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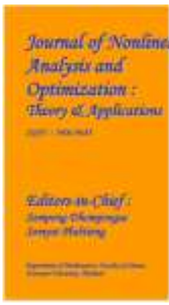

A NEW SMART APPARATUS FOR IN-BELT CONVEYOR OF IDLER ROLLER CONDITION MONITORING

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ABSTRACT— The idler roller, a critical bearing component of belt conveyors, plays a pivotal role in ensuring the efficient transportation of materials in coal mines and other industries. This article presents a novel embedded monitoring node for belt conveyor idlers, equipped with self-powering, multi-parameter sensing, and wireless communication capabilities for real-time health monitoring. The proposed system comprises a belt conveyor idler-monitoring network architecture and three functional modules: an energy-harvesting module utilizing a Halbach permanent magnet array, an energy-management module to balance the energy harvester with the node's power consumption, and a control/sensing module integrated with wireless communication features. Performance evaluation of the node revealed that the energy harvester generates 171.33 mW, sufficient to meet the node's power needs. The energy management circuit supports a network operating time of up to 74 minutes, while communication tests highlighted the challenges posed by narrow spaces on the reliable communication range. Overall, the system effectively collected and transmitted temperature and vibration data, fulfilling the monitoring requirements for belt conveyor idlers. The embedded node introduces a robust technical solution for proactive health monitoring of belt conveyor systems. Its self-powering capability minimizes reliance on external power sources, enhancing reliability in remote or inaccessible environments. The integration of vibration and temperature sensing ensures comprehensive monitoring, identifying potential faults before they escalate into failures. Additionally, the system's wireless communication functionality allows for seamless data transmission, enabling centralized monitoring and real-time decision-making. The study also underscores the adaptability of the energy-harvesting module, which ensures sustainability by aligning power generation with the operational demands of the node. Future research will focus on expanding the monitoring capabilities to include additional parameters such as load distribution and wear analysis, further strengthening fault diagnostics. Scaling the system to monitor multiple idlers simultaneously while maintaining low power consumption and robust communication is another area of exploration. Furthermore, leveraging machine learning algorithms for advanced data analysis can enhance predictive maintenance, reducing downtime and operational costs. This research paves the way for smart, energy-efficient monitoring solutions, contributing to the reliability and efficiency of belt conveyor systems in demanding industrial environments.

Index Terms— Belt conveyor, embedded, energy harvesting, energy management, idler-monitoring node.

I. INTRODUCTION

Belt conveyors are a vital type of material transportation machinery that operate based on the friction drive principle and are widely utilized in coal mines and various industrial contexts. The safe operation of belt conveyors is critical to ensuring the safety and efficiency of coal mine transportation. Any failure in the conveyor system can lead to significant economic losses due to production downtime and, in extreme cases, may pose severe safety risks to workers. Among the components of the belt conveyor, the idler roller plays a crucial role in supporting and guiding the conveyor belt, reducing resistance, and ensuring its stable operation. Failure of idlers can cause damage or wear to the conveyor belt, directly impacting production safety. Consequently, monitoring the health of idlers is essential to maintaining the seamless operation of belt conveyors. Currently, the primary method for detecting faults in long-distance belt conveyor idlers is manual inspection. However, this approach is labor-intensive, prone to errors, lacks real-time capabilities, and poses safety concerns. To address these limitations, intelligent monitoring methods are being explored as alternatives. Common idler health-monitoring techniques include vibration monitoring, noise analysis, temperature measurement, and visual inspections. For instance, Al-Kahwati et al. demonstrated the use of J48 decision trees to classify vibration signals, effectively diagnosing idler damage and providing early warnings. Similarly, Yang et al.

