

ANOMALY DETECTION METHODS AND SYSTEMS FOR ROTATING EQUIPMENT

TECHNICAL FIELD

5 [01] The present disclosure relates to a field of industrial machinery maintenance, and in particular to anomaly detection methods and systems for rotating equipment.

BACKGROUND

10 [02] In the field of industrial machinery maintenance, a commonly used approach is routine preventive maintenance. This method involves servicing pumps and other rotating equipment at fixed intervals and replacing consumable parts throughout the equipment's life cycle. For example, pump bearings may be repacked with grease annually until they reach their rated service life, thereafter the entire bearing assembly must be replaced.

15 [03] However, routine preventive maintenance presents several disadvantages. First, it can lead to increased costs, as components may be prematurely replaced even when they are still functional. Second, this approach is inefficient in addressing failures caused by improper installation or operation, which are not easily detectable through scheduled maintenance alone. Finally, preventive maintenance may result in unnecessary downtime, since equipment is periodically taken out of service
20 regardless of its actual condition.

SUMMARY

[04] According to various embodiments of the present disclosure, anomaly detection methods and systems for rotating equipment are provided.

25 [05] An anomaly detection method for rotating equipment, comprising:

[06] collecting tri-axial acceleration raw data from sensors attached to the rotating equipment;

30 [07] pre-processing the raw data through alignment and averaging over one rotation period of the rotating equipment to obtain pre-processed data;

[08] extracting and combining features from the pre-processed data, the features including time-domain statistics features, frequency-domain characteristics features, and time-frequency domain features;

5 [09] training a transformer-based autoencoder model by utilising the features to generate embeddings representing normal operational behaviour; and

10 [010] detecting an anomaly by reconstructing input data with the transformer-based autoencoder model; a deviation between the input data and reconstructed data beyond a preset range indicates the anomaly.

[011] An anomaly detection system for rotating equipment, comprising

15 [012] a processor; and

[013] a memory with computer code instructions stored thereon, the memory operatively coupled to the processor such that, when executed by the processor, the computer code instructions cause the computer device to implement:

20 [014] collect tri-axial acceleration raw data from sensors attached to the rotating equipment;

[015] pre-process the raw data through alignment and averaging over one rotation period of the rotating equipment to obtain pre-processed data;

25 [016] extract and combine features from the pre-processed data, the features including time-domain statistics features, frequency-domain characteristics features, and time-frequency domain features;

30 [017] train a transformer-based autoencoder model by utilising the features to generate embeddings representing normal operational behaviour; and

[018] detect an anomaly by reconstructing input data with the transformer-based autoencoder model; a deviation between the input data and reconstructed data beyond a preset range indicates the anomaly.

5 [019] Details of one or more embodiments of the present disclosure will be given in the following description and attached drawings. Other features, objects and advantages of the present disclosure will become apparent from the description, drawings, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

10 [020] In order to better describe and illustrate the embodiments and/or examples of the contents disclosed herein, reference may be made to one or more drawings. Additional details or examples used to describe the drawings should not be considered as limiting the scope of any of the disclosed contents, the currently described embodiments and/or examples, and the best mode of these contents currently understood.

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[021] FIG. 1 illustrates a flowchart of an anomaly detection method for rotating equipment according to an embodiment of the present disclosure;

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[022] FIG. 2 illustrates a diagram of an anomaly detection system for rotating equipment according to an embodiment of the present disclosure.

DETAILED DESCRIPTION OF THE EMBODIMENTS

25 [023] In order to facilitate the understanding of the present disclosure, the present disclosure will be described more fully below with reference to the relevant drawings. Preferred embodiments of the present disclosure are shown in the drawings. However, the present disclosure can be implemented in many different forms and is not limited to the embodiments described herein. On the contrary, the purpose of providing these embodiments is to make the disclosure of the present disclosure more thorough and comprehensive.

30 [024] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. The definitions are provided to aid in describing particular embodiments, and are not intended to limit

the claimed invention. The term “and/or” used herein includes any and all combinations of one or more related listed items.

5 [025] In order to understand this application thoroughly, detailed steps and structures will be provided in the description below to explain the technical solution proposed by this application. Preferred embodiments of this application are described in detail below. However, in addition to these details, there may be other embodiments of this application.

