شرکت سیمان ممتازان کرمان

Kerman Momtazan Cement Co

The goals of Momtazan Cement Company, as one of the leaders in the construction industry and cement production, have been determined based on commitments to quality, safety, and environmental protection. Focusing on providing high quality products and performing production operations using new technologies, this company seeks to meet the needs of customers in the field of construction. Also, sustainable development and increasing productivity in production processes are one of the basic goals of this company. In this regard, Momtazan pays special attention to protecting the environment and reducing the negative effects of its activities on nature. Also, improving the level of safety in the workplace and commitment to providing proper after-sales services are other goals of this company, which shows attention to customer satisfaction and maintaining credibility in the market.

Iman Amiri Hanza
Senior, AI master developer

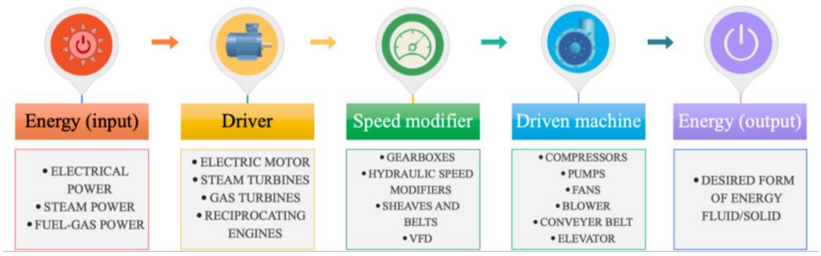
Multiple Fault Detection and Diagnosis of Rotary Machine based on AI/ML algorithms

Introduction

Industry 4.0 marks a new era of smart manufacturing, where machinery is essential. Rotating machines play a crucial role in manufacturing processes. Maintenance of these machines is a top priority for engineers to prevent unplanned shutdowns and extend machinery lifespan.
Predictive maintenance (PdM) is a growing trend in maintenance practices. One of the challenges in PdM is fault diagnosis. Advances in Artificial Intelligence (AI) have led to a data-driven approach to predictive maintenance in smart manufacturing. While existing research has focused mainly on single-fault diagnosis in rotating machines, there is a lack of literature on multi-fault diagnosis.
There is a need for a comprehensive review covering sensor selection, data acquisition, feature extraction, multi-sensor data fusion, and AI techniques for multi-fault diagnosis. The research identifies foundational work in the field, conducts a comparative study on various aspects of multi-fault diagnosis in industrial rotating machines, highlights challenges and research gaps, and proposes solutions leveraging recent AI advancements for multi-fault diagnosis, paving the way for future research in this area.

The industries form the foundation of the nation's economy. Recent technological advancements, particularly in Artificial Intelligence (AI), have propelled these industries to new heights through the evolution into smart factories, ushering in the era of the fourth industrial revolution. Smart factories utilize smart manufacturing, with machines serving as the fundamental components. Within industries, rotating machines play a crucial role in transferring energy between fluids and solids. Process machinery encompasses various sub-elements of rotating machines that work collectively to convert energy into a usable form. These sub-elements include driver machines, driven machines, speed modifiers, shafts, and couplings. Driver machines convert electrical, steam, or fluid energy into rotary power to operate process machinery.

Examples of driver machines include electric motors, turbines, and reciprocating engines. Driven machines transport process fluids or solids to specific points within a process, using devices like pumps, fans, compressors, and conveyor belts. Speed modifiers adjust the output shaft speed of the driver machine as needed, using components such as gearboxes, sheaves, belts, and Variable Frequency Drives (VFDs). Shafts are rotating machine elements that transmit energy from the driver to the driven machinery, connected on both ends by couplings.



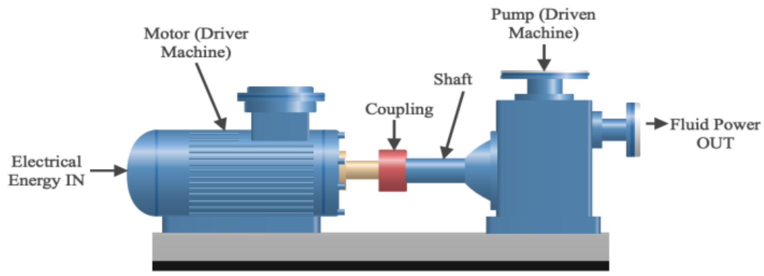


Figure 1: Flow Diagram of Process Rotating Machinery (Ex: an electric motor coupled to a centrifugal pump)

Rotating machinery is crucial in manufacturing operations, and prioritizing proper maintenance is essential for maintenance engineers. A sound maintenance plan significantly impacts the manufacturing industry's success. The P-F Curve illustrates how equipment failure occurs and emphasizes the importance of early detection to allow for timely replacement or repair without disrupting production. The curve distinguishes Potential failure (P) based on historical data and Functional failure (F) as the actual failure point. Maintenance engineers strive to minimize failure probability through diverse maintenance approaches. The graph also highlights the relationship between equipment condition, repair costs, and the timeliness of maintenance actions. Implementing the correct maintenance strategy enables the early detection of potential failure modes.