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utilized stacked sparse encoders and convolutional neural networks to process audio data and extract fault features via spectral clustering algorithms. Liu et al. developed methods for analyzing temperature variations and audio signals to detect idler faults, while Qu et al. designed pressure sensors for monitoring idler conditions. Despite these advancements, most approaches focus on isolated idler analysis and lack scalability for monitoring long-distance belt conveyors. Wireless sensor networks (WSNs) present a promising solution for real-time, large-scale idler monitoring. These networks consist of microsensor nodes that collect environmental and operational data, offering advantages such as low cost, flexible deployment, and high fault tolerance. Researchers have proposed various WSN applications in underground environments. Minhas et al. developed a monitoring and reporting system capable of localizing events with a 90% success rate. Muduli et al. introduced a sensor node deployment scheme for longwall coal mine monitoring, while Moridi et al. explored ZigBee networks for underground communication systems. Although these studies highlight the potential of WSNs, their integration with large-scale belt conveyor systems, especially for monitoring idlers, remains underexplored. This article identifies several gaps in the existing research. First, while significant progress has been made in processing and diagnosing idler-related signals, the reliable collection and sensing of idler status data remain a challenge. Second, although wireless monitoring networks for underground mines have been studied, there is limited integration of these systems with large-scale mechanical equipment like belt conveyors. The need for self-powered, multi-parameter sensing nodes capable of real-time wireless communication in distributed idler monitoring systems has yet to be fully addressed. To bridge these gaps, this study proposes a new embedded monitoring node specifically designed for the condition monitoring of idler rollers in belt conveyors. The proposed node incorporates an embedded structure that minimizes modifications to existing idlers while preserving their basic functions. It features multi-parameter sensing capabilities, including temperature and acceleration monitoring, to ensure comprehensive health assessments. An energy harvesting and management system is integrated into the node, enabling continuous operation without reliance on external power sources. The node also supports real-time wireless communication, facilitating seamless data transmission for centralized monitoring. To validate its functionality, a prototype was developed and subjected to rigorous testing, demonstrating its ability to operate reliably under complex working conditions. Future work will focus on refining the energy efficiency of the node, enabling it to operate for extended durations without manual intervention. Advanced machine learning algorithms could be integrated for predictive maintenance, allowing the system to detect subtle anomalies and prevent failures proactively. Additionally, expanding the sensing capabilities to include load distribution and wear analysis will further enhance fault diagnostics. By addressing these aspects, the research contributes to the development of smart, scalable, and efficient health monitoring solutions for belt conveyor systems, ensuring their safe and reliable operation in demanding industrial environments. Furthermore, the proposed monitoring system's scalability and adaptability make it well-suited for broader applications in various industrial domains beyond coal mining, such as logistics, manufacturing, and power generation. By leveraging the integration of multi-parameter sensing, self-powered operation, and wireless communication, this system can be adapted to monitor other critical machinery components, ensuring operational efficiency and minimizing downtime. As industries increasingly adopt automated and intelligent solutions, the insights gained from this research can pave the way for developing advanced condition monitoring systems that are both cost-effective and sustainable, driving the next generation of industrial automation and safety management technologies.

