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Monitoring The Vibration Condition Of Mechanical Equipment With A Wireless Sensor Network

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ABSTRACT:

In order to compensate for the shortcomings of wired mechanical equipment condition monitoring systems, the use of wireless sensor networks is suggested. It is crucial to construct a dual-processor wireless sensor network node in order to capture vibration signals from mechanical equipment. Developing a complete wireless sensor network mechanical vibration monitoring system also requires research into the self-organizing network, wireless transmission protocol, and on-chip processing function. The clustering network structure is suitable for large-scale networks, has strong scalability, can rapidly adjust to system changes, and is beneficial for using distributed algorithms. The issue of restricted collection and storage capacity when a wireless sensor network is used to mechanical vibration signal acquisition is partially resolved by the creation of high-performance vibration measurement nodes. The experimental findings demonstrate that while the node's time domain signal collection and amplitude will be small, the node's on-chip processing results match those of the host computer, with a small amplitude difference and a maximum error of 8.18%, suggesting that the node's performance can meet on-chip processing requirements. Experiments confirm that the design strategy is feasible.

Keywords: Monitoring, Vibration Condition, Wireless Sensor Network, Transmission Protocol.

1. INTRODUCTION

Rapid advancements in science, technology, and industrial production have increased the need for mechanical equipment to be precise, complicated, and automated. Additionally, issues with equipment safety, dependability, and maintainability are becoming more and more noticeable. A growing number of individuals started researching mechanical equipment vibration monitoring technology, leading to the introduction of several mechanical vibration monitoring systems that, to some degree, guaranteed the stable and safe functioning of mechanical equipment [1]. Currently, wired monitoring technology is mostly used by the more established mechanical equipment condition monitoring systems, whether they are dispersed or centralized. To accomplish the analysis, processing, and diagnosis of vibration signals, they must all send the vibration signals from different sensors to the data processing center via the appropriate wiring connections. Nevertheless, there are several drawbacks to this wired connection-based mechanical vibration monitoring system that impair the quality of vibration monitoring and mechanical equipment failure diagnostics. For instance, the system lacks flexibility, requires a lot of cables and related gear, is expensive to implement, and is difficult to maintain. It is prohibited to alter the layout or add or remove monitoring stations once the system has been installed [2]. Vibration monitoring of equipment transmission parts in certain sealed environments and mechanical rotation environments, as well as vibration, deformation, and crack fault monitoring of certain critical components in heavy machinery and other equipment, are examples of unique and extreme situations where wired connections are particularly challenging to implement. Additionally, intelligent machining equipment vibration signal monitoring is available for tool life prediction and cutting quality control throughout the machining process. Wired monitoring is very challenging in these situations [3, 4]. There are many obstacles to overcome when using wireless sensor networks for mechanical vibration monitoring. The difficulties of mechanical vibration signal collection, low sample frequency, and limited data storage capacity are all addressed in this research, which also builds a wireless sensor network node appropriate for mechanical vibration monitoring. It is possible to identify the source of defects by analysing and processing vibration data. Using the vibration signal analysis approach to monitor any section of the machinery is the most effective way to repair mechanical defects in mechanical equipment. It may also determine the extent of a malfunction without dismantling mechanical parts and even alter the system that is used for regular maintenance.

According to the study, these sensor nodes are unsuitable for collecting mechanical vibration signals for two reasons: (1) Typically, the sampling frequency used for mechanical testing falls between 1 and 10 kHz. Vibration data from high-frequency sampling will be abundant. Due to its very limited storage capacity, the current node is only appropriate for short-term storage and sluggish variable acquisition. (2) While the majority of current sensor nodes employ CPU on-chip A/D converters to gather analog data, mechanical vibration signals need high precision collection in order to evaluate and identify weak fault signals [5]. The processor's on-chip A/D often has poor accuracy, a low signal-to-noise ratio, a low sampling rate, and is easily disrupted by the digital circuit. Temperature and illumination are examples of slow-changing signals with low accuracy requirements that are often collected using this method. Using the newly developed wireless sensor network monitoring mode to create a wireless and distributed vibration monitoring system is an alternate approach to addressing the aforementioned issues with mechanical vibration wired monitoring systems [6]. A novel technique for gathering and processing data, wireless sensor networks may operate in long-term unsupervised settings and continuously monitor, sense, and gather data about different surroundings or things.