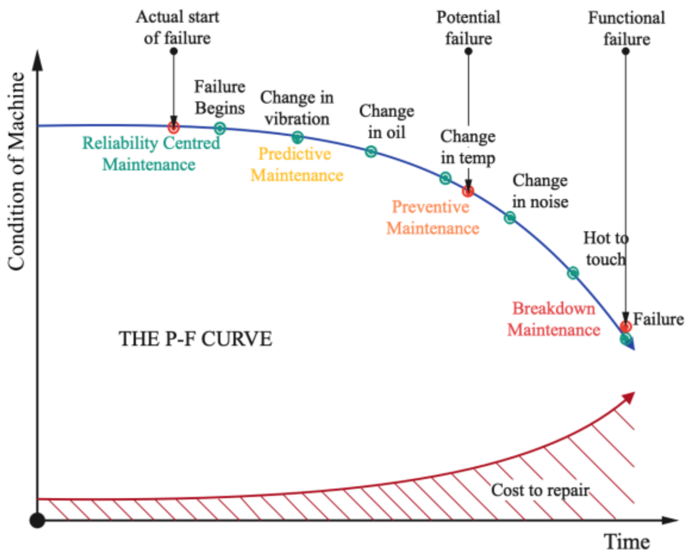


Figure 2: The PF Curve depicting the Significance of Early Fault Diagnosis

How do we choose the best fault detection and isolation method for our system?

Define our system model and fault types

The first step is to define our system model and the types of faults that can occur in it. **A system model is a mathematical representation of the system's behavior, structure, and dynamics, which can be based on physical laws, empirical data, or expert knowledge.**

A fault type is a classification of the fault's nature, location, magnitude, and duration, which can be categorized as additive, multiplicative, parametric, or structural. Depending on our system model and fault types, we may need different FDI methods that can handle the complexity, uncertainty, and nonlinearity of our system and faults.

Choose our FDI approach and technique

The next step is to choose our FDI approach and technique. **An FDI approach is a general framework or strategy for performing FDI, which can be classified as model-based, data-driven, or hybrid.**

- **A model-based approach relies on a system model and compares the actual and expected outputs to detect and isolate faults.**
- **A data-driven approach uses historical or real-time data and applies machine learning or statistical methods to learn the fault patterns and identify anomalies.**
- **A hybrid approach combines both model-based and data-driven methods to leverage their strengths and overcome their limitations.**

An FDI technique is a specific algorithm or tool that implements an FDI approach, such as observers, filters, parity equations, neural networks, decision trees, or fuzzy logic. Depending on our FDI approach and technique, we may need different data sources, computational resources, and performance measures for our FDI method.

Evaluate our FDI method's performance and robustness

The final step is to evaluate our FDI method's **performance** and **robustness**.

- **Performance refers to how well our FDI method can detect and isolate faults in terms of accuracy, speed, sensitivity, and specificity.**

- **Robustness refers to how well our FDI method can cope with uncertainties, disturbances, noise, and model errors in the system and the data.**

To evaluate our FDI method's performance and robustness, we need to define our performance **criteria** and **metrics**, such as:

- Detection rate
- Isolation rate
- False Alarm rate
- Detection time
- Isolation time
- Fault Severity Estimation

We also need to design our test scenarios and cases, such as:

- Normal Operation
- Single Fault
- Multiple Faults
- Intermittent Faults
- Incipient Faults

We can use simulation, experimentation, or field data to test our FDI method and compare it with other methods or benchmarks.

Choosing the best FDI method for our system is not a one-size-fits-all solution, but a process that requires careful analysis, comparison, and validation. By following these steps and criteria, we can select an FDI method that meets our system's requirements and objectives, and enhances our system's reliability and safety.

Terms and terminology

Here are the commonly used terms in diagnosing faults in industrial rotating machines:

• Industry 4.0: The current automation trend that combines cyber-physical systems, the Internet of Things, and cloud computing.

• Predictive maintenance (PdM): Engineers aim to predict machine failures based on prevailing conditions.

• Big Data Analysis: Advanced analytics applied to large and diverse data sets.

• Artificial Intelligence (AI): Simulating human intelligence on machines.