II. LITERATURE SURVEY

A) Research on the fault analysis method of belt conveyor idlers based on sound and thermal infrared image features - The large number, scattered distribution, and complex working environment of idlers makes their faults challenging to detect. In this paper, a fault analysis method of belt conveyor idlers based on sound and thermal infrared image (TII) features is proposed. According to 18 classes of idler sound and TII data, the time-domain (TD) features of sound signals are analysed using statistical methods, the frequency-domain (FD) and time-frequency-domain (TFD) features of sound signals are analysed with the quantization and dimension reduction method based on Fisher's linear discriminant, and the TII features are analysed using statistical methods. The analysis results show that final and catastrophic faults can be detected by using FD features of idler sound and TII temperature rise of the idler outer load area and shaft end, and TFD features of idler sound signals can be used to detect typical bearing defects, which features high reliability, low cost, and easy implementation. Belt conveyors are continuous transportation equipment in modern production. They have become one of the three main means of industrial conveyance, with the other two being trains and trucks. Their advantages include large capacity, long distance, low freight, high efficiency, stable operation, convenient loading and unloading, suitability for bulk material transportation. Thus belt conveyors have been widely used in the coal industry, mines, ports, electric power, metallurgy, chemical industry, and other fields [1], [2]. Idlers are the main components that support the conveyor belt along its length [3] and typically comprise rollers, shafts, bearings, bearing seats, and sealing components. The idler fault is one of the common faults of a belt conveyor, including bearing faults and roller faults, which can increase the energy consumption of belt conveyors, cause belt deviation, breakage, fire, and other accidents, and result in major economic losses and casualties. However, due to the large number, scattered distribution, dynamic load force [4], and complex working environment of idlers, it is very difficult to detect idler faults. At present, there is no effective and applicable solution for idler fault detection [5]. Idlers are typical rotating components, and the intuitive and effective method to detect the faults is to measure the vibration signal and perform fault detection algorithms. For example, Li et al. [6] proposed an online monitoring and fault diagnosis system of idlers based on the wavelet packet decomposition and support vector machine, in which the vibration signals of idlers were collected using acceleration sensors. The results show that wavelet decomposition coefficients of the vibration signals are effective features of the idler fault detection. Muralidharana et al. [7] proposed an idler fault diagnosis method based on statistical features and the decision tree algorithm. Experimental results show that the kurtosis, standard deviation, and mean values of vibration signals are effective features of the idler fault detection. Ravikumar et al. [8] proposed an idler fault diagnosis method based on the artificial neural network (ANN) and naive Bayes (NB) algorithm. The idler vibration data was directly used as the input to train and verify the diagnosis model, and experimental results show that NB performs better than ANN. Liu et al. [9] verified by experiment that the root mean square (RMS) values of vibration signals can be used to detect final failures of idlers. Ravikumar et al. [10] proposed an idler fault diagnosis method based on TD statistical features and the K-star algorithm, and verified that the standard deviation, kurtosis, range, and mean values of vibration signals are effective distinguishing features of the idler fault detection. However, this type of method has the disadvantages of poor reliability, high cost, and difficult implementation. First, since the vibration sensors must be directly or indirectly mounted on the target idlers, and the vibration of the frame, conveyor belt, and other rotating components will interfere with the monitoring data, which makes this type of method unreliable. Second, the number of idlers is large and the distribution is scattered, many sensors are required, which results in high hardware, construction, and maintenance costs. Finally, due to the small size of the idler, it is difficult to mount the contact sensors, and the data transmission and power supply of the sensors are difficult to effectively solve and implement. Acoustic-based fault detection methods are widely favored because they are easy to implement, are non-invasive, and are low-cost. There are related mining studies to inspect belt conveyor structures [11] and detect the longitudinal tear of a conveyor belt [12], which achieve good performance. More research has focused on acoustic-based fault diagnosis methods for idlers. Liu et al. [13] used Fourier transform to analyse the experimental data and obtained the sound frequency band (FB) which can effectively detect final failures of idlers. According to this work, Liu et al. [14] proposed an idler fault diagnosis method based on Mel frequency cepstrum coefficient (MFCC) and gradient boosting decision tree, and verified that the MFCC feature of idler sound is an applicable feature for the classification of two types of final faults. However, the experimental environment is a test rig with only one idler set instead of a real belt conveyor, which ignores the running noise. Besides, there are only a few types of idler faults and the duration of the sound sample is too long. Yang et al. [15] proposed an idler fault diagnosis method based on MFCC and deep neural network, and the results show the high performance of this method, while the problem of long sound sample duration still exists. Peng et al. [16] proposed an audio-based intelligent fault diagnosis method for idlers, in which the wavelet coefficients of idler sound are used as the input of convolutional neural network (CNN) to classify idler roller stick and fracture faults. This method reduces the sound sample duration to less than 0.5 s, but few types of faults remain. Zhang et al. [17] proposed a frequency domain statistical index called teager energy spectral kurtosis, where the faulty idler is located by identifying the resonance frequency band of the fault feature in the idler sound signal. It can improve the noise immunity of the acoustic-based idler fault diagnosis method. The problems in the present research are that the types of idler faults are not sufficient [18], the selection of sound features is arbitrary, and most of them have ignored the interference of belt conveyor running noise. Thermal infrared image sensor is widely used in the industrial fault detection [19], [20], [21]. It can detect faults by perceiving the abnormal heat of faulty parts. Du et al. [22] used an infrared thermal imager to collect the abnormal heat of mining wheels, so as to detect the serious wear and abnormal speed of mining vehicles. Yang et al. [23] applied the TII sensor to the detection and early warning of longitudinal tear of mine conveyor belts through the frequency-domain characteristic coefficient T of the infrared radiation field. The TII sensor is also used to determine the operational condition of a conveyor belt drive system structure [24]. The resistance of idlers is one of the key parts of the operating resistance of a belt conveyor [25], [26], idlers in final/catastrophic failure stage will increase the thermal infrared radiation due to the increase of resistance. With the aid of TII sensors, Liu et al. [13] verified that measuring the shaft end temperature is a simple and effective way to detect the final failure of idlers. In general, the side idlers have a greater probability of damage than the horizontal idlers, partly because the former are subjected to larger axial forces [26], [27], [28] and the outer ends are exposed, then it is more profitable to detect the side idlers from a convenient view, while it is hard to monitor the horizontal ones which are subjected to the widest range of load [29], [30]. “Smart mines” [31] require the integrated application of various sensor perceptions, data communication, intelligent decision-making, and other technologies, so that the mine has self-learning, analysis, and decision-making abilities. Coal mine intelligence will enter the stage of unmanned operation and underground intelligent inspection robots will be an important part of the intelligent safety management system of coal mines [32]. The inspection robot can be equipped with one set of sound and TII sensors for periodic fault detection of all idlers, which can reduce the cost of hardware and maintenance. However, there is no systematic research on the applicability analysis and selection of the sound and TII features of idlers. n this paper, we investigate idler faults based on sound and TII features. According to the sound and TII data of the idlers in our experiment, the TD features of the sound signals are analysed using statistical methods, the FD and TFD features of the sound signals are analysed using the quantization and dimension reduction method based on Fisher's linear discriminant (FLD), and the TII features are analysed using statistical methods. The results can provide an experimental basis for improving the integrality, reliability, and intelligence of idler fault detection.