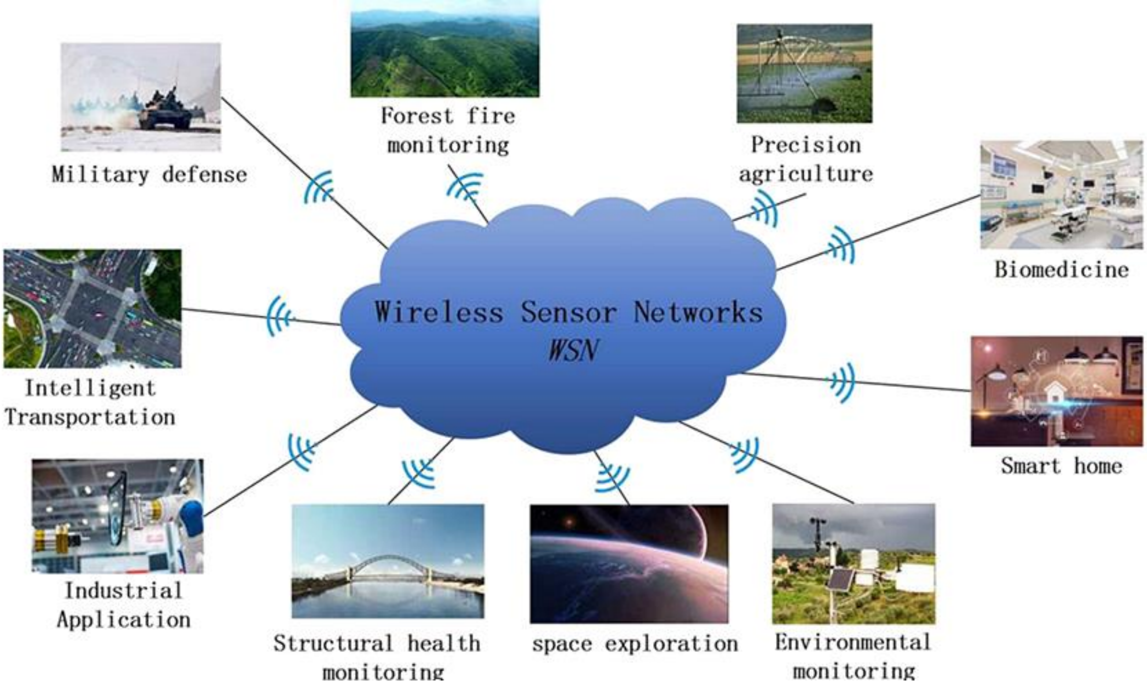

Fig. 1. Application fields of wireless sensor networks

As Fig. 1 illustrates, it has significant application value and prospective application prospects in the domains of industry, medical treatment, traffic management, environmental monitoring, military, and disaster assistance.

2. LITERATURE REVIEW

The military, precision agriculture, smart home, environmental protection, safety, and industrial monitoring sectors have all confirmed and shown the viability of wireless sensor network technology. According to Arce et al., a mechanical vibration signal is a crucial signal source for determining if mechanical equipment is functioning properly. It is possible to forecast the health status of mechanical equipment beforehand by detecting and diagnosing vibration signals [7]. Wireless sensor network monitoring mode is a revolutionary technique for obtaining vibration signals. In some specific situations, a wireless data transmission mode is built employing a large number of dispersed sensor nodes self-organizing approach to make up for the limitations of the traditional cable monitoring system. Other limitations of the technology include communication gaps between sensor nodes, problems with time synchronization, and a lack of real-world protocols that can be implemented in wireless sensor networks (WSN) [8, 9]. According to Zhang and Liu, machine vibration monitoring technology is very crucial, and the issues of big rotating equipment's dependability, availability, maintainability, and safety are becoming more and more noticeable [10]. Sensor nodes are the most fundamental building blocks of wireless sensor networks, according to Guimarães et al., and the application domain of wireless sensor networks is determined by node performance. There are a lot of generic wireless sensor network nodes available right now. Due to their poor hardware capability, the majority of these nodes are limited to collecting temperature, humidity, light, and low-frequency vibration data for the purposes of monitoring agricultural growth environments, animal living behaviors, and structure health [11]. Halakarnimath et al. fully implement the idea of "ubiquitous computing" by using a multi-hop relay to send the perceived information to the user terminal over a random ad hoc wireless communication network. Wang et al.

