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Towards devising a vibration based machinery health monitoring system

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ABSTRACT

Excessive vibration is one of the main causes of damaging the vulnerable parts of the machines. However, a low-cost vibration monitoring system is yet to be proposed in the literature to the best of our knowledge. In this paper, we propose a low-cost wireless vibration monitoring system that can be used to monitor the machine vibration remotely at any time. It will help the maintenance department to decide on the maintenance required for a particular machine and improving the lifetime of the machine as well. By using our device, we find which machine in the textile factory needs more maintenance. Besides, by analyzing our data, we establish a relationship between machine vibration, machine age, and machine quality.

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1. Introduction

Many parameters are considered while monitoring a machine's health condition such as sound, mechanical wear, robustness, etc. However, vibration signals carry a great deal of information about a mechanical system's health [1,2]. Vibration analysis is a very popular technique among condition monitoring systems [3]. Machine health monitoring helps in scheduling maintenance, taking measures in stopping the consequence of machine failure. Any change in the machine's health condition will result in changing the output of the vibration signal. Excess vibration for a long period can cause deterioration in rotary machinery [4] which can result in reduced production efficiency [5,6]. It can also decrease the performance and the expected lifetime of a machine [4]. Failure of a machine due to vibration can result in machine shutdown [7].

Finding a way of continuously monitoring the vibration of a running machine is important. Existing Wi-Fi and Ethernet-based solutions [8,9] can monitor vibration data of machinery. However, they are expensive and improper to use in a factory due to several reasons. Although the Wi-fi and Ethernet itself are not that costly, installing them inside a factory would need additional infrastructure. This can make the vibration monitoring system expensive. Other solutions are not wireless. Applying them inside an industry would require maintenance personnel to continuously stand in front of the machine.

As a solution to those problems, in this paper, we present a low-cost wireless vibration monitoring system. Here, we sense the vibration data of machinery through an SW-420 vibration sensor on Arduino UNO R3. The sender Arduino sends the data through an HC-05 Bluetooth module to the receiver Arduino. Based on our work, we make the following contributions:

- We use a low-cost SW-420 vibration sensor for collecting vibration data.
- We present a system where data will be sent wirelessly through a Bluetooth module which is highly applicable inside the factory compared to other existing systems.
- We deploy the device in textile factories and collect real-life data of machine vibration.
- By deploying our device in textile factories to collect real data, we have obtained important findings on the relation between machine age and machine vibration.
- Analyzing the vibration data of different machinery, we can better un- derstand the maintenance requirements of those machineries.

2. Background and related work

In the textile factories, over the years, excess vibration has been a common reason for machine health degradation. Every textile

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machinery consists of many rotary parts. The rotating parts in various machines get deteriorated due to vibration which leads to machine failure in some cases. In that case, the whole production process is hampered which affects the production efficiency.

Existing Ethernet-based vibration analysis systems [8] use Ethernet for transmitting the vibration data which makes the system expensive. Also using Ethernet does not apply to a factory since additional infrastructure will be necessary to use Ethernet. Wi-Fi-based vibration analysis systems [9] are also expensive and difficult to use inside a factory. Besides, establishing a Wi-Fi connection inside a factory would require a significant number of Wi-Fi routers that could make the device expensive.

On the contrary, Experimental Modal Analysis (EMA) [10], Pattern recognition [11], and Optical fiber probe [12] based vibration analysis approaches are not wireless so data cannot be transmitted very far inside the factory. GSM-based vibration monitoring systems [13] are very expensive. Fiber Optic vibration sensor [14] based vibration analysis is also too expensive, needs a wired connection, and is much complex to be used inside a factory. Sensorless vibration monitoring [15] approaches use estimation on vibration harmonics related to current. Fully self-powered vibration monitoring systems [16] use vibration sensors based on AC-TENG that is expensive. φ-OTDR [17,18], Operational modal analysis [19] based vibration monitoring systems are not wireless. FEM-based damage assessment through vibration monitoring system [20] uses fiber optic cable to send vibration data which would require a huge infrastructural change to be applied in the industry. Self-vibration monitoring systems [21] use an accelerometer that is connected to the experimented object. Hence, this system can not send data to a longer distance. That is why these approaches are less feasible in the industry.

Other than machines in textile factories, many existing studies proposed different wireless and real-time structural health monitoring systems [22–25]. Those systems can monitor a structure's health condition and can differentiate between vibration patterns of different structures. However, in textile machinery, such a system is yet to be developed.