B) A Brief Review of Acoustic and Vibration Signal-Based Fault Detection for Belt Conveyor Idlers Using Machine Learning Models - Due to increasing demands for ensuring the safety and reliability of a system, fault detection (FD) has received considerable attention in modern industries to monitor their machines. Bulk materials are transported worldwide using belt conveyors as an essential transport system. The majority of conveyor components are monitored continuously to ensure their reliability, but idlers remain a challenge to monitor due to the large number of idlers (rollers) distributed throughout the working environment. These idlers are prone to external noises or disturbances that cause a failure in the underlying system operations. The research community has begun using machine learning (ML) to detect idler's defects to assist industries in responding to failures on time. Vibration and acoustic measurements are commonly employed to monitor the condition of idlers. However, there has been no comprehensive review of FD for belt conveyor idlers. This paper presents a recent review of acoustic and vibration signal-based fault detection for belt conveyor idlers using ML models. It also discusses major steps in the approaches, such as data collection, signal processing, feature extraction and selection, and ML model construction. Additionally, the paper provides an overview of the main components of belt conveyor systems, sources of defects in idlers, and a brief introduction to ML models. Finally, it highlights critical open challenges and provides future research directions. As industrial systems have become increasingly complex and expensive, performance degradation, productivity decrease, and safety hazards have become increasingly unacceptable. Belt conveyor systems are a critical component of many modern industries. They are perhaps the most extensively used transport method for conveying dry bulk materials in many production and manufacturing industries, such as coal, chemicals, electricity, steel production, and others [1–3]. Uninterrupted and trouble-free operation of belt conveyor systems is the compulsion of modern industries. As these systems have several components, a failure of one component can cause belt damage, economic loss, and death [4]. For example, a report from Brazil showed that from 2014 to 2016, fires caused by conveyor idler failures resulted in losses of approximately AUD one million, in addition to 600 h of downtime [5]. Potential faults and abnormalities in such systems must be identified and detected as soon as possible to minimize performance degradation and prevent dangerous situations before a sequence of damage can be catastrophic. Numerous factors can result in the causes and damage of a belt conveyor, including the working conditions, continuous movement, contact with rotating components, and material transport [6]. These causes and damages in belt conveyor systems have led to the development of intelligent data-driven fault diagnosis and detection systems with the aid of machine learning (ML) models that use vibration [4], thermal [7], and acoustic [8] methods to detect faults in belt conveyor systems. A fault diagnosis is defined as determining the type, size, and location of the fault, the time of fault detection, and the behavior of the fault in accordance with the appropriate assessment of the faults [9]. Fault detection is an essential component of fault diagnosis, which involves identifying or indicating faults in a process or system and then isolating the faulty process or variable to obtain additional useful information concerning the faults [10,11]. The effect of the early detection of faults in belt conveyor systems can lead to a minimum amount of downtime and maximized production. However, the traditional fault detection of belt conveyor systems is manual, requiring workers to inspect rotating machinery such as rollers [12] regularly. In addition, some conveyors are very long, several kilometers long, and it can be challenging to manually inspect the entire conveyor length [13]. As a result, it is time-consuming and labor-intensive to perform manual FD, which will not allow the fault to be found in time due to the reliance on subjective measurements by maintenance operators. The methods of FD have evolved rapidly in recent years from manual detection to intelligent detection using ML models. n intelligent FD, machine learning theories are applied to detect machine faults [11]. This can be characterized as a classification problem or a pattern recognition problem in order to release human labor and automatically recognize a machine's state of health, which is why it has attracted significant attention in the last two or three decades. Although intelligent FD has achieved a substantial number of successes, a review of the development of intelligent FD in belt conveyor idlers leaves a blank space and rarely provides guidelines for future development. For example, Qurthobi et al. [14] provide a systematic review of acoustic approaches to mechanical failure detection, including 52 studies of recent implementations and structures focusing on all rotating machinery without emphasizing specific components such as idlers. Wei et al. [15] present a review and summary of research on early fault diagnosis of gears, rotors, and bearings. In their review, however, idlers were not mentioned. An additional review [11] was conducted that focused on the task of diagnosing failures in rotating machinery in general. As a result, the evidence accumulating from previous research is not well documented regarding belt conveyor idlers. Furthermore, a review is necessary due to the unique characteristics of belt conveyor idlers and their spatial distribution. Idlers are subject to high levels of wear and tear due to the constant contact with the conveyor belt and the heavy loads they support. This can lead to the development of unique faults such as misalignment, shell wear, damage to the rollers, or structural deformation [16]. Idlers typically have low rotational speeds, making it more difficult to detect faults using traditional monitoring methods that are typically used for higher-speed machinery [17,18]. • Idlers are typically exposed to harsh environments, such as dust, heat, and moisture, which can accelerate the degradation of the components and increase the likelihood of faults [19]. Idlers have a simple construction and are low-cost components, which means that there is a high number of them in a conveyor system. This can present challenges for monitoring and diagnosis, as many idlers need to be inspected regularly. • Idlers have an important role in the conveyor system, supporting the belt. Therefore, the early detection of faults in idlers is crucial to prevent belt damage and to ensure the conveyor system runs reliably [16]. Idlers are part of a complex system, and they are affected by the dynamic behavior of the conveyor system, which can vary depending on the specific application, operating environment, conveyor design, and loads [20]. These peculiarities of idlers make a review specifically focused on fault detection in idler belt conveyors important, as it can help to identify the most common types of faults, the most effective methods for detecting them, and any challenges or limitations associated with monitoring these systems, which are specific to idler belt conveyors. Researchers have focused on developing FD systems for rotating machinery using vibration and acoustic signals over the last two decades [4,21]. This is because vibrations and acoustic signals provide better indicators of conveyor belt damage in the early stages. Figure 1 shows the level of detection for acoustic and vibration methods for detection machinery components such as idlers [22]. Based on the figure, it can be seen that vibration and acoustic information can provide superior signatures for detecting early faults to other methods, such as heat or thermal imaging methods. Further, there are a number of articles published recently on vibration and acoustics methods that demonstrate the effectiveness of both methods in the detection and monitoring of belt conveyor idlers. Acoustic and vibration methods are widely believed to be the most effective in detecting faulty idlers [4,8]. Observing the vibration responses of belt conveyor idlers can reveal their state, and vibration analysis is widely used for fault detection [23]. A vibration sensor must be used to capture the state of idlers, which is a contact sensor that can be difficult to install [24]. Compared to vibration, acoustic recording is a safe and non-destructive method for capturing the sound of faulty idlers. While they are both affected by the position of the sensor, both can detect multiple idlers simultaneously and detect a wide range of defective idlers. As a result, researchers prefer both for detecting faulty idlers.

