Construction of vibration monitoring system based on Wireless Sensor Network (WSN) for machining process

F N Azmi*, K Saptaji and M R Fikri
Department of Mechanical Engineering, Sampoerna University, Jl. Raya Pasar Minggu, Kav 16, Jakarta 12780, Indonesia

*fijai.azmi@mysampoernauniversity.ac.id

Abstract. At present, the wired vibration sensor monitoring system for rotating machinery has been successfully implemented in the modern industry. Regardless of its advantages such as real-time transmission and the fast response, the complex configuration can cause a problem such as tucked cables and higher cost as it is employed in large equipment. Therefore, in this current study, the vibration monitoring system based on Wireless Sensor Network (WSN) is developed. The new monitoring system proposed in this study involves the utilization of the Xbee module, Raspberry Pi, Arduino UNO, and Grove vibration sensor. Three parameters which are the indoor range, cost optimization, and the capability to connect to the internet are the main considerations to build the system. In order to validate the proposed vibration monitoring system based on WSN, milling experiment was conducted. From the vibration sensor being installed in the milling machine, it can be observed that the system is adequate to accomplish vibration data through wireless connection with the distance about 3 meters. By real time investigation of the vibration data, the system able to recognize any error in the milling process. Therefore, the system capable to prevent failure in the machining process specifically in the milling process.

1. Introduction
Nowadays, wired vibration sensor monitoring system for rotating has been successfully developed and already implemented in the modern industry [1]. The system meets the requirement of monitoring system with the condition of machinery. Wired connection gives several advantageous such as real-time data transmission and fast respond [1,2]. However, at certain complex condition wired connection will give disadvantage rather than advantage and even will caused fatal problem in the production process [2]. The tucked cable is one of problem which will disturb the machinery. Other problem will occur when the monitoring system is installed in large equipment. It will need more cables and the production cost will increase as well. Therefore, for complex circumstance wired monitoring system is not applicable [2].

In order to solve this problem, new type of vibration monitoring system is proposed. Wireless vibration monitoring system with the absence of cables is the best approach to do monitoring system since there will be no problem with tucked cable. Wireless vibration monitoring system work based on the working principle of wireless sensor networks (WSN). WSN is a set of sensor node which distributed along the machinery surroundings which have high possibility to fail. The sensor node is used to sense, measure and gather physical data such as temperature, humidity, vibration, etc. [3]. In this study, vibration sensor is applied to get vibration data of rotating machinery.
In pursuing the goal of replacing wired system with wireless system, this study uses raspberry pi, Xbee module, Arduino UNO and vibration sensor as the main component. Arduino UNO and vibration sensor are the sensor node are the component which gather the vibration data. Raspberry pi act as the base station which will record the data from the sensor node. Both sensor and base station are connected wirelessly by Xbee module so that the system can work wirelessly and cooperatively.

2. System architecture

Wireless sensor network consists of a combination of sensor node and base station to gather the data. It is used for system monitoring wirelessly. Both sensor node and base station are connected by radio receiver and transmitter [4]. Sensor node which responsible for collection and distribution of information connected with the radio transmitter device while the base station as the main controller is connected with radio receiver module. Each of the sensor node carry a program which handle the data of the sensor in a certain manner. Furthermore, the program keeps the sensor communicate with base station [5]. One base station may handle more than one sensor nodes. It is one of the advantages of using WSN as the monitoring system [5]. Monitoring humidity, temperature, vibration can be done in the same time. A set of WSN have five main components: processor, memory, radio transceiver, sensor, and power source [6]. In this study, the WSN is built with the combination of Raspberry pi as the processor of base station, Arduino UNO as the processor of sensor node, Zigbee as the radio transceiver which connect between sensor node and base station, and vibration sensor as the sensing device.

2.1. Raspberry Pi

In this study, Raspberry pi is proposed as the base station of the wireless vibration sensor monitoring system. It is chosen because of the base station need computer board which has several advantages such as small, cheap, customizable and programable, and the ability to control the sensor node [7]. Raspberry Pi was introduced in 2012. It is oriented for education purpose of computer board with affordable price [7]. This computer board is one of the best platforms for interfacing with many devices [8] in this study is the sensor node. Raspberry pi is equipped with processor and graphic chip, RAM, and interface connector [9] which shown in figure 1.

Figure 1. Raspberry pi model B [9].

In this study the wireless vibration sensor monitoring system is targeted in the complex machinery which require compact package of monitoring system. Due to the complex condition, the parameter which get attention the most is the mass, dimension, cost and capacity of the memory storage. The comparison of raspberry pi and others processor module is listed in table 1.
### Table 1. Comparison of raspberry pi and other platform.

| Platform     | Dimension (mm) | Mass (g) | Cost per node (USD) | RAM (KB) | Memory (KB) |
|--------------|----------------|----------|---------------------|----------|-------------|
| Raspberry pi [9] | 85.6*53.98*17  | 45       | 25-35               | 512,000  | 64 × 10^6   |
| Mica Z [10]   | 58*32*7        | 18       | 99                  | 4        | 128         |
| Telos B [11]  | 65*31*6        | 23       | 99                  | 10       | 48          |
| Iris [12]     | 58*32*7        | 18       | 115                 | 8        | 128         |
| Cricket [13]  | 58*32*7        | 18       | 225                 | 4        | 512         |
| Lotus [14]    | 76*34*7        | 18       | 300                 | 64       | 512         |

As listed in table 1 raspberry pi has highest performance compare to other platforms. It has the highest storage with lowest cost which make the raspberry pi is the best platform for base station of wireless vibration sensor monitoring system.

2.2. Arduino UNO

Arduino is open-source platform [15] designed to construct and program electronic device. It can do both transmit and receive data and information to or from electronic device [16]. It is equipped with Arduino board and software with base of C++ [17]. Nowadays, Arduino mostly used as microcontroller due to its simplicity of programming language with ability to control numerous instruction [18]. Arduino UNO is chosen as the microcontroller in this project. The main component in Arduino UNO board is shown in figure 2.

![Arduino UNO board](image.jpg)

Arduino UNO works based on ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a USB connection, a power jack, an ICSP header, one reset button, 16 MHz quartz crystal [19]. Those components make Arduino UNO is the complete package of microcontroller.

2.3. Xbee module

The other main component of WSN is radio transceiver. In this study, the Xbee module is taken as the radio transceiver of the WSN. Xbee modules based on the IEEE 802.15.4/Zigbee Wireless Personal Area Network (WPAN) standards to build a low-power, low maintenance, and self-organizing WSN [20] which manufactured by Digi International [21]. It provides simple point-to-point communication and mesh networking [21]. Xbee module is chosen for radio module device due to its capability to do real time data transmission. It able to do wireless connection with the range up to 30 meters with current transmission about 45 mA. The other advantages are it has lower power consumption, addressable module and small dimension. In this study, the Xbee module which is used has wire type antenna. This type antenna provides omnidirectional signal. Which means the radiation signal has same magnitude in all direction.
3. Method

3.1. Construction of base station

The base station is the component where all of the vibration data is gathered. It is a combination of small computer package and radio receiver module. The computer package consists of computer board which is Raspberry pi, 7-inch LCD screen as the main component and can be added with mouse and keyboard as the complimentary device. The connection of the base station is shown in figure 3.

![Base station connection block diagram.](image)

Raspberry pi act as the place to gather and process data which connected to Xbee module as the wireless communication protocol with the other component to display the data. Xbee module which is used in this study is Xbee module series 1. Xbee module is configured as coordinator and connected with raspberry pi trough USB connection by Xbee shield. The coordinator mode of Xbee module give advantage to the module as receive the data and control the entire network. The data from the sensor node which is sent through Xbee module is received and the base station will process the data. Afterwards, the data is stored in database storage and displayed to the user.

The configuration process of Xbee module was done by XCTU software through following steps:

1) XCTU software was downloaded from official website of Digi International
2) The Xbee module was connected to computer by USB adapter
3) The Xbee radio module was added to the XCTU software
4) The Xbee was set to coordinator in API mode following the parameters in figure 4
5) The address of the Xbee module was created
6) The configuration of Xbee in XCTU software was uploaded to the Xbee modul.
3.2. Construction of sensor node

The task of sensor node is to gather and collect the data which is vibration signal. The signal is sensed by the vibration sensor. Afterwards, the data from the sensor is transmitted to Arduino UNO via serial connection. In the Arduino UNO, the data was converted from analog to digital. The digitalized data then transmitted to the base station by wireless connection with the help of Xbee radio module. After that the data will be processed by the base station.

The sensor node consists of Grove vibration sensor as the sensing node to measure the mechanical vibration, Arduino UNO as the microcontroller and Xbee series 1 as the radio transmitter. Xbee is connected by UART communication with the Arduino UNO. In the sensor node, the Xbee was configured as a router. The configuration of Xbee as a router was similar as the coordinator. The configuration was done through the following steps:

1. XCTU software was downloaded from official website of Digi International
2. The Xbee module was connected to computer by USB adapter
3. The Xbee radio module was added to the XCTU software
4. The Xbee was set to end device in API mode following the parameters in figure 5
5. The address of the coordinator Xbee module was added to the router
6. The configuration of Xbee in XCTU software was uploaded to the Xbee module
4. Result
In this study, the wireless vibration sensor monitoring system was tested in track milling machine. The experiment was done by measuring the mechanical vibration created by milling process in steel. The milling process was conducted in steel with depth cut of 0.1 mm and 0.2 mm, the spindle speed of 1500 RPM, feed rate 500 mm per minute and high-speed steel (HSS) with diameter of 8 mm as the cutting tool. The setup experiment is shown in figure 6 until figure 8.