As a remedy to this problem, we propose a system that is real-time, wireless, and low cost compared to all the existing approaches. The system for our data transmission is performed by the Bluetooth module which is suitable inside a factory since a Bluetooth connection is possible anywhere inside a factory (Fig. 1).

3. Proposed solution

3.1. System design

Our proposed device (Fig. 2) is composed of two units: the sender unit, and the receiver unit. The vibration sensor in the sensor unit collects the vibration data and the controller module sends the data via Bluetooth to the receiver unit. The receiver unit saves the data on an SD card and sends it to a smart-phone via Bluetooth. In the end, the smart-phone displays the vibration data tables.

3.1.1. Sender unit

The sender unit (Fig. 2a) consists of an SW-420 vibration sensor, a DS-3231 Clock Module, an HC-05 Bluetooth Module, and an Arduino Uno R3 as the controller module.

We use the SW-420 vibration sensor for sensing the vibration which is shown in (Fig. 3). This sensor module signals logic states depending on vibration. The module signals logic LOW in a no vibration state. The module gives logic HIGH when detects any vibration. The sensor gives output in microseconds for the period that the logic state stays HIGH. It is a single-roller-type full induction trigger switch. The switch is generally in a conduction state when there is no vibration or tilt. The switch is rendered instantly disconnected when it detects any vibration. The conduction resistance will increase generating a current pulse signal, thus triggering the circuit.

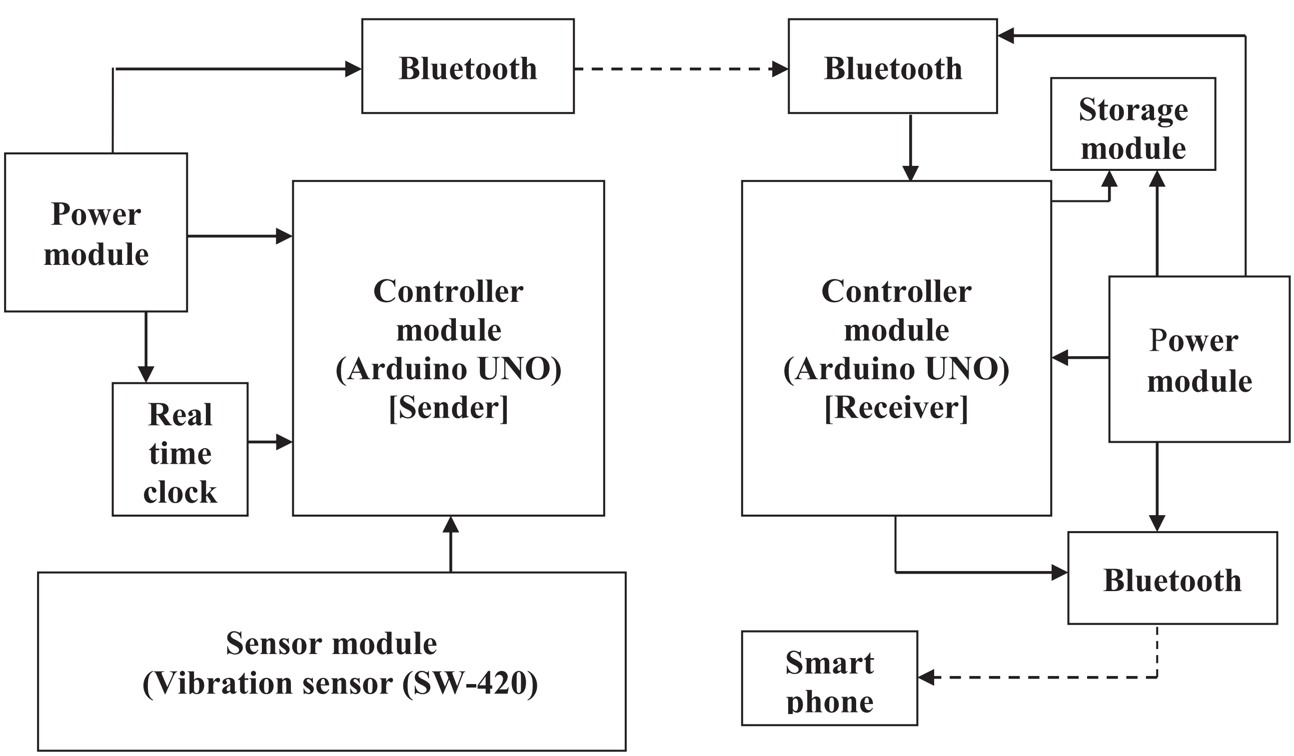

Fig. 1. Block diagram of our proposed system.