C) A Dynamic Self-Attention-Based Fault Diagnosis Method for Belt Conveyor Idlers **-** Idlers are typical rotating parts of a belt conveyor carrying the conveyor belt and materials. The complex operating noise and unstable features lead to poor accuracy of sound-based idler fault diagnosis. This paper proposes a fault diagnosis method for belt conveyor idlers based on Transformer's dynamic self-attention (DSA). Firstly, the A-weighted time-frequency spectrum of the idler sound is extracted as the input. Secondly, based on the DSA block, the multi-frequency cross-correlation DSA algorithm is designed to extract the cross-correlation features between different frequency bands in the input feature map, and the global DSA algorithm is applied to perceive and enhance the global correlation features in parallel. Finally, the cross-correlation and global correlation features are concatenated and linearly projected into a fault-type space to diagnose typical bearing and roller faults of idlers. The method makes full use of the relevant information scattered in different frequency bands of the idler running sound under complex working conditions and reduces the negative effect of the strong running noise on the extraction of weak fault features. Experimental results show that the fault diagnosis accuracy is 94.6% and the latency is 27.8 ms. Belt conveyors are continuous transportation equipment in modern production. Featured with large transportation capacity, long distance, low freight, and high efficiency, belt conveyors have been widely used in the coal industry, mines, ports, electric power, metallurgy, chemical industry, and other fields [1,2]. Idlers are the key components of a belt conveyor carrying the conveyor belt and materials. Due to poor lubrication, fatigue, foreign debris intrusion of the bearing, uneven load, or heavy impact on the roller, etc. [3], the idlers suffer from abnormal vibration and noise, damage, fracture, jamming, and other faults, resulting in increased transportation energy consumption and serious accidents, such as deviation, tearing, and fire of the conveyor belt. Due to the large number, scattered distribution, and complex working conditions of idlers, diagnosing faults of idlers by using their running sound appears to be an efficient approach. However, the strong running noise of belt conveyors will submerge the running sound of idlers, which

