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Analysis of the classifier fusion efficiency in the diagnostics of the accelerometer

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ABSTRACT

The paper presents the construction and application of multiple classifiers to increase the accuracy of the fault detection module in the diagnostic task. The structure of the ensemble of classifiers is presented and the applied voting mechanisms explained. Methods of storing knowledge in the intelligent diagnostic systems are introduced and their taxonomy provided. Next, the selected algorithms implemented in the fault detection operation are briefly described. Problems with the practical implementation of the proposed solution are considered. The scheme is used to detect faults in the analog part of the MEMS accelerometer. The paper is concluded with the possible prospects for the proposed scheme.

1. Introduction

Contemporary diagnostic systems often rely on the Artificial Intelligence (AI) methods, which provide fast and reliable apparatus for the fault detection and location based on the analysis of previously collected data. Their advantages over traditional mathematical and numerical approaches (such as the sensitivity analysis [1] or dictionary methods [2]) are the automated operation and the ability to extract knowledge from data sets, often difficult for the human designer. Disadvantages include sensitivity of the classification accuracy to the quality of the learning data. Also, as most methods are heuristic, their proper implementation requires thorough adjustment of parameters (such as the number of neurons in the hidden layer of the Artificial Neural Networks – ANN) to fit the specific problem. This process is complicated and time-consuming, thus requiring multiple optimization algorithms as the auxiliary tools during the AI method preparation (such as genetic algorithm [3] or Particle Swarm Optimization [4], used to set the best values of Support Vector Machines' (SVM) parameters). Multiple algorithms are applicable to the classification and regression tasks (such as rule-based systems, ANN, SVM [5], or Bayesian approaches [6]), facilitated by powerful computer systems on which they are implemented. Although usually each method is applied separately, attempts to compare different algorithms have been made [7]. The important conclusion from this research is that each method makes mistakes for different fault scenarios in the same System Under Test (SUT). The next step is the attempt to combine these approaches to obtain the higher diagnostic quality than for separate algorithms. If algorithms being part of such an ensemble represent different method of storing knowledge, there is the high chance their combined work will benefit in better classification of faults or identification of the SUT parameters.

In the modern world sensors are ubiquitous elements of all measurements and control systems. Present in home devices as well as professional equipment, they influence the proper work of most of technical systems our civilization relies on. Therefore it is imperative to ensure their proper

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operation for as long as possible. In [8], the scenarios of poisoning the sensor are considered, which makes them useless. This calls for both the effective post-production testing of each sensor and the self-diagnostics procedures implemented in the device. The importance of analysing and modelling the accelerometer was noticed in [9], while the calibration procedures for the sensor operation in noisy conditions were proposed in [10]. This justifies the selection of this analog SUT for the experiments.

The paper presents the design and efficiency analysis of the classifier fusion in the diagnostics of the modern accelerometer sensor. The task of the module is to determine whether the SUT works according to the design specifications or not (fault detection). In the case of detecting the improper behaviour, its source should also be identified (fault location). The output of the ensemble should be the discrete information about the source of the fault and its deviation from the desired (nominal) value.

The aims of the presented research (being the continuation of work presented in [11]) were as follows:

- To implement and verify the usefulness of the classifier fusion in the diagnostic task.
- To analyse various classification methods and select the most suitable for the proposed scheme.
- To verify the testability of the diagnosed object (accelerometer), assuming that only the standard accessible nodes (outputs of the SUT) are available. This includes preparation of data sets for classifiers, which greatly influences their efficiency.

To achieve the presented goals, the group of candidates for the fusion was considered. They were selected according to the form of stored knowledge about the SUT behaviour (which is discussed in Section 2). Because all considered AI approaches extract knowledge automatically from the data sets, structure of the latter is discussed in Section 3. In Section 4, the architecture of the classifier fusion is presented, including the number of constituent modules and available voting mechanisms. In Section 5 the analysed system is introduced, including its work regime and the approach to extract characteristic information from its responses to build training and testing data sets. Section 6 covers experimental results and their interpretation. Finally, Section 7 contains conclusions and future perspectives of the proposed methodology.

2. Methods of representing knowledge in the intelligent diagnostic systems

The abundance of available methods used to perform classification and regression tasks is related to various form of storing knowledge about the diagnosed object, extracted from the training data set during the machine learning process. In the presented research, only the classification task is considered, limiting the number of applicable approaches. The operation consists in assigning the vector of SUT characteristic information (symptoms) to the integer number, representing the object state: $R^n \rightarrow Z$. The taxonomy of the most powerful and widely used approaches of representing knowledge is shown in Fig. 1. Five main categories include:

- Rules, which have the generic form: *premises* → *conclusion*, where *premises* is the set of conditions that must be fulfilled to reach the *conclusion* (here the decision about the SUT state). The advantage of such form is the legibility to the human being, who is able to read and modify rules, if necessary. The most popular methods for extracting knowledge of such form are Decision Trees (DT) and rules induction algorithms [12].
- Probability apparatus is based on the Bayes theorem. Here knowledge is the set of conditional probabilities that point (with the specific certainty) at the particular fault in the SUT. The most convenient method in this domain is the Naïve Bayes Classifier (NBC), requiring the discretization of training data before it can be further processed. In multiple applications, Bayesian Networks are used as well [6].
- Numerical structures include matrices with real numbers, which are used as weights of computational units (neurons) in various configurations of ANN. Depending on the architecture, knowledge may be stored in one or more matrices. Their advantage is speed, as making decision about the SUT state requires only single matrix transformations. The disadvantage is the illegibility of such form to the human operator. Adjusting values of weights requires applying the optimization procedure, such as the error backpropagation or Levenberg–Marquardt algorithms [13]. The additional optimization is required to select the optimal architecture of the ANN (number of layers and neurons in each layer). This depends on the complexity of the SUT (and the number of analysed symptoms). The network is flexible enough to deal with systems of varying size (by adjusting weight matrices during the training), but the optimization of its architecture must be done for each SUT separately, as in the case presented in the paper.
- Distance-based measures are extension of the dictionary approach. The decision about the SUT state is based on the similarity between the examples from the training set and the vector of symptoms from the actual SUT. Here the decision about its state is made based on the voting of k examples closest to the analysed vector. The adjusted parameters of the approach include the number of considered neighbours k, selection of the voting mechanism (see Section 4) and the distance metrics (with Euclidean being the most popular).
- The final category is the conglomerate of the above forms, and covers approaches considering measurement uncertainty (such as noise and inaccuracies in the measuring equipment). Currently the most popular representatives of this group are SVM frequently applied in diagnostics [14]. Although in all presented methods the uncertainty is treated similarly, significant differences between them are noticed. For instance, Fuzzy Logic (FL) and Rough Sets (RS) are rule-based [15], while SVM and Fuzzy Neural Networks are types of ANN (the first one is also considered as the probabilistic approach). While FL requires the external