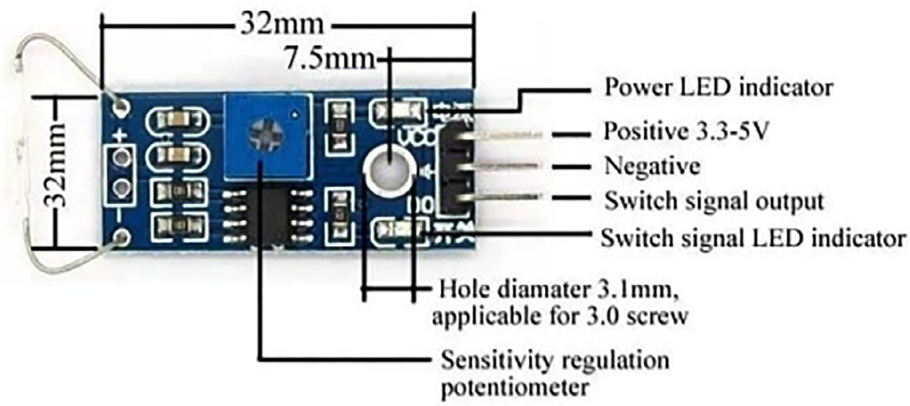

Fig. 2. SW-420 Vibration sensor.

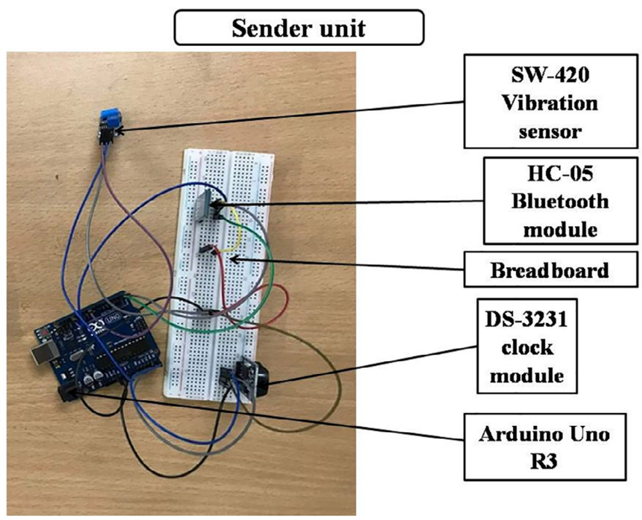

Fig. 3a. Sender unit of this device.

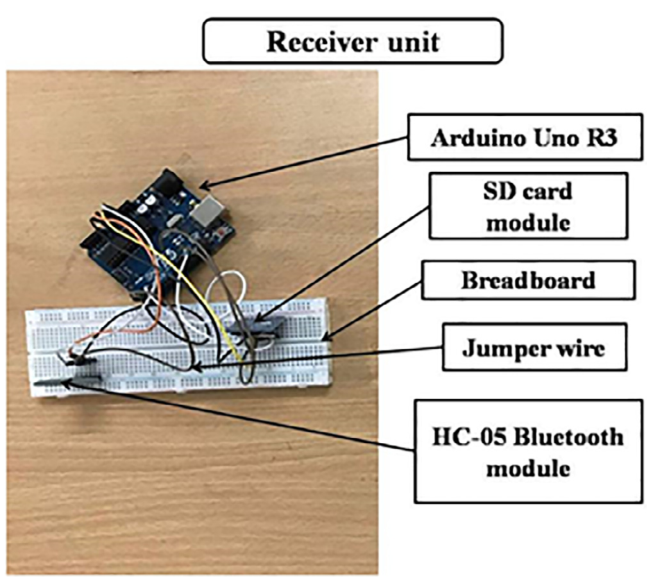

Fig. 3b. Receiver unit of this device.

3.1.2. Receiver unit

The receiver unit (Fig. 2b) consists of an SD Card Module, an HC-05 Bluetooth Module, and an Arduino Uno R3 acting as the controller module. The receiver unit receives the vibration data and real-time clock data through HC-05 Bluetooth Module from the sender unit. Then we save those data on the SD Card Module continuously. Arduino Uno R3 controls all the operations. A Smartphone displays the data.