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seriously reduces accuracy and reliability, posing a severe challenge to the fault diagnosis method. Recent successes in artificial intelligence have promoted and significantly increased the use of machine-learning and deep-learning technologies in the fault detection and diagnosis of belt conveyors. In terms of idler fault diagnosis, Muralidharana et al. present an idler fault diagnosis method based on a decision tree (DT) algorithm, which uses the statistical metrics of idler vibration signals to train the DT-based fault diagnosis model, and the experimental results show a good performance in the classification of four types of idler faults [4]. Ravikumar et al. propose an idler fault diagnosis method based on the K-star algorithm, which uses the time-domain features of idler vibration signals as the input of the K-star algorithm and achieves better idler fault classification results [5]. Peng et al. propose an idler fault diagnosis method based on convolutional neural networks (CNN), where the CNN is trained by using the wavelet packet decomposition features extracted from idler sound signals, and this method achieves accurate and robust idler fault diagnosis [6]. Yang et al. present an idler fault diagnosis method based on deep convolutional neural networks (DCNN), which uses Mel frequency cepstrum coefficients (MFCC) of idler sound signals as the input to train the DCNN, and compared with support vector machine (SVM) and CNN, this method shows more accurate results in the prediction of idler fault degree [7]. Liu et al. propose a method for idler fault diagnosis based on machine learning, where the MFCC of idler sound signals is also used as the input to train the gradient boosting decision trees (GBDT) in fault classification, and the experimental results show that this method achieves a diagnostic accuracy of 94.53% on the test set [8]. In the aspects of conveyor belt fault detection, Qu et al. propose a conveyor belt damage detection method based on adaptive depth convolution networks, which realizes faster and more reliable conveyor belt damage detection than SVM [9]. Mao et al. present a defect classification algorithm for steel cord conveyor belt defects based on improved skewness decision tree SVM [10]. Che et al. propose a longitudinal tear detection method for conveyor belts based on SVM, which uses the audio and video features of longitudinal tearing to train SVM, and this method achieves more accurate detection results than K-nearest neighbors and random forest (RF) algorithms [11]. Meanwhile, machine-learning and deep-learning technologies are becoming increasingly pervasive as a means of improving the accuracy and robustness of the conveyor belt deviation fault detection [2,12], conveyor belt speed measurement [13], and positioning of inspection devices for belt conveyors [14] in a complex environment. With loud running and environmental noise in the working scene of belt conveyors, the energy of the interference part in the collected sound or vibration signal is much stronger than the useful signal. Extracting inconspicuous useful features from the chaotic signal is the key challenge to the fault diagnosis algorithm. Idlers are typical rotating machinery. In recent years data-driven machine-learning and deep-learning algorithms have consolidated their leading position in the fault diagnosis of rotating machinery [15,16]. Zhang et al. propose a bearing fault diagnosis method based on SVM: by determining the search interval and optimal parameter combination in the feature space, the SVM classification model is optimized to improve the accuracy of fault diagnosis [17]. Jiang et al. propose a fault degree identification method for wind turbine gearboxes based on multiscale convolutional neural networks (MSCNN), which is used to extract multiscale and complementary high-level fault features and classify faults, and this method achieves better identification results than traditional CNNs [18]. Li et al. propose a rotating machinery fault diagnosis method based on deep-transfer learning, which transfers the diagnostic knowledge learned from the sufficient supervision data of multiple rotating machines to the target equipment through domain adversarial training, to improve the fault diagnostic accuracy of rotating machinery under weak supervision [19]. Xing et al. propose a gear fault diagnosis method based on deep-belief networks. Aiming at the problem of feature distributions changing under new working conditions, the distribution-invariant deep-belief network is used to learn distributioninvariant features directly from raw vibration data, to improve the accuracy of gear fault diagnosis under varying working conditions [20]. Aiming at the same problem under new working conditions, Moshrefzadeh et al. propose a bearing fault diagnosis method based on subspace k-nearest neighbors (S-KNN), using spectral amplitude modulation and improved kurtosis of the modified signal's squared envelope spectrum algorithms to decompose the vibration signals and extract features and train the S-KNN model using the obtained feature vectors. The experimental results show that the classification result of S-KNN based on the features is better than that of SVM [21]. As for the machine-learning-based algorithms, the performance of feature-extraction algorithms has a significant impact on their diagnosis results, and as for the deep-learning-based algorithms, which combine feature extraction and classification to achieve end-to-end fault diagnosis, network architectures, and data sets are the key points, and as the network cannot run in parallel in the depth direction, a deeper network suffers from a longer inference latency. In 2017, Google proposed a sequence prediction network based on a self-attention mechanism called Transformer [22], which is outstanding in natural language processing. In 2020, Facebook successfully introduced the transformer structure into machine vision. This network detects the target in parallel using the correlation between the target and the whole image content, and it outperforms the CNN baseline Faster RCNN [23]. Since then, Transformer has rapidly emerged in machine vision tasks such as low-level computer vision [24], object detection [25], video question answering [26], image quality evaluation [27], etc. Different from CNNs focusing on local features [28], Transformer uses the dynamic self-attention mechanism to establish the global correlation between elements in the sequence, so it focuses on the global features [25]. To extract the periodic or constant broadband weak features from signals with strong noise interference, a global feature perception way is more suitable than a local one. The idler sound signal is submerged by strong energy noise, and the fault features are correlated by the time and frequency axes of its time-frequency domain (TFD) feature map [29]. Using CNNs to perceive the global fault features requires a deep network, while Transformer can achieve better performance by using a much shallower one. Using Transformer's DSA mechanism to extract multi-frequency cross-correlation (MF-Cov) features from the TFD feature map of faulty idler sound, as well as perceive and enhance the global correlation features, will facilitate improvements in the accuracy of the idler fault diagnosis algorithm under strong noise background. In order to improve the accuracy and reliability of the sound-based idler fault diagnosis method under strong noise, an idler fault diagnosis method based on DSA is proposed in this paper. The A-weighted TFD feature map of the idler running sound is used as the input, then based on Transformer's DSA, the MF-Cov DSA algorithm is designed to extract the cross-correlation features between different bands in the input feature map, and the global DSA algorithm is applied to perceive and enhance the global correlation features in parallel. Then both features are concatenated and linearly projected into the low dimensional fault type space to realize fault diagnosis.