solved the issue by converting the conventional serial processing and centralized processing system into distributed processing using wireless sensor networks [12]. Tan et al. suggested using wireless acceleration sensor networks based on micro-electro-mechanical systems (MEMS) technology for application research in ubiquitous structural health monitoring. WSN may be used to detect vibration in mechanical equipment [13]. According to Kang et al., wireless sensor networks are a novel area of study that combines distributed information processing technology, embedded technology, communication technology, MEMS technology, and contemporary sensor technology [14]. Using a wireless sensor network module for certain items, Manikandan and Chinnadurai suggested a novel industrial wireless sensor network for mechanical condition monitoring and defect diagnostics by gathering the rotor's acceleration and current signals. After classifying faults using neural networks and signal feature extraction, the routing node performs fault fusion to determine the operational condition of mechanical equipment [15]. In order to manage the 24-bit high-precision converter for data collecting, the development node of the high-performance structural health monitoring system that Yuvaraju and Pranesh researched uses a high-performance single-chip microprocessor. The ARM9 processor, which runs Linux, serves as the primary control unit. It transfers a lot of data over Wi-Fi and employs a wireless module to achieve high accuracy synchronous acquisition. For wireless sensor networks, developing a reliable transport protocol is essential to the uptake of new applications. Each sensor node may be required to do some local calculations and data aggregation, depending on the application. In wireless sensor networks, transmission control protocol (TCP) is costly to utilize because of its three-way handshake procedures and high packet header size. Although the user datagram protocol (UDP) was developed to facilitate erratic data transmission, sensors are thought to benefit more from it.

In conclusion, this study examines the issue of present sensor networks' inability to monitor the vibration of mechanical equipment. Designing a wireless sensor network node with two processors is crucial to enabling the detection of vibration signals from mechanical equipment. To create a comprehensive set of wireless sensor network mechanical vibration monitoring systems, it is also required to research the self-organizing network, wireless transmission protocol, and on-chip processing function of wireless sensor networks.

3. PROPOSED METHODOLOGY

Despite significant advancements in some areas, the majority of wireless sensor networks remain in the theoretical stage of mechanical vibration monitoring, and several issues have to be resolved. The multipath effect, which is brought on by the reflection and scattering of signals by various large instruments and metal pipes in the plant, as well as the electromagnetic noise produced during the operation of motors and instruments, will interfere with the proper reception of wireless signals; there are also high requirements for real-time communication; for instance, the reliable data transmission rate should exceed 95%; and there are numerous wireless network types, such as Bluetooth, in the factory environment, which have serious interference with one another. Less than 1.5 times the sensor sample time should be the data transmission delay for industrial closed-loop control applications.

Given the aforementioned issues, this study uses the clustering network structure, which is appropriate for large-scale networks, supports the use of distributed algorithms, has strong scalability, and can react swiftly to system changes. Through data fusion, the cluster head lowers data traffic and conserves network energy. Applying it to the mechanical equipment condition monitoring system is quite important. The three primary components of a clustering routing protocol are data transmission, network construction, and cluster head selection.