3.2. Cost sheet

The device is composed of several low-cost modules which make the total cost only $ 33.20. The cost is shown in Table 1. The price details of each piece of hardware equipment were collected from Techshopbd [26].

3.3. Algorithm

First, we connect an SW-420 vibration sensor and a DS-3231 clock module to an Arduino Uno R3. Then, we connect an SD card module with another Arduino Uno R3. The Arduino with the sensor and clock module is considered as the sender unit and the Arduino with the SD card module is considered as the receiver unit.

Next, we take two HC-05 Bluetooth modules and set one of them in master mode and the other in slave mode. Then, we pair both Bluetooth modules together. We connect the master Bluetooth module to the sender unit Arduino and the slave Bluetooth module with the receiver unit Arduino. Then we add another HC-05 Bluetooth module to the receiver unit. We pair it with a smartphone so that we can display the data on the smartphone while performing the experiments. Finally, we upload the necessary code to Arduino of both units.

Table 1
Costing of necessary hardware equipment.

Component name	Model name	Quantity	Unit price (USD)
Vibration sensor	SW-420	1	0.47
Microcontroller	Arduino UNO R3	2	9.47
Real time clock	DS-3231	1	2.66
MicroSDstorage board (SDIO/SPI)		1	4.26
Micro SD card (4 GB)		1	3.24
Bluetooth module	HC-05	3	12.41
Power supply	9 V battery	2	0.69
Total cost			33.20 USD


a) Data collection on a soft windingmachine

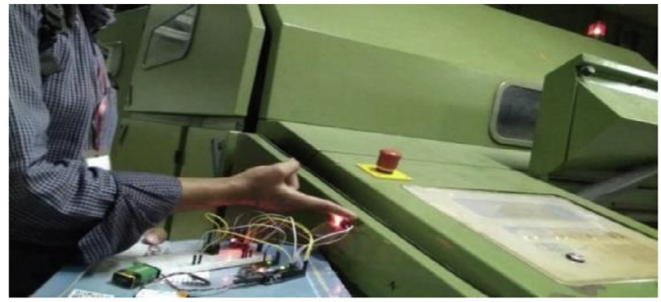
b) Data collection on a carding machine

Fig. 4. Data collection in Gangeetal Thread Factory and RK Group of Industries.

4. Experimental evaluation

We attach the SW-420 sensor firmly with the experimented machine since the sensor is extremely sensitive. We keep the receiver unit at a distance to test proper wireless data transmission.

4.1. Gangeetal thread factory

To experiment with our device first we go to the Gangeetal Thread factory which is a yarn dyeing factory. There we test our device on different winding machines and later analyze the data. Fig. 4a shows data collection on a soft winding machine. Fig. 5 shows that soft winding machine-1 has the most amount of vibration among the other winding machinery in the Gangeetal thread factory.

4.2. R.K group of industries

Next, we go to a composite textile factory named R.K group of industries to collect more data on textile machinery (Fig. 4b). There we test our device on the utility section and production section of the industry.

4.2.1. Utility section

First, we test our device on the different machinery of the utility section. Fig. 6a shows the vibration characteristics in different machinery of utility section. It shows that the generators in the utility section have more vibration than the boilers.

4.2.2. Production section

Next, we go to the production section of the industry. We collect vibration data of different machinery on production sections and later analyze it. Figs. 6a and 6b show the vibration characteristics in different machinery of production section. It shows that the ring-spinning machine has the highest level of vibration among the production section machinery. See (Fig. 6c).