BLOCK DIAGRAM

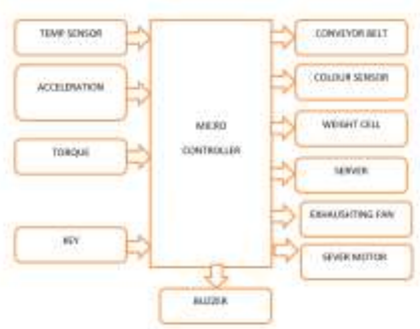

Fig: Block Diagram

BLOCK DIAGRAM DESCRIPTION

POWER SUPPLY

A **regulated power supply** transforms unregulated AC (Alternating Current) into a stable DC (Direct Current). It guarantees consistent output despite variations in input. A regulated DC power supply is also known as a linear power supply, it is an embedded circuit and consists of various blocks

- **Regulated Power Supply Definition**: A regulated power supply ensures a consistent DC output by converting fluctuating AC input.
- **Component Overview**: The primary components of a regulated power supply include a transformer, rectifier, filter, and regulator, each crucial for maintaining steady DC output.
- **Rectification Explained**: The process involves diodes converting AC to DC, typically using full wave rectification to enhance efficiency.
- **Filter Function**: Filters, such as capacitor and LC types, smooth the DC output to reduce ripple and provide a stable voltage.
- **Regulation Mechanism**: Regulators adjust and stabilize output voltage to protect against input changes or load variations, essential for reliable power supply

SENSORS

Sensors are used for sensing things and devices etc. A device that provides a usable output in response to a specified measurement. The sensor attains a physical parameter and converts it into a signal suitable for processing (e.g. electrical, mechanical, optical) the characteristics of any device or material to detect the presence of a particular physical quantity. The output of the sensor is a signal which is converted to a human-readable form like changes in characteristics, changes in resistance, capacitance, impedance, etc.

LM35 TEMPERATURE SENSOR

If you are looking for an inexpensive, accurate, easy-to-use temperature sensor, then LM35 is an excellent choice. It has an accuracy of ±¼°C at room temperature and ±¾°C over a full −55°C to 150°C temperature range. It does not require any external trimming, although the main drawback of this sensor is that it outputs data in analog format, making it very prone to external noise and interference. So, in this tutorial, we will learn how to wire up a **LM35 Temperature Sensor with Arduino** and also we will output the temperature data in the serial monitor window.

LM35 TEMPERATURE SENSOR PINOUT

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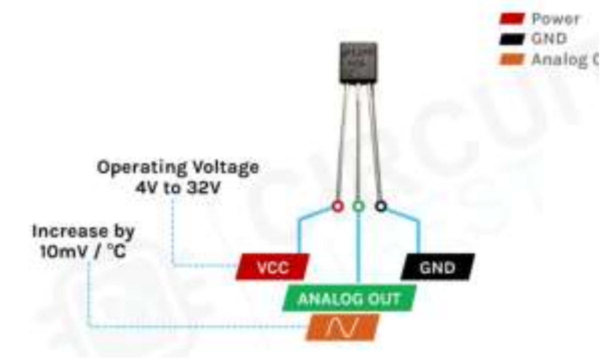

Fig: Temperature Sensor

MEMS SENSOR WORKING AND ITS APPLICATIONS

The term MEMS stands for micro-electro-mechanical systems. These are a set of devices, and the characterization of these devices can be done by their tiny size & the designing mode. The designing of these sensors can be done with the 1- 100-micrometer components. These devices can differ from small structures to very difficult electromechanical systems with numerous moving elements beneath the control of incorporated micro-electronics. Usually, these sensors include mechanical micro-actuators, micro-structures, micro-electronics, and micro-sensors in one package. This article discusses what is a MEMS sensor, working principle, advantages and it's applications

Weight Sensor?

Definition: A load cell or weight sensor is one kind of sensor otherwise a transducer. The **working principle of the weight sensor** depends on the conversion of a load into an electronic signal. The signal can be a change in voltage; current otherwise frequency based on the load as well as used circuit.

Theoretically, this sensor detects changes within a physical stimulus like force, pressure or weight and produces an output that is comparative to the physical stimulus. So, for a specific stable load otherwise weight size, this sensor provides an output value and that is comparative to the weight's magnitude. The best example of this sensor module is SEN0160.

Module – SEN0160

The SEN0160 weight sensor module is based on HX711 ADC; it is an accurate 24-bit ADC which is designed for industrial control as well as weighs scale applications to connect straight with a bridge sensor. Evaluated with other integrated circuits, this HX711 includes basic functions and also some features like a quick response, high integration, immunity, etc. This chip reduces the cost of electronic scale as well as improves the reliability and performance.

Fig SEN0160-wireless-sensor-module

RPI –PICO

A Raspberry Pi Pico is a low-cost microcontroller device. Microcontrollers are tiny computers, but they tend to lack large volume storage and peripheral devices that you can plug in (for example, keyboards or monitors).

A Raspberry Pi Pico has GPIO pins, much like a Raspberry Pi computer, which means it can be used to control and receive input from a variety of electronic devices

Raspberry Pi Foundation is well known for its series of single-board computers (Raspberry Pi series). But in **January 2021 they launched their first micro-controller board known as Raspberry Pi Pico**.

