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Misfa Susanto

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Prototype of Sensor Node for Low-Cost Machine Vibration Monitoring System Using Accelerometer Sensor

Misfa Susanto*
Department of Electrical Engineering
University of Lampung
Bandar Lampung, Indonesia
misfa@eng.unila.ac.id
*Corresponding author

Rizky Saputra
Department of Electrical Engineering
University of Lampung
Bandar Lampung, Indonesia
rizkysaputra000@gmail.com

Herlinawati
Department of Electrical Engineering
University of Lampung
Bandar Lampung, Indonesia
herlinawati@eng.unila.ac.id

Shirley Savetlana
Department of Mechanical Engineering
University of Lampung
Bandar Lampung, Indonesia
shirley.savetlana@eng.unila.ac.id

Syaiful Alam
Department of Electrical Engineering
University of Lampung
Bandar Lampung, Indonesia
syaiful.alam@eng.unila.ac.id

***Abstract*—One important aspect in industrial manufacturing processes is the maintenance of machines' conditions. Therefore, monitoring the machine healthiness conditions is a crucial action. The drawback of conventional monitoring method is inefficiencies of the method due to the need to visit every single machine. One parameter for monitoring the machine's healthiness is vibration for the machines that have the motor components. This paper proposes a real-time monitoring system for such vibration monitoring. The proposed system is based on wireless sensor network (WSN). The nodes' prototype of proposed WSN was built and consisted of three nodes i.e. two sensor nodes and one sink node. The main component of the proposed system is Arduino uno which is not expensive relatively. In order to monitor the vibration parameter, the used sensor is the ADXL345 accelerometer sensor. The system design and testing have been carried out. The testing has been done for two aspects; the evaluation of communication performances and the machine vibration field measurements. The parameter for the testing of communication aspect is the data throughput that has been collected for the network performance evaluation. For the testing in real situations, the coffee grinder machine was chosen to be applied for the vibration monitoring system using one sensor and one sink nodes. From the testing results, the system achieved 546 bps of best throughput and was able to measure on the conditions of various supply powers to the machine. It implies the feasibility of the system in monitoring the vibration of the machine.**

Keywords—Monitoring system, wireless sensor node prototype, accelerometer sensor, industrial machine vibration, field testing

I. Introduction

Maintenance of a machine and monitoring the health of machinery used in industrial processes are a necessary aspect to guarantee the continuity of a manufacturing industry. It is specially for the machine that results in vibration in its operation. The vibration is resulted in from the machine that has motor components. Hence, the monitoring of vibration for a machine is important action in manufacturing industry, by so the necessary actions can be taken as early as possible when the obsolete event of industry processes presents.

One conventional way to monitor the healthiness of machine is visiting every single machine by using a portable measurement tool. This conventional vibration monitoring has some drawbacks that are inefficiency of machine checking actions in the monitoring tasks, i.e. the technician needs to visit in place where the machine is located, the motor component of the machine is normally located at hard-to-reach side of the machine, and the measurement tools are relatively expensive, and there will be a delay for the user to get the measured data due to un-connected measurement device to the network. Therefore, it is necessary to build a real-time monitoring system of the machine in manufacturing industry.

The drawbacks of that conventional monitoring method can be resolved by using wireless sensor network (WSN). WSN is a self-organized wireless network and consists of sensor nodes to sense the physical phenomenon and a sink node as a data collector from the sensor nodes [1]. The sensed data by sensor nodes is sent to a sink node in which a data center can be connected to this sink node for further data processing and interpretation. A user can access the collected data from this data center without a global connection creating a local network. In order to have the collected data from the sensor nodes can be sent dan accessed from the distance user, the sink node can be equipped with a gateway that connects to the global network or internet in which the wireless sensor network can be seen as the Internet of Things (IoT). Fig. 1 describes the components of wireless sensor network and its connection to the internet.

WSN is known as a promising technology to build the fundamental of IoT. It has wide range of applications, for healthcare, smart home, smart farming, etc [1]. Many researches in WSN were conducted through simulation

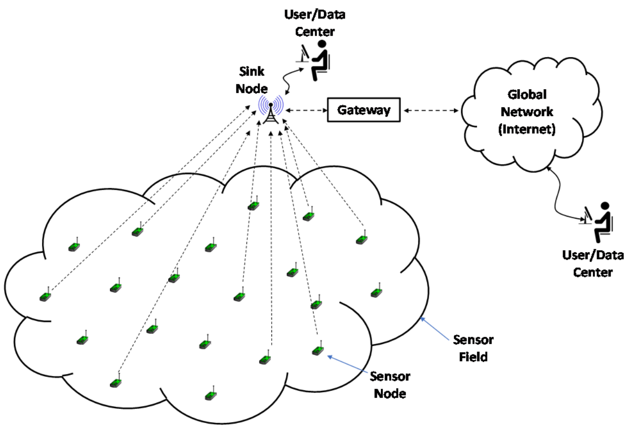


Fig. 1. The architecture of wireless sensor network.

experiments such as in [2-4] just few to mention and implementation or field experiments [5-7] among others. In line with the machine vibration monitoring, WSN offers its flexibility and the feature of real-time data monitoring. In [8], a balanced network topology control method based on the fuzzy analytic hierarchy process (FAHP) was proposed in WSN for machine vibration monitoring. Simulation experiments were conducted and their results ensure the improvements in terms of link quality, data throughput, and power consumption. In [9], a case study using WSN for monitoring vibration on an operational water pumping station in a metropolitan city was studied. The field experimental was carried out and the presented data has identified a potential problem for the vibration with the ball-bearing of a particular motor in use. However, none of the aforementioned literatures has the goal to achieve the low-cost sensor nodes.

This paper proposes the use of low-cost monitoring system based on WSN using an accelerometer sensor for the machine vibration monitoring. The prototype of wireless sensor nodes was built and examined in the real situation that was implemented on the traditional coffee grinding machine. The prototyping of wireless sensor nodes is purposed to achieve the low-cost wireless sensor nodes. The low-cost nodes can be achieved by using an Arduino Uno-based microcontroller which is relatively cheap available on the market which is different to most of wireless sensor nodes implementation for machine vibration monitoring.

This paper is organized as follow. Following this introduction section, the designed system description is detailed in Section 2. Section 3 discusses the implementation of the system and measurements. Section 4 presents the results and its discussions. Section 5 concludes the paper and discusses possible future works.

II. System Description

A. System Design and Components

In this paper, it is designed an WSN prototype that consists of two sensor nodes and one sink/coordinator node. The block diagrams of sink node and ssensor node architectures are shown in Fig. 2 and Fig. 3, respectively. The used main

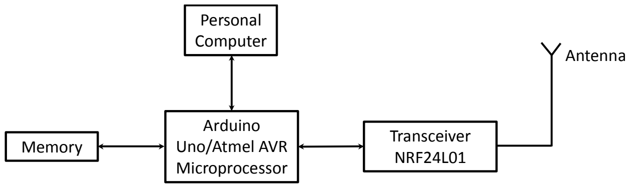


Fig. 2. The architecture of sink node.

microcontroller is Arduino uno which is based on Atmel AVR microprocessor for both of sensor and sink nodes. Arduino uno is based on ATMega 328 microcontroller with voltage operating of 5 V. It has a flash memory of 32 KB, SRAM of 2 KB, and EEPROM of 1 KB [10]. The microprocessor is connected with the transceiver module of nRF24L01. The working frequency of transceiver module of nRF24L01 is 2.4 GHz, support the connections up to 8 transmit/receive (Tx/RX), the maximum of 32-byte payload, bidirectional communication, and up to 1.1 km of transmission distance [11]. Since the sink node is collecting the information data sent by the sensor nodes, thus it does not have the sensor module. The main microcontroller of sink node is connected to the personal computer to process and display the vibration measurement results. The personal computer is installed the MATLAB software for processing and displaying the data collected from sensor nodes. The personal computer also supplies the energy power to the main microcontroller of sink node through USB interface.

The sensor node architecture in Fig. 3 depicts similar components as the sink node i.e. sensor node has Arduino uno main board, the nRF24L01 transceiver module, and an antenna, except the power supply of sensor node is feed by 9 volt (9 V) battery and it has the accelerometer sensor module. The accelerometer sensor module that has been chosen is the accelerometer sensor of ADXL345. It is because of the ADXL345 accelerometer sensor is low cost and ADXL345 sensor works on the temperature range of -40^{0}C – 85^{0}C [12] which is quite wide range for the working temperature range.

B. The Design of Network Scenarios

For the purpose of monitoring of machine vibration, it is necessary to design the network architecture that can achieve the goal. There are certainly some possible network architectures. In this paper, we design a simple network

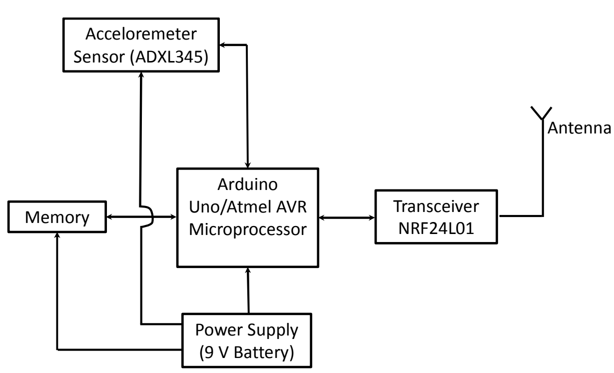


Fig. 3. The architecture of sensor node.

architecture for the machine vibration monitoring. The network architecture consists of two sensor node and one sink node. The sensor nodes capture the vibration of the targeted machine and sends the measured vibration to the sink node. The sink node receives and collects the vibration data from the sensor node. The sink node is connected to a personal computer; in our case it is a laptop. The laptop has a MATLAB software on it to display the vibration measurement results which is displayed graphically. The sensor node is located under neat of the machine which closes to the motor component of the machine. We choose to use a conventional coffee grinder machine that is used in a home industry in Tanggamus Regency of Lampung Province of Indonesia. We choose this type of machine due to Lampung province is one of provinces in Indonesia that produces the coffee as their featured products.

Prior to the actual measurement of machine vibration monitoring, we design the network scenario and test it in the term of network performance parameters. Most possible network scenario in this case is non line of sight (NLOS) scenario. NLOS condition is represented as the presence of shrubs between sensor nodes and sink node. The distances from the sensor nodes to the sink nodes are varied from 10 meters until the maximum distances (that the network parameters can be measured) with 10 meters of distance are increased in step. The network parameter that is measured is data throughput which is one of Quality of Service (QoS) parameters. Fig. 4 shows the network scenario that we design and use in the network testing for the vibration measurement.

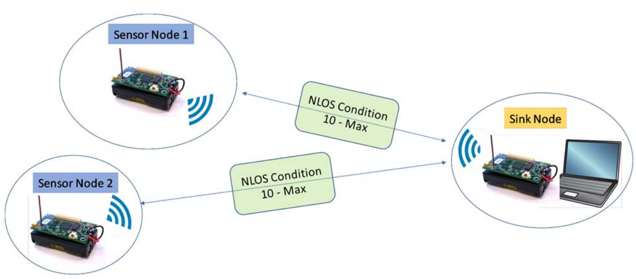


Fig. 4. The network architecture for the network performance evaluation.

III. System Implementation and Measurements

This section discusses the implementation of the monitoring system components i.e. the sensor nodes and the sink node. Also, the actual measurements of the machine vibration are discussed.

A. System Implementation

The main component of sensor and sink nodes is Arduino uno which is based on Atmel AVR microprocessor that was explained in Section 2. The different between sensor node and sink node has also been explained in Section 2. Table 1 summarizes the specifications of sensor and sink nodes' components. Fig. 5 shows the prototype of implemented sensor and sink nodes.

TABLE I. The Specification of Sensor and Sink Nodes' Components

No.	*Components*	*Specification*
1.	Arduino Uno:	
	Microcontroller	ATMega 328
	Operating voltage	5V
	Input voltage (recommended)	7 – 12 V
	Input voltage (limits)	6 – 20 V
	Digital I/O pins	14 (6 provide PWM output)
	Analog input pins	6
	DC current per I/O pins	40 mV
	DC current for 3.3 V pins	50 mA
	Flash memory	32 KB (0.5 KB used by bootloader)
	SRAM	2 KB
	EEPROM	1 KB
	Clock Speed	16 MHz
2.	nRF24L01 Communication module:	
	Frequency	2.4 GHz
	On air data rate	250 kbps, 1 Mbps, 2 Mbps
	Output	Tx 11.3 mA, Rx 13.5 mA
	Supplied Power	1.9 V – 3.6 V
	Protocol	Enhanced ShockBurst
3.	Accelerometer Sensor Module ADXL345:	
	Supply voltage	3.3 – 3.6 V
	Supply current	400 µA
	Temperature range	-40°C – 85°C
	Bandwidth response XY	400 Hz
	Bandwidth response Z	300 Hz