The nodes in wireless sensor networks self-organize to form a network, send monitoring data to the sink node via a multi-hop relay, and then use a long-distance or temporarily established sink link to send the entire area's data to the distant center for centralized processing. It is possible to utilize a satellite connection as a sink link. Unmanned aircraft flying over the monitoring region may also be used to retrieve the data on the sink node. The cluster hierarchical management mode may be used if the network scale is too big. Fig. 2 depicts the usual design of a wireless sensor network.

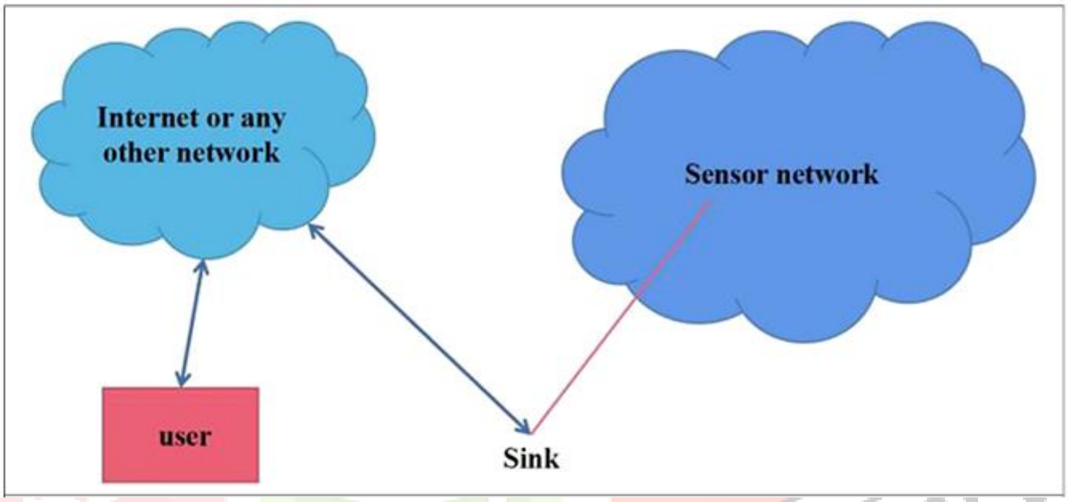

Fig. 2. Typical wireless sensor network architecture

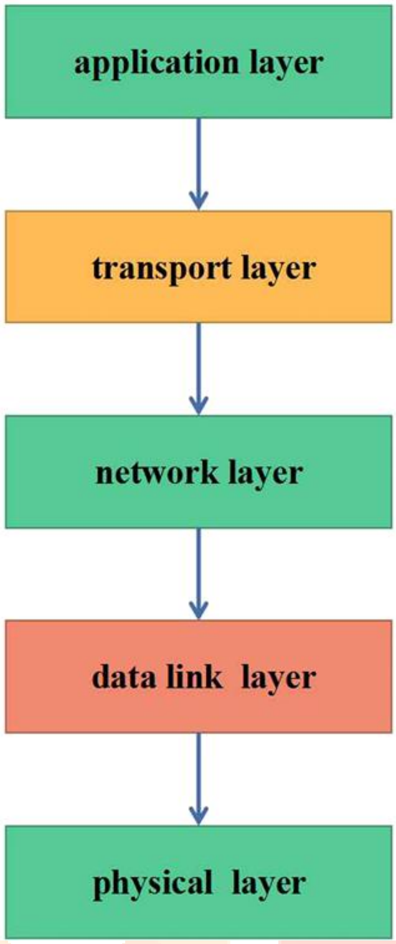

Fig. 3. Wireless sensor network protocol hierarchy

The wireless sensor network protocol hierarchy is shown in Figure 3. The three management functions of energy management, task management, and mobility management are included into each wireless sensor network layer in this architecture. Each tier, however, places a distinct focus on realizing the three management. For instance, the application layer distributes monitoring tasks to each subnet and sensor node while primarily taking task management into account. While the network layer and data connection layer handle energy management, the application layer also takes mobility management into account. These two levels also include mobile management. Energy management is also present at the physical layer, but task and mobility management are given less thought.