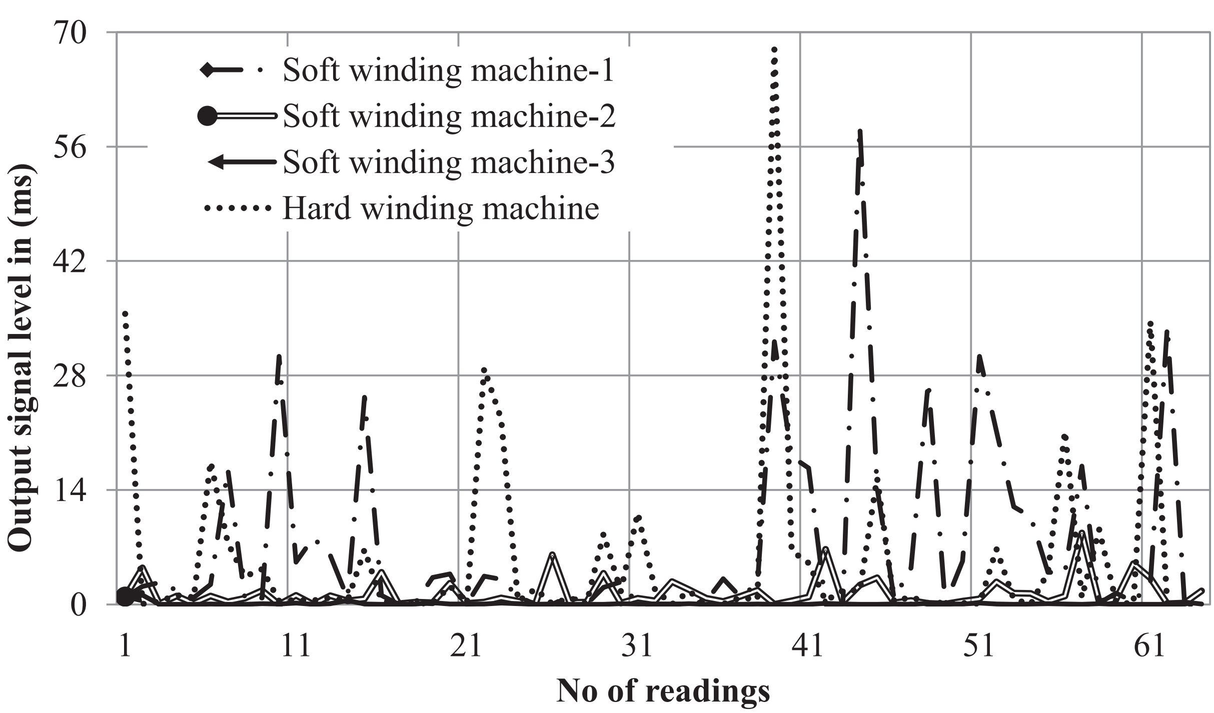

Fig. 5. Vibration data of different winding machines in Gangeetal Thread factory.

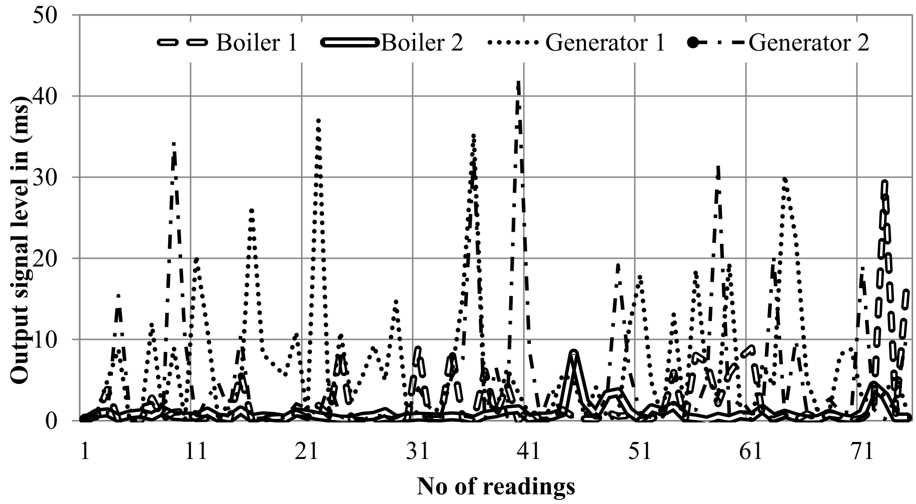

Fig. 6a. Vibration data of different machinery of utility section in RK group of industry.

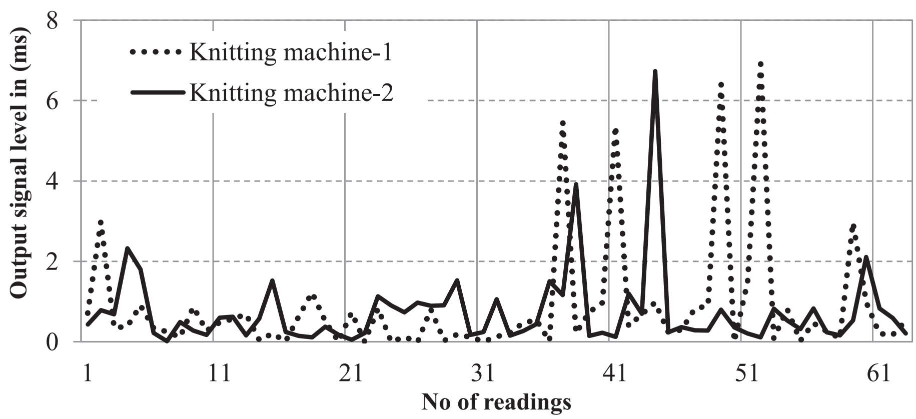

Fig. 6b. Vibration data of knitting machines in production sections.