• Data-driven approach: Making decisions based on data analysis rather than observation.

• Multi-sensor data fusion: Combining data from different sources to reduce uncertainty.

• Multi-fault diagnosis: Identifying multiple faults through data analysis.

• Rotating machines: Mechanical components in industries like oil and gas that use kinetic energy.

• Maintenance strategy: Rules for planned maintenance work sequence.

Multi Fault Diagnosis in Rotating Machines

Manufacturing process machines, particularly rotating machines, operate around the clock, leading to mishandling and wear and tear from extended use, resulting in various faults. The components of rotating machines exhibit different types of faults categorized into three levels:

- Component-level faults
- System-level faults
- Interrelated faults

Component-level faults encompass issues with components like bearings, shafts, and pulleys. For instance, bearings, crucial components of rotating machines, can experience faults such as inner race faults, outer race faults, and rolling element faults. Similarly, shafts can develop faults like misalignment, while rotors in rotating machines may suffer from unbalance faults.

System-level faults pertain to overall system issues that need monitoring.

Interrelated faults comprise additive faults, which result from combining different faults from multiple components (e.g., Unbalance and Misalignment), and multiplicative faults, which involve the multiplication of various fault types within a single component (e.g., shaft bend and shaft crack).

Additive faults are typically easier to diagnose compared to multiplicative faults.

