Thesis project available

Data Analytics for Prognostics and Health Management (PHM)

(duration: approximately 9 months)

❖ Title of the research:

Development of methods for big data modelling of degradation and failure processes with interpretability

❖ Context of the research

We live in the age of information and data for industry, where almost every situation, process, and decision is monitored, recorded, and analyzed. The prodigious quantity of available data allows the construction of *representations* of these fragments of reality (the situations, processes, or decisions occurring in industry). These representations can be constructed based on rules, concepts, or mathematical equations, and are usually referred to as *models*.

Because a model is a representation of part of reality (we can refer to that part of reality as a *system*), evaluating its quality usually encompasses various aspects that strongly relate to the purpose of the model. In some cases, the model is designed specifically to discover how the system responds in output when it receives a certain input. This situation can be managed with a model that replicates the input–output relations of the system, regardless of how it does so, and it is suited for many modelling tools, including those known as black-box models.

A completely different situation is when we are interested not only in *what* the output will be, but also in *why* it will be this. It is clear that a pure input–output relation is not enough in the latter case. Explanations of the input–output relation need to be obtained. In this case, the internal structure of the model is crucial.

With respect to the above, we can say that the quality of a model can be measured according to (at least) two different dimensions. First, how accurately the model reproduces the input/output relation of the modelled system. Second, how clearly it explains or describes the underlying mechanism producing (or the knowledge justifying) the input–output relation. Whereas the former question (accuracy) has always been important in practical industrial applications, the latter one is attracting significant attention for specific, sensitive industrial applications because of the interest in explainable artificial intelligence (XAI). This interest is growing as a result of the increasing influence that *models* have on industrial production. Indeed, digitalization for smart production has become an important topic for the deployment of the paradigm of Industry 4.0.

The present thesis project aims at exploring solutions for handling big data from industrial monitoring applications to describe degradation and failure processes in a way that is both accurate and interpretable.

❖ Objective of the research

Modelling of the RAM characteristics of smart production systems in industry 4.0 based on big data and with solutions that are both accurate and interpretable.

❖ Required skills

- Interest in developing innovative research and original solutions.

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REFERENCES

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Semantic interpretability in hierarchical fuzzy systems: Creating semantically decouplable hierarchies

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A B S T R A C T

Analysing the interpretability of a fuzzy system (either hierarchical or not) involves consideration of its semantic properties and evaluation of its structural complexity. The present paper concentrates on the semantic aspects of interpretability in hierarchical fuzzy systems. Complexity reduction is also considered, but from the perspective of its interaction with semantic preservation. In that sense, the paper shows that only the use of intermediate variables with meaning (interpretable variables) will transform the complexity reduction into a real improvement in interpretability. The paper formalises this idea by introducing the concept of semantically decouplable hierarchies. Under the assumption of semantic decouplability, it is shown that the interpretability of the overall hierarchical system can be directly obtained from that of its subsystems. Consequently, the paper defines and measures the interpretability of a semantically decouplable hierarchical fuzzy system as the aggregation of the interpretability of its subsystems. Finally, several options will be considered for this aggregation process.

1. Introduction

We live in the age of information and data. Almost every situation, process, and decision is monitored, recorded, and analysed. The prodigious quantity of available data allows the construction of *representations* of these fragments of reality (the situations, processes, or decisions previously mentioned). These representations can be constructed based on rules, concepts, or mathematical equations, and are usually referred to as *models*.

Because a model is a representation of part of reality (we can refer to that part of reality as a *system*), evaluating its quality usually encompasses various aspects that strongly relate to the purpose of the model. In some cases, the model is designed specifically to discover how the system will behave in the presence of a certain stimulus. That type of situation can be properly managed with a model that *simply* replicates the input–output relations of the system, regardless of how it does so. This task is well suited for many modelling tools, including those known as black-box models.

A completely different situation is when we are interested not only in *what* the output will be, but also in *why* it will be this. It is clear that a pure input–output relation is not enough in the latter case. Pieces of knowledge describing or explaining that input–output relation need to be presented. Consequently, the internal structure of the model will be crucial to address this type of situation.

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MOKBL+MOMs: An interpretable multi-objective evolutionary fuzzy system for learning high-dimensional regression data

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ABSTRACT

This work presents a multi-objective evolutionary linguistic fuzzy system that addresses regression problems, especially those that are dimensional and scalable. A multi-objective knowledge base learning (MOKBL) is developed in the first stage of this model. MOKBL learns the most relevant and least redundant features by considering the desirability of the components of the fuzzy system. At the same time as feature selection, MOKBL slightly tunes the membership functions to provide greater initial adaptation of the fuzzy rule-based system components. In the second stage, multi-objective modifications (MOMs) are organized to modify the generated fuzzy system and to perform post-processing tasks. MOMs more finely tune the membership functions and prune additional rules. The newly proposed rule pruning method can eliminate weak rules from the rule base using the concepts of support and confidence. The membership functions tuning process is accomplished using the tasks of core displacement and width alteration of the symmetric functions. MOKBL+MOMs and its stages were validated using 28 real-world datasets and compared with two state-of-the-art regression solutions through non-parametric statistical tests. The experimental results confirmed the effectiveness of MOKBL+MOMs in terms of interpretability (complexity), accuracy, and time.

1. Introduction

Regression models, which estimate output values using a set of input data samples, play an important role in many real-world problems. These models are used in a variety of engineering applications such as prediction, forecasting, data analysis, and function approximation. Statistical models like linear regression and logistic regression have been proposed to carry out these tasks [33]. Recently, machine learning methods such as decision trees, neural networks, support vector machines, evolutionary algorithms and Fuzzy Rule-Based Systems (FRBSs) have been adapted to address regression problems [34].

The abilities of FRBSs to deal with imprecision, noisy data, uncertainty, and nonlinear approximation make them a powerful and well-suited solution for regression problems [38]. FRBSs are based on the fuzzy set theory proposed by Zadeh [47]. These systems utilize linguistic concepts to model input and output relationships in the form of fuzzy linguistic if-then rules which are used to make inferences about the unseen data samples. Two main types of FRBSs are Mamdani [31] and TSK models [44], which differ in their rule structures and inference mechanisms. In the Mamdani models, both antecedent

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