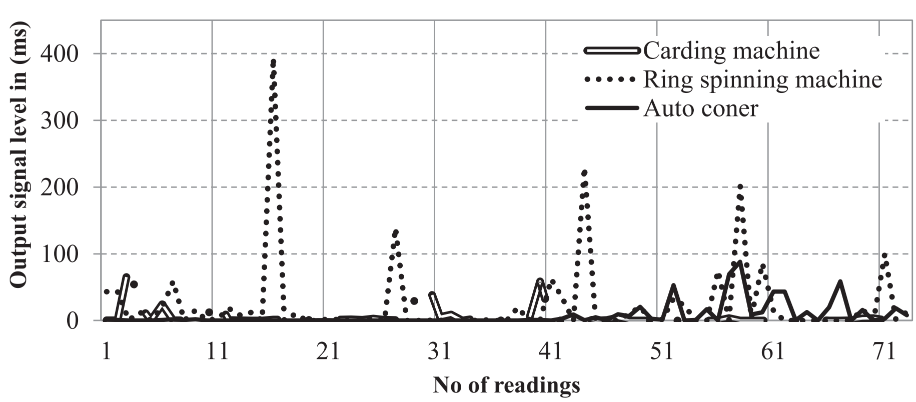

Fig. 6c. Vibration data of different machinery in the spinning machines in the production section.

4.3. Findings

While collecting vibration data of the soft winding machines in the Gangeetal Thread Factory, we also collect data about those machine's age and quality. We presumed that the vibration level of the machinery depends solely on its age and increases proportionally with its age. However, after collecting the data about their vibration pattern, years of usage, and their quality, we see that the machines with higher quality have lower vibration despite being used for many years. And the machine with high quality and less age has the least vibration. Fig. 7 shows the vibration level of the different soft winding machines.

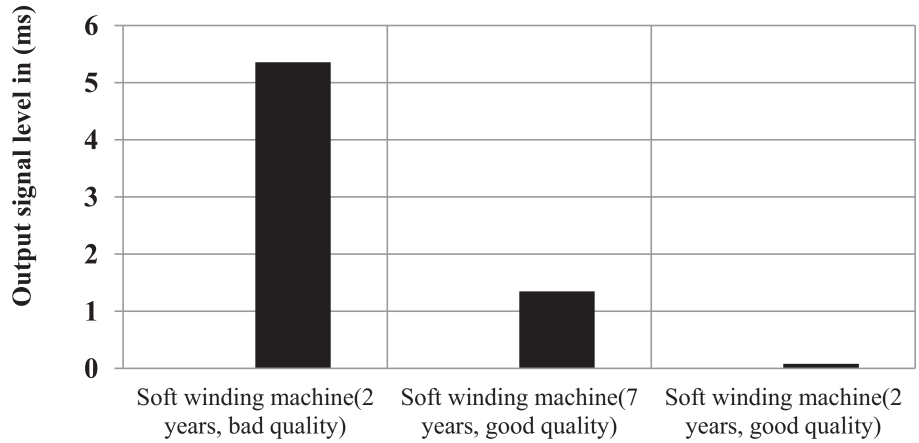

Fig. 7. Vibration comparison of soft winding machines of different age and quality.