![Figure 6. Vibration sensor.](image1)

![Figure 7. Sensor node.](image2)

![Figure 8. Experimental setup.](image3)
From the experiment which conducted, the vibration data could be real-time displayed in the base station with the wireless distance between base station and sensor node about 3 meters. The result of the vibration data shown in figure 9 and figure 10.

![Vibration data depth cut of 0.1 mm.](image1)

**Figure 9.** Vibration data depth cut of 0.1 mm.

![Vibration data depth cut of 0.2 mm.](image2)

**Figure 10.** Vibration data depth cut of 0.2 mm.

The figure 9 and figure 10 is the vibration data which recorded by the base station. the x-axis of the graph is the time in second. The y-axis of the graph is the vibration data in Hz. In 0.1 mm depth cut the lowest vibration data is 5.96 Hz and the highest is 6.13 Hz. In 0.2 mm depth cut the lowest vibration data is 6.33 and the highest is 6.53 Hz. Taking from figure 9 and figure 10, difference between 0.1 mm depth cut and 0.2 mm depth cut is about 0.4 Hz. The bigger depth cut effect on higher vibration which is reasonable. The vibration has almost same behaviour as the time goes since the vibration was measured in the semi CNC milling machine which has high accuracy and precision.

5. **Conclusion**

This study constructs wireless vibration sensor monitoring system using Arduino UNO and vibration sensor as the sensor node, raspberry pi as the base station, and Xbee as the wireless communication protocol. The system successfully records the vibration data of milling process and the result can be distinguished in different depth cut. The overall system has several advantages such as low cost, low power consumption and easy to develop and maintain. The presence of raspberry pi gives big advantage in integration of the system which can be operated with or without mouse and keyboard. Moreover, the system can be implemented in the bigger machinery with multiple different sensor module. Furthermore,
wireless vibration monitoring system is excellent in many machine monitoring systems and data collection.

References

[1] Dawson B 1976 Vibration condition monitoring techniques for rotating machinery *The shock and vibration digest* 8 3
[2] Li H, Xu G and Xu G 2018 Mechanical vibration monitoring system based on wireless sensor network *International Journal of Online and Biomedical Engineering (iJOE)* 14 126-137
[3] Jadhav S and Hambarde S 2015 Automated Irrigation System using Wireless Sensor Network and Raspberry Pi *International Journal of science and research (IJSR)* 4 2056-2058
[4] Gungor V C and Hancke G P 2009 Industrial wireless sensor networks: Challenges, design principles, and technical approaches *IEEE Transactions on industrial electronics* 56 4258-4265
[5] Jelicic V, Magno M, Brunelli D, Paci G and Benini L 2012 Context-adaptive multimodal wireless sensor network for energy-efficient gas monitoring *IEEE Sensors journal* 13 328-338
[6] Schmidt M 2014 *Raspberry Pi: a quick-start guide* (Pragmatic Bookshelf)
[7] Vujović V and Maksimović M 2014 Raspberry Pi as a Wireless Sensor node: Performances and constraints In *2014 37th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)* (pp 1013-1018) IEEE
[8] “Buy a Raspberry Pi 3 Model B – Raspberry Pi,” Buy a Raspberry Pi 3 Model B – Raspberry Pi [Online] Available: https://www.raspberrypi.org/products/raspberry-pi-3-model-b/ [Accessed: 19-Dec-2019]
[9] Richardson M and Wallace S 2012 *Getting started with raspberry PI* (O'Reilly Media, Inc)
[10] Crossbow Technology Inc MICAz, Wireless Measurement System” 6020-0060-04 Rev A datasheet
[11] MEMSIC Inc, “TelosB, TelosB Mote Platform” 6020-0094-03 Rev A datasheet
[12] MEMSIC Inc, “Iris, Wireless Measurement System” 6020-012-02 Rev A datasheet
[13] MEMSIC Inc, “Cricket-Kit, MCS Mote Developer’s Kit” 6020-0082-02 Rev A datasheet
[14] MEMSIC Inc, “Lotus, Higher-Performance Wireless Sensor Network Platform” 6020-0705-01 Rev A datasheet
[15] M Banzi 2009 *Getting Started with arduino* (O'Reilly Media, Inc)
[16] Gibb A M 2010 New media art, design, and the Arduino microcontroller: A malleable tool *Pratt Institute*
[17] P D Minns 2013 *C programming for the PC the Mac and the Arduino microcontroller system* Bloomington (IN: AuthorHouse)
[18] M Margolis 2011 *Arduino cookbook* (O'Reilly Media, Inc)
[19] “Arduino Uno Rev3,” Arduino Uno Rev3 | Arduino Official Store [Online] Available: https://store.arduino.cc/usa/arduino-uno-rev3 [Accessed: 19-Dec-2019]
[20] S Imran and V Venkatesh 2016 Cost Effective Air Quality Monitoring System Based on Xbee Wireless Sensor Networks *Indian Journal of Science and Technology* 9
[21] Faludi R 2010 *Building wireless sensor networks: with ZigBee, XBee, arduino, and processing* (O'Reilly Media, Inc)