Key Technologies of Mechanical Equipment Condition Monitoring and Wireless Sensor Network

3. 1) Condition Monitoring of Mechanical Equipment

Specific flaws are the only ones that cause the vibration characteristics of equipment. The cause of failures may be identified by analysing and interpreting vibration signals. The most efficient way to get rid of mechanical problems in mechanical equipment maintenance is to use the vibration signal analysis technique to monitor any section of the machinery. Simultaneously, it may replace the routine maintenance system and assess the extent of the issue without disassembling mechanical components. When equipment is operating, vibrations will inevitably be produced. In general, vibration is made up of random noise, additional vibration components, and a number of basic harmonic vibration components. Uneven vibration is mostly caused by nonlinear self-excited vibration, whereas the majority of the frequencies of simple harmonic vibration components are connected to rotor speed or natural frequency.

Numerous features that represent the equipment's problem and operating condition may be derived by examining the vibration waveform, watching and deducing the vibration process, and determining the equipment's change law. The research on fault-tolerant control, monitoring system, and credibility system based on fault detection and separation, multi-sensor data fusion technology, online real-time fault detection algorithm, diagnosis technology of intrinsically nonlinear dynamic systems, hybrid intelligent fault diagnosis technology, and remote cooperative diagnosis technology based on the Internet are all examples of current and future mechanical fault diagnosis research hotspots.

3. 2) Wireless Communication Technology

standard for wireless communication. Wireless communication technology is the most active area of network and communication technology nowadays. It has many standards, has been effectively used in its sector, and new technologies are constantly being developed. Wireless sensor networks do not designate a single standard as the official mainstream communication technology among the several general wireless communication technology standards. Currently, 802.15.4/ZigBee, Bluetooth, and ultra-wideband technology Wi-Fi are the most widely used wireless communication technology standards. Table I provides a clear comparison of each standard's particular parameters.

TABLE I. COMPARISON OF WIRELESS COMMUNICATION STANDARDS

Name	ZigBee	Bluetooth	UWB	Wi-Fi
Standard	IEEE802.15.4	IEEE802.15.1	IEEE802.15.3	IEEE802.11a,b,g
Rate	20/40/250 Kbps	1–3 Mbps	110 Mbps–l .6 Gbps	10-105 Mbps
Transmission distance	10–300 m	10 m	4–20 m	10–100 m
Power waste	Ultra low	Low	Low	High
Number of nodes	65 535	8	128	32
Application area	Detection and control	Alternate outside line	High-speed wireless access	Wireless access
Technical advantages	Power consumption and cost	Cost and convenience	High rate	Bandwidth, flexibility

4. RESULTS AND DISCUSSION

The adxl001 acceleration sensor is chosen to receive the vibration signal via the 16-bit A/D converter on the node's data collection board in order to evaluate the node's performance in mechanical vibration monitoring. The experiment involves gathering the vibration signal at a sample frequency of 1 kHz, storing it on a secure digital (SD) card, and then analyzing the vibration data on the SD card at the PC end. The time domain waveform and amplitude spectrum of the vibration shock response gathered by a single wireless sensor network node are shown in Figs. 5 and 6. Studies by Ohtsu and Holm and Eide have shown a similar pattern.

The node's on-chip processing result matches the host computer's processing result, and the amplitude difference is minimal, with a maximum error of 8.18%. However, the time domain signal of the node's gathered data is tiny, and the corresponding amplitude will also be modest. Resolving the issue of the node gathering tiny time-domain signals may demonstrate that the node's performance can satisfy on-chip processing requirements. It has been noted that the quality of vibration monitoring and the identification of mechanical equipment faults are impacted by some drawbacks of conventional mechanical vibration monitoring systems.

For instance, the system's maintainability is low, several cables and related gear are needed, and the deployment cost is considerable. Clustering network structure has been shown to enable the employment of distributed algorithms and respond rapidly to system modifications. It is suitable for large networks and scales well. The experimental results show that although the node's on-chip processing results will be comparable to those of the host computer, with just a little amplitude difference, the node's time domain signal gathering will produce a modest amplitude. The suggested approach concludes that it can monitor, perceive, and collect data on a range of surroundings or monitoring objects in real time, as well as operate under long-term unattended conditions. It scales well and is perfect for big networks. The experimental findings indicate that although the node's on-chip processing outputs will be essentially equivalent to those of the host computer, its time domain signal collection will result in a very small amplitude.