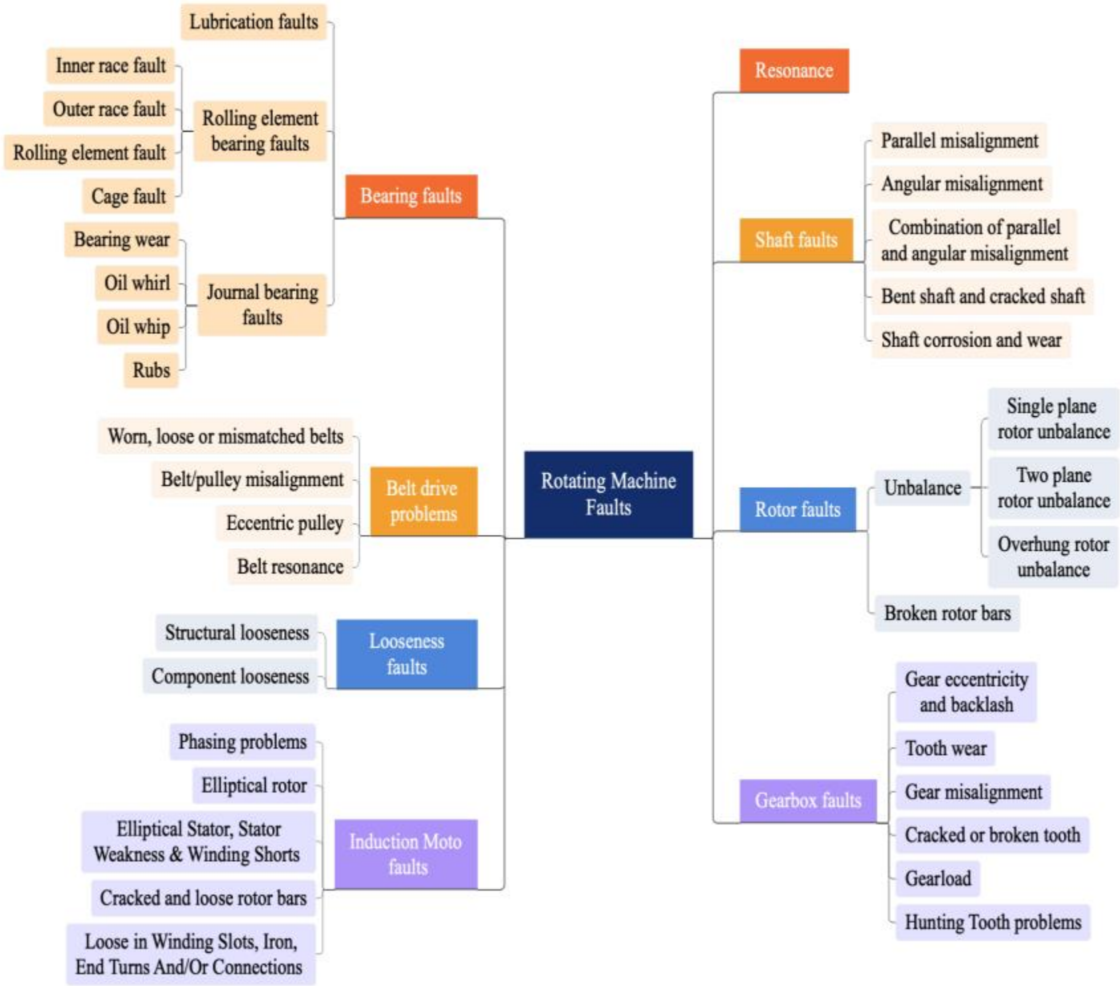


Figure 3: General Component-level Faults in Rotating Machines

Steps to implement AI Model in fault diagnosis of rotating machines

The implementation stack of AI for multiple fault diagnosis is depicted in Figure 4. The figure is divided into several layers connected through a single directional road map. Each layer reveals a specific task accomplished via a particular set of either hardware or software or protocols or data stores. The first and the primary layer is the physical layer that includes the machine under test, the different sensors, the data communication medium, and the data acquisition system. Before moving ahead, it is essential to decide whether cloud computing or edge computing will be employed in fault diagnosis. Data pre-processing is the next important task that involves data storage, feature extraction, and data fusion. The next step is implementing the data analysis using ML/DL algorithms to achieve an accurate diagnosis. It includes training, testing, and validation of the algorithm and the results obtained. Once the diagnosis results are obtained, the final step is to convert the model to optimized C code to be implemented on the microcontroller. The advantages of using microcontrollers are:

they consume low energy, are cheap, they are flexible, and most importantly, they have high security. Some widely used microcontrollers include Coral Dev Board, NVIDIA® Jetson Nano™ Developer Kit, Raspberry Pi 4 computer model B, etc.

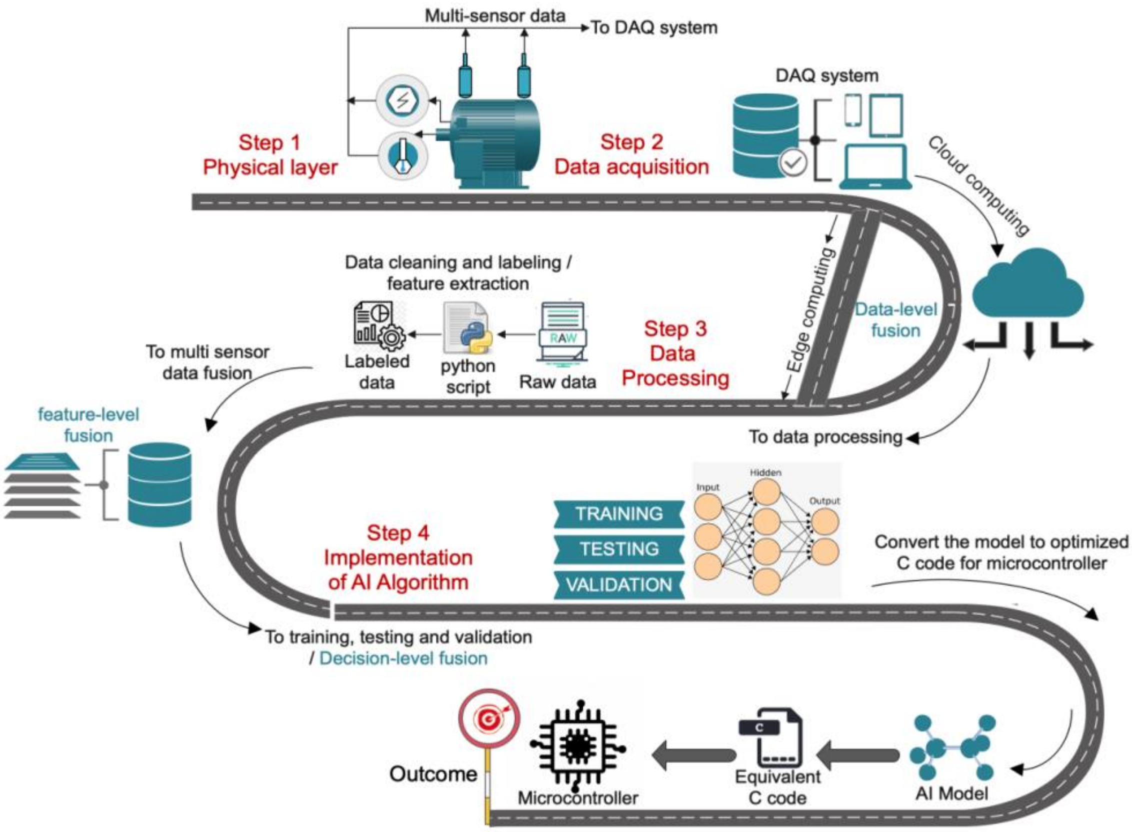


Figure 4: Implementation Stack of AI for Multi-Fault Diagnosis of Rotating Machines