B. System Testing

Prior to the actual measurement of machine vibration, we have calibrated the sensors. Then, we have carried out the testing on the network performance of QoS as explained in the Section 2. Finally, we have carried out the actual measurement of machine vibration using one sensor node and one sink node. The network scenario for the actual vibration testing is illustrated in Fig. 6. The sensor node is located under neath of coffee grinding machine close to the motor component of the

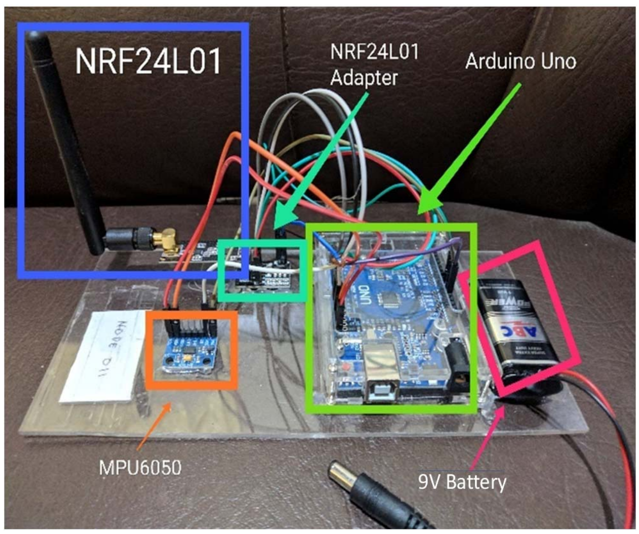


Fig. 5. The prototype of sensor and sink nodes.

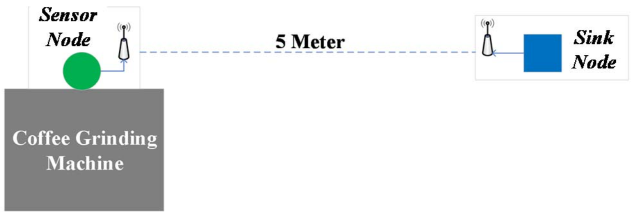


Fig. 6. The network architecture for the actual machine vibration measurement.

machine. The distance between sensor node and sink node was set to 5 meters.

IV. Results and Discussion

This section presents the testing and measurement results that have been carried out. Fig. 7 shows the data throughput performance of the network scenario shown in Fig. 4. In the scenario, the sensor nodes send the dummy packets with 0.5 seconds interval for each distance between sensor and sink nodes. In the sink node, we calculate the throughput using Eq. 1 and the results are plotted in Fig. 7. As we can see in Fig. 7, the throughput decreases as the distance between sensor nodes and sink node increases. The best throughput performance is achieved for the distance between 10 meters and 60 meters in which the throughput has achieved 546 bps. And then the throughput decreases as the distance between sensor and sink nodes increase until the throughput achieves 0 bps at the distance of 130 meters, it is due the obstacle between the sensor and sink nodes. In other words, it can be said that at certain distance the throughput decreases due to the obstacles between sensor and sink nodes and the maximum transmission range of sensor node has been achieved.

$$Average\ Throughput = \frac{Total\ Success\ Packets\ Received}{Total\ time\ sending\ the\ packets} \quad (1)$$

For the actual machine vibration measurements, we have carried out in four conditions of the coffee grinder machine. The conditions are based on the supply power to the machine that results in the motor rotation of the machine. The supply powers to the machine that have been used are 5%, 35%, 70%, and 100% of supply powers. Each measurement has been carried out for the duration of one minute with the sampling period of 30 times every one second. For the frequency domain transformation, it used 2048 samples. The collected data of machine vibration is shown in Fig. 8 (a) in time domain and Fig. 8 (b) in frequency domain for 5% of supply power. Other percentages of supply power to the machine are not presented in this paper. However, for all testing results of all supply power percentages were compared and analyzed using the whisker statistical analysis and were plotted in Fig. 9.

In Fig. 8, it is shown that for the percentage of 5% of machine's supply power, the maximum amplitude achieved 30 m/s^2 (Fig. 8 (a)) and it was achieved on 9.25 Hz (Fig. 8 (b)). It means at 5% supply power to the machine; the machine produced the vibration at the frequency 9.25 Hz with the magnitude of 3 m/s^2. From Fig. 9, the vibration measurement for 5% of machine supply power achieved the minimum acceleration on -21.55 m/s^2 and the maximum acceleration on 20.61 m/s^2. As the percentage of machine's supply power was increased, the distribution of measured acceleration increased until the supply power percentage was 100%. The measured acceleration distribution on the maximum supply power (100%) achieved -26.45 m/s^2 to 25.72 m/s^2. From the measured acceleration for the machine, it can be said that the built monitoring system based on wireless sensor network was capable to be used to monitor the machine vibration. However, the network can be expanded with a greater number of sensor nodes for monitoring the large scale of industrial machinery and other types of industry machines.

