

# An intelligent system for diagnosis of fault types and fault degrees: with applications to planetary gearboxes and pumps

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## ABSTRACT

Diagnosis of fault types and fault degrees are important tasks in fault diagnosis. The current way of diagnosis of fault degrees doesn't preserve the ordinal information contained in fault degrees. The goal of this research is to develop a diagnosis method preserving the ordinal information, and furthermore to develop an intelligent diagnosis system that is capable of detecting a fault, and identifying fault types and fault degrees.

## 1. INTRODUCTION AND PROBLEM ADDRESSED

Fault diagnosis and condition monitoring is of prime importance to the safe operation of machinery in various industries, such as mining, power, and aerospace. It provides information on the health condition of machinery, based on which preventive maintenance or other action could be conducted to avoid consequences of severe damage or failure.

There are mainly three tasks to be completed in a fault diagnosis and condition monitoring system: 1) detection of a fault; 2) diagnosis of fault types, 3) diagnosis of fault degrees. The first task is to indicate if a fault occurs or not; the second is to determine the location of a fault; and the third is to estimate the degree of a fault. The first two tasks are the first step of fault diagnosis, and are most considered and studied in literatures. The third task is a very important aspect of a condition monitoring system, because it provides more detail information on a fault. Research on this topic is, however, limited.

Diagnosis of fault degrees is different from diagnosis of fault types in that the fault degrees have ordinal information in them. For example, a severe damage is worse than (i.e. "<") a medium damage; and slight damage is better than (i.e. ">") medium damage. Nevertheless, for two damage types, say type A and type B, they are nominal variables and can not be compared using ">" or "<" operator.

Most reported work on diagnosis of fault degrees uses signal-processing based method of generating an indicator

to represent the fault degrees (Feng et al, 2010). However, such methods have strong requirements on the expertise of a diagnostician to apply them successfully and cannot distinguish fault levels automatically. To alleviate this requirement, researches (Lei and Zuo, 2009) have used intelligent classification methods. In this case, the problem of fault degree diagnosis is simply regarded as the problem of fault type diagnosis, which misses the ordinal information in fault degrees. Some researches (Pan et al, 2010) use technologies such as fuzzy-c means and self-organizing map to assess fault degrees. In those methods, only normal data is used to build an assessment model. Logistic regression builds the assessment model by utilizing data from two health status (normal (0) and failure (1)). In both cases, the damage level information is not fully used.

Based on the literature review, the ordinal information isn't preserved in the existing intelligent diagnosis methods for fault degrees. The study which is being carried out will propose a method which keeps the ordinal information in fault degrees; and furthermore develop a reliable fault diagnosis system which is capable of detecting a fault, identifying the fault type as well as the fault degree.

## 2. PROPOSED PLAN

To preserve the ordinal information contained in fault degrees, we will employ ordinal ranking to build a ranking model for diagnosis. Ordinal ranking (Lin, 2008) is a recently studied supervised learning algorithm. It is different from classification in that its labels are ordinal variables while the labels of classification problems are nominal variables. Ordinal ranking generates a ranking model, whose output value monotonically changes with the fault degree; thus the ordinal information between fault degrees is kept.

The application of ordinal ranking to fault diagnosis faces one challenge: feature selection for ordinal ranking. Feature selection is essential for ordinal ranking, because it can enhance accuracy and improve the efficiency of training. Existing features selection methods are for classification purpose. A feature selection method specifically designed for ordinal ranking will work more efficiently in improving

the performance of the ranking model. We will first propose a criterion to evaluate the relevance between features and ranks in terms of monotonicity; then propose a method to select features that are most relevant to fault degrees.

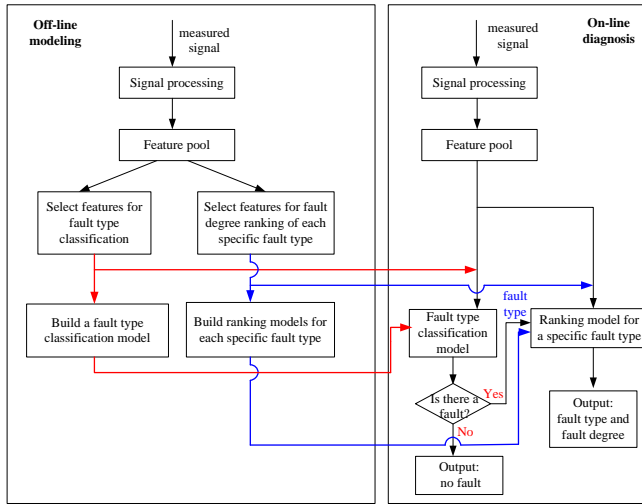


Fig.1 A diagnosis system of fault types and fault degrees

After the problem of diagnosis of fault degrees is solved, we will develop an intelligent fault diagnosis system which is able to detect a fault, and distinguish the fault type and degree. The flow chart of the system is shown in Fig. 1. It consists of two parts: off-line modelling and on-line diagnosis. In off-line modelling, a fault type classification model is built to determine whether a fault exists; and if there exists a fault, what type it is. A fault degree ranking model is built to determine the fault degree for a specific fault type. The steps to build these models are as follows. First, data is collected and features are extracted to constitute a feature pool using signal processing technologies such as time-domain analysis; frequency-domain analysis; and time-frequency analysis. Then, feature selection is conducted for classification and ordinal ranking, separately. Finally a fault type classification model and a fault degree ranking model are built with the selected features, separately. In on-line diagnosis, the data is processed to generate a feature pool in the same way as in off-line modelling. Then features that have been selected for classification in the off-line modeling part will be input to the trained classification model. After that, the results of the classification is checked: if there is no fault, the diagnosis ends; if there is a fault, then the classified fault type, together with selected features for ranking are input to a corresponding ranking model to diagnose the fault degree.

The effectiveness of the proposed fault diagnosis system will be tested on a planetary gearbox and a centrifugal pump.

### 3. CURRENT PROGRESS

The experiment data have been collected from a gearbox and a pump, separately, at the following health statuses:

- Gearbox: normal condition; three levels of pitting damage on a planetary gear (i.e. slight, medium, and severe); and two levels of crack on a sun gear (i.e. half crack and missing tooth).
- Pump: normal condition; three levels of impeller vane trailing edge damage (i.e. slight, medium, and severe); and three levels of impeller vane leading edge damage (i.e. slight, medium, and severe).

The performance of ordinal ranking is found to outperform classification on diagnosis of pitting damage levels (Feature selection is not involved in this comparison). We are now in the process of composing the feature selection method for ordinal ranking.

### 4. EXPECTED CONTRIBUTION

This research will contribute to the PHM field in the following aspects:

- The ordinal ranking will be introduced to diagnose the fault degrees for the first time; this fills in the blank of a intelligent diagnosis methods that preserve the ordinal information in fault degrees. The proposed feature selection for ordinal ranking will enhance the performance of the diagnosis results. Comparisons with existing fault degree diagnosis methods (i.e. classification) will be conducted; the pros and cons will be discussed and addressed.
- An intelligent system for fault diagnosis will be developed. This system will built a fault type classification model and a fault degree ranking model, and output the online diagnosis results automatically. The system is capable to detect the fault, and diagnose the fault type as well as the fault degree. Test on gearbox data and pump data will evaluate its application abilities in industries.

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