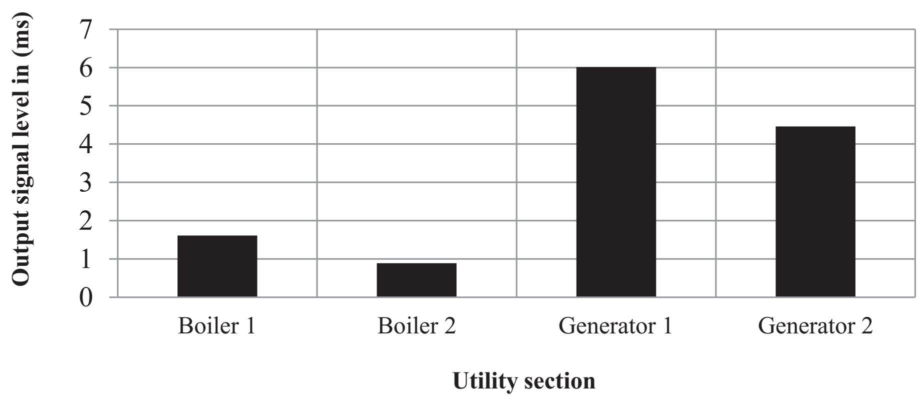

Fig. 8a. Vibration comparison of different machinery of utility section.

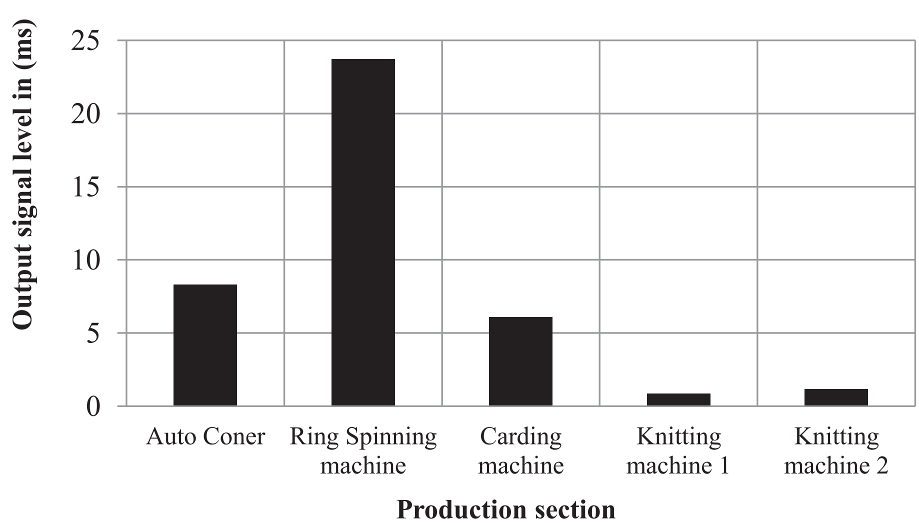

Fig. 8b. Vibration comparison of different of the machinery of production section.

Here we see in Fig. 7 that the soft winding machine that has been used for 2 years having a bad quality, has the most amount of vibration. On the other hand, the soft winding machine which is used for 7 years, however, is of good quality has less amount of vibration. Also, the soft winding machine which has been used for 2 years and having a good quality has the least amount of vibration. The low-quality machines have higher vibrations because they are less robust. In summary, the machine's quality plays a more significant role than the machine's age considering its vibration. Hence, by monitoring the vibration we can determine the machine's health quality.

Next, we analyze the data of the utility and production section in R.K Group of Industries. Fig. 8 shows the vibration comparison of different machinery of utility and production section.

In Fig. 8a, we see that generators have the most amount of vibration in a utility section since boilers don't contain any mechanical component like a motor. In Fig. 8b, we see that spinning machinery (ring spinning machine, carding machine, autoconer) has the most amount of vibration. Each spindle of the ring-spinning machine has an rpm of 15,000–18,000. As a result, it has the most amount of vibration in the spinning section. Therefore, the generators in the utility section and the spinning machinery in the production section need the most regular maintenance.

Hence, to determine the required maintenance level for each machine, the machine vibration data can be used.

5. Conclusion

Machinery vibration data provide proper information about the health condition of different types of machinery. This paper proposes a low-cost wireless vibration monitoring system that can be used to monitor the machine vibration continuously. Compared to other systems, our proposed system is very low cost and most applicable in the factory.

CRediT authorship contribution statement

Md. Harunur Rashid Bhuiyan: Conceptualization, Methodology, Software, Investigation, Data curation, Writing - original draft, Visualization. **Iftekhar Morshed Arafat:** Conceptualization, Investigation, Data curation, Writing - original draft. **Masfiqur Rahaman:** Writing - original draft, Writing - review & editing, Visualization. **Tarik Reza Toha:** Conceptualization, Methodology, Validation, Formal analysis, Writing - review & editing, Supervision, Project administration. **Shaikh Md. Mominul Alam:** Validation, Formal analysis, Writing - review & editing, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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