V. Conclusion and Future Work

This paper proposes a low-cost monitoring system for the purpose of monitoring the machine vibration based on a wireless sensor network using an accelerometer sensor. The measurement of machine vibration in manufacturing industry is an important task that needs to be taken to support the

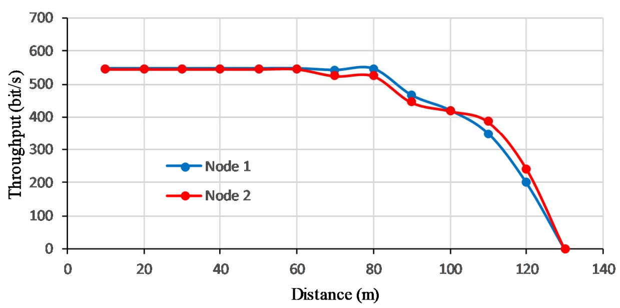
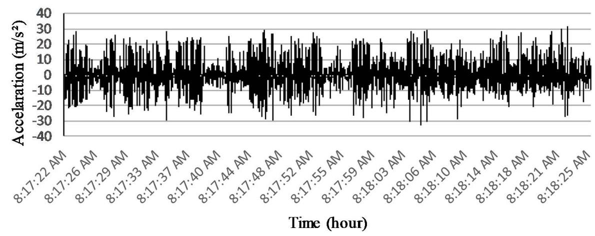
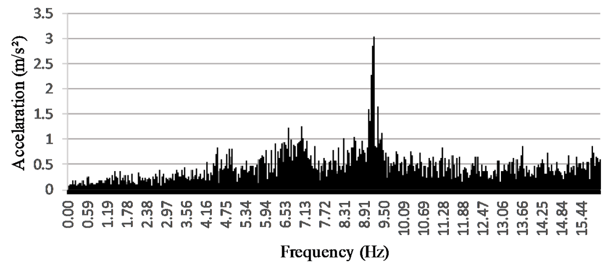


Fig. 7. The measurement results of data throughput performance for the network scenario shown in Fig. 3.



(a)



(b)

Fig. 8. The measured machine vibration for 5% of supply power of coffee grinder machine: (a) in time domain and (b) in frequency domain.

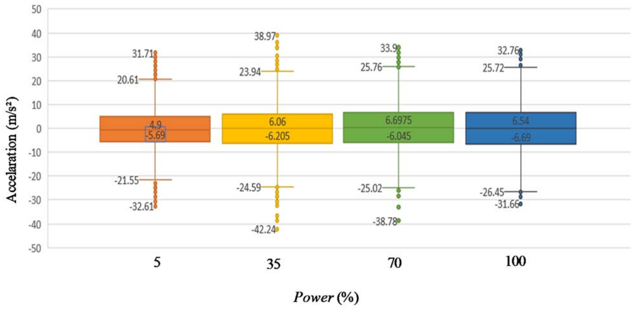


Fig. 9. The measured machine vibration plotted using whisker analysis for the 5%, 35%, 70%, and 100% of machine's supply powers.

production processes. The prototype of wireless sensor nodes has been carried out and the testing has been conducted. The low-cost prototype was achieved by using a cheap Arduino uno-based microcontroller. The testing on network performance aspects and the real acceleration/vibration measurement have been conducted on the conventional coffee grinder machine that uses a motor component. The vibration of the machine is resulted in by the motor component on the machine. The testing on the data throughput achieved 546 bps on the best conditions of the distance between sensor and sink nodes. The testing on the real condition of coffee grinder machine was carried on 5%, 35%, 70%, and 100% of machine's supply powers. The distribution of accelerations increases as the supply power to the machine is increased. The testing and measurement results show that the wireless sensor network-based monitoring system was feasible to be used to monitor the vibration in small-scale industrial machine. However, in order to have monitoring system for the large-scale manufacturing industry, it is needed to develop more complex network scenario with more sensor nodes and possibly for other types of manufacturing industries.

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