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A performance evaluation of three inference engines as expert systems for failure mode identification in shafts

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ABSTRACT

This paper aims to present performance evaluation of three different inference engines (rule based reasoning, fuzzy based reasoning and Bayesian based reasoning) for failure mode identification in shafts. This research was done with a focus on the validation cases and results after their use in failure cases from several industries where the three systems were tested under the same conditions.

Each system was implemented using the same user interface and knowledge base, with different frameworks and techniques as follows: rule based inference reasoning (prolog, C#), Mamdani-fuzzy based reasoning (C, MATLAB®) and Bayesian based reasoning with a variable elimination algorithm (C, MATLAB®).

The best performance was obtained using the Bayesian inference engine. The conditional probabilities give flexibility when evidence is not listed, while the fuzzy and classical IF-THEN systems depend on the rules in the inference engine.

The process presented in this paper could be used for validation of any expert system or for comparison with other expert systems (inference engines) when the knowledge base is the same.

1. Introduction

Presently it is common to find different applications of expert systems in several fields of knowledge, especially in medical diagnosis [1] and also there are applications for failure diagnosis in mechanical systems or elements.

Focused on rule based inference process is possible to find in [2] the results of an IF-THEN expert system for car failure diagnosis, [3] presents a classical IF-THEN inference engine applied to the failure mechanism identification in mechanical components, in [4] was used a case based reasoning combined with a rule based inference engine for failure analysis of mechanical elements and [5] shows an intelligent fault diagnosis system for failures in gearbox of rolling mills.

For fuzzy inference engine there are papers focused in failure diagnosis for pump systems [6], based condition diagnosis [7] and application of failure mode and effects analysis (FMEA) and risk analysis in a fishing vessel [8].

The use of Bayesian inference in expert systems is presented in [9], for blast furnace [10] presents the results in failure modes using Bayesian networks, [11] showed an intelligent fault inference in rotating flexible rotors, [12] presented results in corrosion failure identification in refining plants and Weber [13] showed the increase in the use of Bayesian systems in dependability, risk analysis and maintenance areas between 2000 and 2008.

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However, there is a paucity of literature that shows the comparison results focused on the performance of several inference engines applied to failure identification in mechanical systems under the same conditions and validation cases. Previous papers are literature for a set of cases of failure where was applied only one inference method (fuzzy inference, Bayesian, case based reasoning, neural networks, or a combination of them), but frequently in those papers is not presented the performance comparison with other inference engines in order to find or identify what method or strategy could improve the failure identification process.

The most common techniques for comparison between expert systems are indexed and agreement ratios [14].

By means of failure cases in shafts, rule based, fuzzy inference, and Bayesian inference expert systems were tested and compared with the response obtained from an expert human panel. The rule based expert system was developed using a declarative programming language (prolog+logic server), the fuzzy inference engine was developed using the fuzzy inference system included in MATLAB® and the Bayesian inference system was developed using the variable elimination algorithm based on C and MATLAB®.

This validation was performed using the same failure cases as follows: sixteen cases of fracture, ten cases for wear, ten cases for corrosion and ten cases for plastic deformation. The present paper presents the results of each inference engine, using quantitative methodologies based on visual inspection of failed shafts.

At the end of the analysis, the failure mode for each system was shown, as well as its own fault tree analysis diagram (FTA), for corrective actions according to the maintenance procedures.

The human expert panel was composed of four failure analysis engineers, with thirteen, six, five and four years of experience respectively; one of the authors of the present work was part of the expert panel [15].

These experts evaluated the same forty-six cases under which the three inference engines were tested.

2. Expert system structure and knowledge base

The structure of each expert system tested is shown in Fig. 1. The knowledge base was obtained from human expert knowledge; thus the non-expert user entered the evidence based on their observations of the failed shaft, and with the evidence the inference engine tried to find the possible failure mode, showing the result with the FTA. Using the failure mode result and the FTA, the non expert user would be able to improve maintenance procedures or operations, in order to avoid the same failure mode in the future.

The human expert knowledge was provided by the authors of this work. This knowledge was provided through attribute tables to the three inference engines. The attribute tables related failure modes with the most common visual characteristics that can be identified in the failed shafts (e.g. beach marks, distortion, corrosion products and others), according to the experience of the authors and other analysts [16,17].

2.1. Fracture module

The knowledge base for the fracture module includes the following failure modes: brittle fracture in bending (bfb), torsional brittle fracture (tbf), torsional ductile fracture (tdf), bending fatigue fracture (bff), torsional fatigue fracture (tff), torsional fatigue fracture in the splined shaft (tffss), bending corrosion fatigue (bcf), torsional corrosion fatigue (tcf), stress corrosion cracking under bending (sccub) and torsional stress corrosion cracking (tscc).

An example of a table of attributes for fractures is shown in Table 1, where (M) means mandatory and (O) means optional symptom or evidence. The non expert user selects the evidence according to his or her observations of the failed shaft.

2.2. Wear, corrosion and plastic deformation module

The knowledge base for the wear module includes the following failure modes: superficial fatigue (sf), abrasive wear (abw), adhesive wear (adw) and fretting (fr). The corrosion module includes pitting corrosion (pc) and uniform corrosion (uc). The plastic deformation module includes the following failure modes: torsional plastic flow (tpf), bending plastic flow (bpf), shell buckling under bending (sbub), shell buckling under torsion (sbut), and damage in keyway or spline (dkws).

The attributes for wear, corrosion and plastic deformation are shown in Table 2. The non expert user selects the evidence according to his or her observations of the failed shaft.

2.3. Inference engine

The rule based inference engine is typically represented as IF-THEN rules (modus ponens); for example IF all the evidence of a failure mode is identified THEN the failure mode is identified.

Fuzzy inference reasoning uses IF-THEN rules, but using fuzzy set theory, it is possible to map the inputs and outputs, using the Mamdani or Sugeno systems. As an example the beach marks could have the following conditions: absence, slight presence or evident.