The suggested method claims that it can operate in a long-term unattended setting while monitoring, perceiving, and gathering data on a range of environments or objects in real time.

Vibration wave form analysis, monitoring, and inference of the equipment's vibration process and change law provide a number of characteristics that indicate the equipment's defect and operational condition.

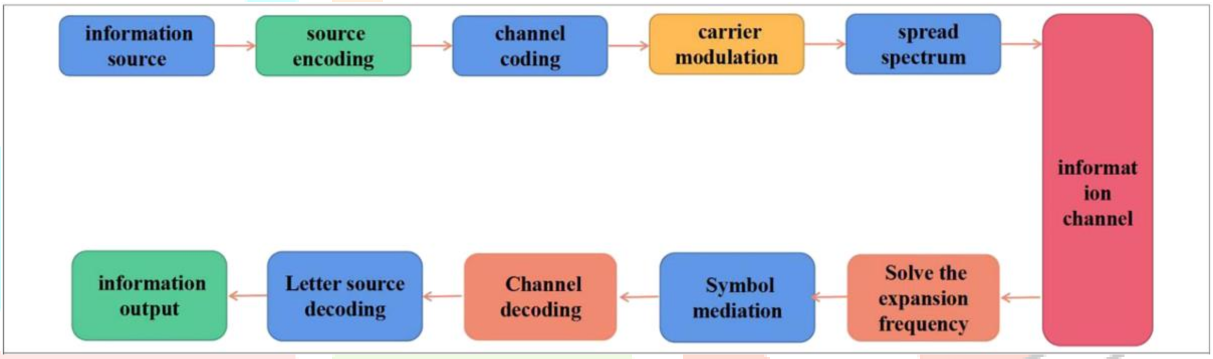

Fig. 4. Typical spread spectrum transceiver mechanism.