10 [026] Referring to FIG. 1, an anomaly detection method for rotating equipment is provided. The anomaly detection method provides a hybrid-based platform for detecting anomalies on pumps, motors and other rotating equipment over multi-modal vibration data. The method is designed to enhance predictive maintenance of industrial machinery, specifically focusing on rotating equipment like large pumps and motors. The method can address the critical need for early identification of operational anomalies, thereby minimizing downtime and maintenance costs.

15 [027] The method detects anomalies in the operation of rotating equipment by monitoring multi-directional raw acceleration data, allowing for timely maintenance interventions. The method aims to transition facilities from preventive to condition-based maintenance, enhancing operational efficiency and reliability.

20 [028] The method provides a holistic view of mechanical conditions by capturing comprehensive operation behaviours by combining acceleration data from multiple directions. The attention mechanisms of transformer models are utilised to capture complex relationships within the data, allowing for accurate anomaly detection.

25 [029] The anomaly detection method includes the following steps:

[030] S100, collecting tri-axial acceleration raw data from sensors attached to the rotating equipment. The rotating equipment can be pumps or motors. In an embodiment, the raw data
30 comprises data in the Axial, Radial X, and Radial Y directions. The sensors can be tri-axial accelerometers mounted on the pumps or motors to capture Axial, Radial X, and Radial Y acceleration

data. This multi-directional data captures comprehensive operational behaviours and mechanical conditions of the equipment.

[031] S200, pre-processing the raw data through alignment and averaging over one rotation period of the rotating equipment to obtain pre-processed data. The raw data is time-based signals. The raw data undergoes signal averaging based on the rotating equipment's rotational cycle, reducing uncorrelated noise while preserving relevant information.

[032] S300, extracting and combining features from the pre-processed data, the features including time-domain statistics features, frequency-domain characteristics features, and time-frequency domain features. In an embodiment, the time-domain statistics features comprise mean and standard deviation. The step extracts a robust set of features from the pre-processed data. These features provide a rich dataset for anomaly detection.

[033] S400, training a transformer-based autoencoder model by utilising the features to generate embeddings representing normal operational behaviour. The fused and feature-rich data is fed into a transformer-based autoencoder model. The model learns the normal behaviour patterns of the pump through its attention mechanisms. The model uses the transformer's attention mechanism to learn and encode complex patterns in the data.

[034] S500, detecting an anomaly by reconstructing input data with the transformer-based autoencoder model. A deviation between the input data and reconstructed data beyond a preset range indicates the anomaly. The autoencoder attempts to reconstruct the input data. Any significant reconstruction errors suggest anomalies, indicating potential operational issues. Concretely, a significant deviation between the input and reconstructed data indicates an anomaly, implying potential operational issues with the pump. In an embodiment, the input data can be real-time data. The anomaly detection method enables highly accurate and efficient real-time anomaly detection, ensuring the proactive management of industrial machinery.

[035] The method introduces an advanced anomaly detection method for industrial machinery that specifically targets rotating equipment, such as large pumps and motors used in various industrial settings. This method leverages a combination of multi-directional acceleration data, signal

processing techniques, and transformer-based neural networks to detect anomalies. Accurate and timely anomaly detection is vital for predictive maintenance, allowing issues to be identified before they escalate into failures, thereby reducing downtime and associated costs.

5 **[036]** This method utilises multi-directional acceleration raw data from sensors, capturing Axial, Radial X, and Radial Y time waveforms. These signals provide comprehensive insights into the mechanical health and operational behaviour of the rotating equipment. By fusing these datasets, the method creates a robust and detailed representation of the equipment's condition.

10 **[037]** The fused multi-directional data is then fed into a transformer-based autoencoder model. Transformer's attention mechanisms and deep neural network architecture excel at learning complex relationships within the data, allowing them to effectively discern normal operational patterns from anomalous ones. This method not only enhances the precision of anomaly detection but also improves the overall reliability and efficiency of predictive maintenance systems.

15 **[038]** The application of this method at industrial facilities, including sectors such as manufacturing, water treatment, and power generation, demonstrates its potential. These facilities operate with high capacity and rely heavily on their pumps and motors, making continuous monitoring and prompt maintenance crucial. By implementing this advanced method, facilities can transition
20 from preventive to condition-based maintenance, resulting in better asset management, reduced maintenance costs, and minimized operational disruptions.

25 **[039]** The method is cost-effective, as only parts with signs of impending failure are replaced, thereby reducing unnecessary expenditures. It also ensures accuracy by applying multi-directional data fusion and a transformer-based autoencoder for continuous monitoring, which helps detect failures arising from installation or operational issues. In addition, real-time anomaly detection minimises unexpected downtimes, thereby improving the stability and efficiency of industrial machinery.

30 **[040]** Referring to Fig. 2, an anomaly detection system 200 for rotating equipment is also provided. The anomaly detection system 200 includes a processor 201 and a memory 202 with computer code instructions stored thereon, the memory 202 operatively coupled to the processor 201 such that, when

executed by the processor 201, the computer code instructions cause the computer device to implement the steps S100 to S500. The anomaly detection system 200 cooperates with sensors and data acquisition unit. The sensors can be tri-axial accelerometers mounted on the pumps to capture Axial, Radial X, and Radial Y acceleration data. The and data acquisition unit is capable of collecting and transmitting high-frequency raw acceleration data to the anomaly detection system 200.

[041] The foregoing embodiments only describe several implementations of the disclosure, which are described specifically and in detail, and therefore cannot be construed as a limitation to the patent scope of the disclosure. It should be noted that, a person of ordinary skill in the art may further make variations and improvements without departing from the ideas of the disclosure, which all fall within the protection scope of the disclosure. The exact design of the instrument should be according to the detailed figure may not be the same as the figures in this application, some specific parts such as gear numbers can be various. Therefore, the protection scope of the disclosure is subject to the protection scope of the appended claims.

What is claimed is:

1. An anomaly detection method for rotating equipment, comprising:
 - 5 collecting tri-axial acceleration raw data from sensors attached to the rotating equipment;
 - pre-processing the raw data through alignment and averaging over one rotation period of the rotating equipment to obtain pre-processed data;
 - extracting and combining features from the pre-processed data, the features including time-domain statistics features, frequency-domain characteristics features, and time-frequency domain features;
 - 10 training a transformer-based autoencoder model by utilising the features to generate embeddings representing normal operational behaviour; and
 - detecting an anomaly by reconstructing input data with the transformer-based autoencoder model; a deviation between the input data and reconstructed data beyond a preset range indicates the anomaly.
- 15 2. The anomaly detection method for rotating equipment of claim 1, wherein the raw data comprises data in the Axial, Radial X, and Radial Y directions.
3. The anomaly detection method for rotating equipment of claim 1, wherein the time-domain statistics features comprise mean and standard deviation.
- 20 4. The anomaly detection method for rotating equipment of claim 1, wherein the input data is real-time data.
5. The anomaly detection method for rotating equipment of claim 1, wherein the rotating equipment
25 comprises pumps and motors.
6. An anomaly detection system for rotating equipment, comprising
a processor; and

a memory with computer code instructions stored thereon, the memory operatively coupled to the processor such that, when executed by the processor, the computer code instructions cause the computer device to implement:

collect tri-axial acceleration raw data from sensors attached to the rotating equipment;

5 pre-process the raw data through alignment and averaging over one rotation period of the rotating equipment to obtain pre-processed data;

extract and combine features from the pre-processed data, the features including time-domain statistics features, frequency-domain characteristics features, and time-frequency domain features;

10 train a transformer-based autoencoder model by utilising the features to generate embeddings representing normal operational behaviour; and

detect an anomaly by reconstructing input data with the transformer-based autoencoder model; a deviation between the input data and reconstructed data beyond a preset range indicates the anomaly.

15 7. The anomaly detection system for rotating equipment of claim 6, wherein the raw data comprises data in the Axial, Radial X, and Radial Y directions.

8. The anomaly detection system for rotating equipment of claim 6, wherein the time-domain statistics features comprise mean and standard deviation.

20 9. The anomaly detection system for rotating equipment of claim 6, wherein the input data is real-time data.

10. The anomaly detection system for rotating equipment of claim 6, wherein the rotating equipment comprises pumps and motors.