Machine (Case Study) IEEE.
[3] Gicrlak P, Burghardt A, Szybicki D, Szuster M, & Muszynka M. 2016 On-line manipulator instrument condition monitoring based on vibration analysis Mechanical System and Signal 89 14-26
[4] Helal I A, Vuong T-H, David J, Bellaaj N M, & David M P 2015 Vibration Monitoring Based on MEMS Accelerometers 16th International Conference on Science and Techniques of Automatic Control & Computer Engineering Monastir
[5] Hong K, Huang H, Fu Y, & Zhou J 2016 A vibration measurement system for health monitoring of power transformers Measurement 93 135-147
[6] Ikram W, Chen S -L., Harvei T, Olsen T, Mikalsen E, Svoen G, Myhre B 2014 Vibration- Based Wireless Machine Condition Monitoring System IEEE
[7] Pratama R A 2015 Perancangan Pengendali Neural Network pada Gerak YAW dan Sudut Slip Samping Kendaraan Roda Empat (Depok: University Indonesia)
[8] Stoica P, & Moses R 2005 Spectral Analysis of Signals (New Jersey: Prentice Hall)
[9] Indonesia K P 2016 Laporan Kinerja Kementrian Perindustrian Tahun 2015 (Jakarta)
[10] Fausett L 1994 Fundamentals of Neural Networks (New Jersey: Prentice-Hal)
[11] Stoica P & Moses R 2005 Spectral Analysis of Signals (New Jersey: Prentice Hall)
[12] Cheung V & Cannons K (n.d.) An Introduction to Neural Network (Canada: University of Manitoba)
[13] Randall R B 2011 Vibration-based Condition Monitoring (Vol. III) (Australia: Wiley)