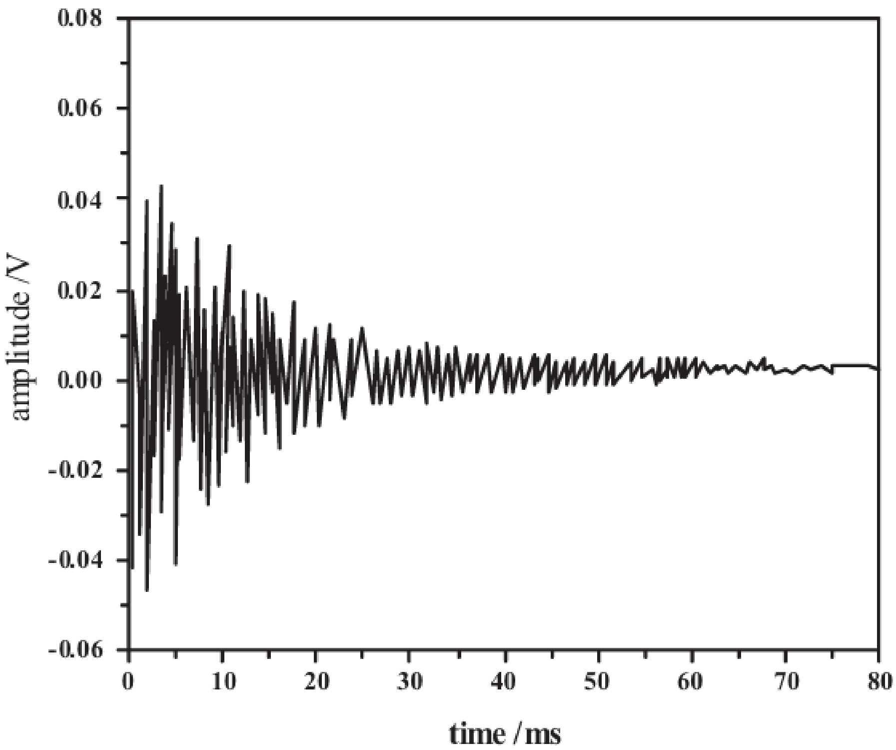

Fig. 5. Time domain waveform of vibration signal

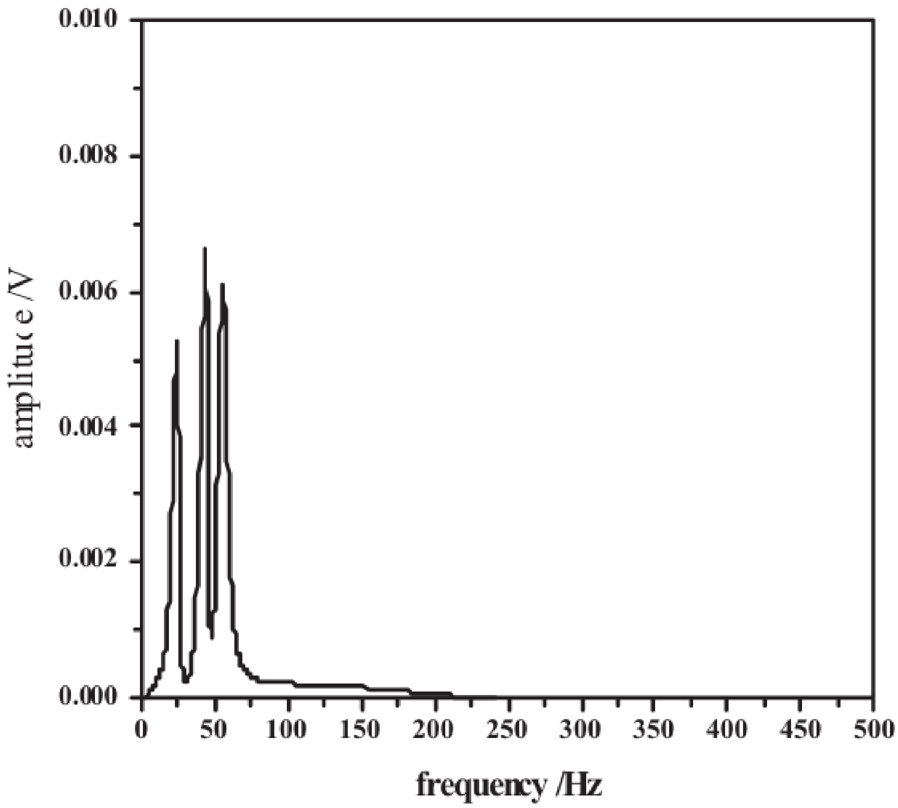

Fig. 6. Amplitude spectrum of vibration signal

5. CONCLUSIONS

In this work, the challenges of using a wireless sensor network for mechanical vibration monitoring are examined, a wireless sensor network node appropriate for mechanical vibration monitoring is developed, and the issues of challenging mechanical vibration signal pickup, low sampling frequency, and limited data storage space are partially resolved. It also looks into these issues, creates a wireless sensor network node suitable for mechanical vibration monitoring, and addresses the difficulties of low sample frequency, difficult mechanical vibration signal collection, and limited data storage. Vibration signals may be analyzed and processed to assist in locating the source of flaws. Vibration signal analysis is the most effective technique to fix mechanical defects in mechanical equipment by keeping an eye on any component of the machine. In order to minimize data transmission and enable real-time mechanical equipment condition monitoring, the on-chip processing method is also used to extract the distinctive characteristics of the mechanical vibration signal on the node. The feasibility of the design plan is verified by experiments. Advances in communication and computer technologies have enabled the creation of small, low-cost sensor nodes with very low energy consumption. They may also be deployed quite fast. Furthermore, WSNs may be used in the next years for mechanical equipment spectrum management, underwater wireless sensor systems, and cognitive sensing.

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