It is built around **the RP2040 Soc, a very fast yet cost-effective microcontroller chip packed with a dual-core ARM Cortex-M0+ processor.** M0+ is one of the most power-efficient ARM processorRaspberry Pi PICO board

Raspberry Pi PICO board

Fig: Raspberry Pi Pico Board

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Raspberry **Pi Pico is a small, fast, and versatile board that at its heart consists of RP2040**, a brand-new product launched by Raspberry Foundation in the UK. It can be programmed using MicroPython or C language.

DESCRIPTION

Belt conveyors are essential for the transportation of materials in various industries, particularly in coal mines, where their reliability and safety are paramount. The conveyor system's performance heavily depends on the health of the idler rollers, which bear the weight of the conveyor belt, ensuring smooth operation and reducing resistance. Failure of the idler rollers can cause damage to the conveyor belt, resulting in production downtime and potential safety hazards. Therefore, continuous monitoring of the idler's health is crucial to prevent such failures and maintain the smooth operation of the conveyor system. Currently, most belt conveyor monitoring systems rely on manual inspections. While this method is still widely used, it has several drawbacks, such as being time-consuming, error-prone, and lacking real-time performance. Manual inspections also pose safety risks to workers, especially in hazardous environments. To address these issues, more advanced methods, including vibration, noise, and temperature monitoring, have been introduced. These methods, however, are typically limited to monitoring individual idlers and often fail to scale effectively for large, distributed belt conveyor systems that span long distances. The concept of wireless sensor networks (WSNs) offers a promising solution for large-scale, distributed monitoring. WSNs enable real-time data acquisition and transmission by deploying multiple sensor nodes, making it possible to monitor the condition of the idlers over a broad area. These networks offer benefits such as low cost, easy scalability, and fault tolerance. Previous research has demonstrated the potential of WSNs for environmental monitoring in underground coal mines. However, integrating WSNs with large-scale mechanical systems like belt conveyors, especially for idler health monitoring, remains underdeveloped, and there is a need for practical solutions tailored to the unique challenges of belt conveyors. In response to these challenges, this study proposes a novel embedded monitoring node designed specifically for the health monitoring of belt conveyor idler rollers. The proposed node features multiparameter sensing capabilities, including temperature and vibration monitoring, and is capable of wireless communication for real-time data transmission. To power the system, an energy-harvesting module based on a Halbach permanent magnet array has been incorporated, coupled with an energy management system to optimize the energy consumption. This embedded system has been designed to minimize the cost of modifying the idlers while maintaining the core functionality of the conveyor system. The node prototype underwent rigorous testing, and the results showed promising performance. The energy harvester produced a power output of 171.33 mW, which was more than sufficient to meet the energy demands of the node. Additionally, the energy management system allowed the node to operate for an extended period of 74 minutes, even in environments with limited power sources. Communication tests revealed how narrow spaces could affect signal transmission, highlighting the need for careful optimization of the wireless network. Overall, the prototype successfully collected and transmitted critical data such as temperature and vibration, demonstrating its potential for real-time health monitoring of idler rollers. The proposed system's ability to perform reliable, real-time monitoring marks a significant advancement in belt conveyor health monitoring. Its scalability, adaptability, and integration of energy harvesting and wireless communication provide a robust solution for large-scale applications. By addressing the limitations of existing methods and offering a more efficient, autonomous solution for idler monitoring, this research paves the way for improved safety, efficiency, and reliability in industrial conveyor systems. Furthermore, the technology can be applied to other sectors requiring large-scale equipment monitoring, offering broad implications for industrial automation and safety management.

CONCLUSION

This article addresses the need for network health monitoring of belt conveyors and introduces a novel embedded condition monitoring node for the idler roller. The proposed node is designed by analyzing the working conditions of belt conveyors and incorporating the idler's motion and structural features with self-powered wireless sensor network technology. This node stands out due to its low transformation cost, compact size, and self-powering ability. The node's power consumption was carefully analyzed, leading to the design of an energy-harvesting device, an energy management circuit, and a control/sensing module. The energy harvester is capable of generating a maximum power of 171.33 mW, which exceeds the theoretical power requirement of 161.76 mW, ensuring the node's energy needs are met. Additionally, the energy management circuit is designed to provide over an hour of working time if the idler stops, allowing the node to continue functioning even if the energy harvester fails. Communication tests revealed that deploying two nodes within a reliable communication range is essential to ensure stable data transmission due to space constraints and other factors. A prototype node and an experimental system were developed to conduct a comprehensive performance test of the idler-monitoring node. The results showed that both the energy harvester and energy management circuit operated as intended. The node was able to monitor the idler's temperature and vibration in real time and transmit data to the upper computer, fulfilling the monitoring requirements. This demonstrated the node's overall performance and provided a technical solution for monitoring the health of the belt conveyor idler and the system as a whole. In future work, the focus will be on improving the reliability and stability of the idler nodes, enabling their practical use in networked monitoring of belt conveyor idlers. Additionally, there are plans to integrate more sensors and utilize advanced data processing and mining techniques to gather real-time, accurate, and comprehensive health information about the idlers.

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