ČVUT
ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

THESIS REVIEWER'S REPORT

I. IDENTIFICATION DATA

Thesis title:	**Application of decision trees to failure detection in HVAC systems**
Author's name:	**Bc. Martin Zázvorka**
Type of thesis :	master
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Control Engineering
Thesis reviewer:	Ing. Raman Samusevich
Reviewer's department:	External (Honeywell Connected Enterprise, Connected Building)

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment — **ordinarily challenging**

How demanding was the assigned project?

The author studies the important problem of HVAC fault detection and diagnostics (FDD). Applications of machine learning methods for HVAC FDD require some form of the results interpretability/root cause analysis to be successful in practice. To address this, the author focuses on the family of models inherently enabling explainability. Being important for the industry, the assignment did not require the development of any novel approach, rather systematic application of existing algorithms and known techniques to a newly gathered dataset.

Fulfilment of assignment — **fulfilled**

How well does the thesis fulfil the assigned task? Have the primary goals been achieved? Which assigned tasks have been incompletely covered, and which parts of the thesis are overextended? Justify your answer.

All points from the assignment have been fulfilled.

Methodology — **correct**

Comment on the correctness of the approach and/or the solution methods.

The author benchmarks selected algorithms paying attention to both detection quality and computational efficiency, analyzing the effect of the most important model parameters. I would appreciate a table summarizing all experiments, as the precise results of some experiments are missing in the plain text, e.g. in the chapter 7.4 CART accuracy is reported to be excellent without a specific number.

Technical level — **D - satisfactory.**

Is the thesis technically sound? How well did the student employ expertise in the field of his/her field of study? Does the student explain clearly what he/she has done?

The author demonstrated his technical ability to apply appropriate techniques to real-world data-centric problems.
At the same time, the technique for out-of-sample performance must be improved. In chapter 6 the author says that records were assigned to training and validation datasets at random, which leads to overoptimistic out-of-sample performance estimation. The records are sampled with a sampling period of 5 minutes, and an HVAC fault is usually present in telemetry data for more than 5 consecutive minutes. It means that with random train/validation split of data each recorded fault can be covered by both training and validation data, hence, out-of-sample performance would be performed on fault instances present in training data.

Next, more attention should have been paid to evaluation metrics selection. First, FDD usually corresponds to imbalanced data. If for instance, 10% of records in data correspond to faults, then a constant model outputting 'no-fault' would achieve 90% accuracy. Unfortunately, I am missing a report of the reasonable accuracy range for each experiment (i.e. 90%-100%). But more importantly, false positives and false negatives have different costs. E.g., classifier A misclassifies 10 broken AHU's as functioning, and classifier B misclassified 10 fully functioning AHU's as broken ones. Both classifiers have the same accuracy, however, the classifier A would lead to overlooked faults and the classifier B would lead to unnecessary service worker truck rolls. Metrics which enable considering different costs of different mistake types would be more suitable for the studied HVAC FDD problem.

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Formal and language level, scope of thesis	**B - very good.**
Are formalisms and notations used properly? Is the thesis organized in a logical way? Is the thesis sufficiently extensive? Is the thesis well-presented? Is the language clear and understandable? Is the English satisfactory?	
The thesis is written in good English, explanations are clear and understandable. The thesis is organized in a logical order except for the last page in the second chapter. The page is about Decision trees and logically should belong to the following chapter dedicated to the decision trees.	

Selection of sources, citation correctness	**C - good.**
Does the thesis make adequate reference to earlier work on the topic? Was the selection of sources adequate? Is the student's original work clearly distinguished from earlier work in the field? Do the bibliographic citations meet the standards?	
I would appreciate the addition of the coverage of related work, as tree-based models have been applied to the HVAC FDD problem before, including not covered ensembles of decision trees based on gradient boosting. The author focuses a lot on explainability of the developed models. And machine learning explainability has been an active area of research. I would appreciate prior work on ML explainability (not specific to decision trees) being covered and checked alongside the performed analysis.	

III. OVERALL EVALUATION, QUESTIONS FOR THE PRESENTATION AND DEFENSE OF THE THESIS, SUGGESTED GRADE

Questions:

1. *What training/validation split would you suggest to derive better estimation of out-of-sample performance? In which cases stratified random sampling of devices is required in addition to time-based training/validation split?*
2. *Which classification metrics would you consider to be a better alternative to accuracy for HVAC FDD? Could you please explain either F1 score or ROC-AUC in detail.*
3. *Regarding machine learning explainability techniques which are not decision-tree specific, could you please explain either SHAP or LIME values?*

The grade that I award for the thesis is **C - good.**

Date: **15.6.2020** Signature: