Slovak University of Technology in Bratislava
Faculty of Informatics and Information Technologies

FIIT-xxxx-xxxxxx

Bc. Miroslav Hájek

Machinery vibrodiagnostics with the industrial internet of things

Master's Thesis

Thesis Supervisor: Ing. Marcel Baláž, PhD.

May 2023

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Study programme:	Intelligent Software Systems
Study field:	Informatics
Training workplace:	Institute of Computer Engineering and Applied Informatics
Thesis supervisor:	Ing. Marcel Baláž, PhD.
Departmental advisor:	Ing. Jakub Findura
Consultant:	Ing. Lukáš Doubravský

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SLOVENSKÁ TECHNICKÁ
UNIVERZITA V BRATISLAVE
FAKULTA INFORMATIKY
A INFORMAČNÝCH TECHNOLÓGIÍ

Návrh zadania diplomovej práce

Finálna verzia do diplomovej práce [1]

Študent:

Meno, priezvisko, tituly:	Miroslav Hájek, Bc.
Študijný program:	Inteligentné softvérové systémy
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Výskumník:

Meno, priezvisko, tituly:	Marcel Baláž, Ing. PhD.

Projekt:

Názov:	Vibrodiagnostika strojov s priemyselným internetom vecí
Názov v angličtine:	Machinery vibrodiagnostics with the industrial internet of things
Miesto vypracovania:	Ústav počítačového inžinierstva a aplikovanej informatiky, FIIT STU, Bratislava
Oblasť problematiky:	Internet vecí, Spracovanie signálov, Feature engineering

Text návrhu zadania[2]

Monitorovanie prevádzkového stavu rotačných strojov za účelom včasného odhalenia poškodení je dôležité pre plynulý priebeh priemyselných procesov bez náhleho zlyhania kľúčového technického vybavenia. Nadmerné vibrácie alebo graduálna či náhla zmena ich charakteru sú spoľahlivými indikátormi opotrebenia dielcov. V mnohých prípadoch bývajú zavedené iba pravidelné pôchodzkové merania s následným vyhodnotením časových a frekvenčných priebehov kvalifikovaným personálom. Kontinuálna diagnostika a prediktívna údržba rozširujúca sa so zariadeniami IIoT spôsobuje enormný nárast objemu zaznamenaných dát. Sledovanie výchyliek operátorom a manuálna identifikácia súčiastok vyžadujúcich údržbu v celom závode sa tak stáva prakticky nerealizovateľná.

Preskúmajte spôsoby zisťovania bežných poškodení strojov z vibračných signálov a analyzujte algoritmy na redukciu množstva posielaných dát zo senzorov vzhľadom na osobitosti aplikačnej domény. Navrhnite reprezentáciu údajov na základe typických čŕt signálu, ktorá zníži výpočtové nároky na zvyšok komunikačného reťazca. Zvolený spôsob predspracovania má zároveň umožniť diagnostiku poškodení zvoleného stroja. Implementuje vaše riešenie s ohľadom na možné nasadenie na prostriedkami limitovanú senzorovú jednotku. Následne posúďte efektívnosť, porovnajte dosiahnuté presnosti diagnostiky a verifikujte voči zaužívaným postupom.

[1] Vytlačiť obojstranne na jeden list papiera

[2] 150-200 slov (1200-1700 znakov), ktoré opisujú výskumný problém v kontexte súčasného stavu vrátane motivácie a smerov riešenia

Literatúra[3]

- NANDI, Asoke Kumar; AHMED, Hosameldin. Condition monitoring with vibration signals: compressive sampling and learning algorithms for rotating machines. Hoboken, NJ, USA: Wiley-IEEE Press, 2019. ISBN 978-1-119-54462-3.
- YU, Gang. A Concentrated Time–Frequency Analysis Tool for Bearing Fault Diagnosis. IEEE Transactions on Instrumentation and Measurement. 2020, vol. 69, no. 2, pp. 371–381. ISSN 1557-9662. DOI: 10.1109/TIM.2019.2901514. Conference Name: IEEE Transactions on Instrumentation and Measurement.

Vyššie je uvedený návrh diplomového projektu, ktorý vypracoval(a) Bc. Miroslav Hájek, konzultoval(a) a osvojil(a) si ho Ing. Marcel Baláž, PhD. a súhlasí, že bude takýto projekt viesť v prípade, že bude pridelený tomuto študentovi.

V Bratislave dňa 22.2.2023

Podpis študenta   Podpis výskumníka

Vyjadrenie garanta predmetov Diplomový projekt I, II, III

Návrh zadania schválený: áno / nie[4]

Dňa: ....

Podpis garanta predmetov

[3] 2 vedecké zdroje, každý v samostatnej rubrike a s údajmi zodpovedajúcimi bibliografickým odkazom podľa normy STN ISO 690, ktoré sa viažu k téme zadania a preukazujú výskumnú povahu problému a jeho aktuálnosť (uveďte všetky potrebné údaje na identifikáciu zdroja, pričom uprednostnite vedecké príspevky v časopisoch a medzinárodných konferenciách)

[4] Nehodiace sa prečiarknite

Declation of Honour

I hereby declare on my honour that I wrote this thesis independently under supervision of Dr. Marcel Baláž, after consultations and with use of cited literature.

Bratislava, May 2023 ....

Bc. Miroslav Hájek

Acknowledgement

Annotation

Slovak University of Technology in Bratislava
Faculty of Informatics and Information Technologies

Degree course: Intelligent Software Systems

Author: Bc. Miroslav Hájek

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Anotácia

Slovenská technická univerzita v Bratislave

Fakulta informatiky a informačných technológií

Študijný program:	Inteligentné softvérové systémy
Autor:	Bc. Miroslav Hájek
Diplomová práca:	Vibrodiagnostika strojov s priemyselným internetom vecí
Vedúci diplomovej práce:	Ing. Marcel Baláž, PhD.

Máj 2022

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1 Introduction

Following is very coarse draft! Manufacturing is experiencing a shift in the traditional asset operational status evaluation and utilization. The goal is to promote safety and production efficiency when the useful life of machine moving parts is extended. In the factories and logistics where this sort of equipment is vital, there is a trend to be able to monitor the health of the machinery parts and above that to diagnose the fault in time to repair it without additional costs. Vibrations are the most nonintrusive way where such faults can be sensed and appear distinctly for an analyst to identify the root cause of the malfunction.

In critical circumstances, such measurements are already in place in some form, but in order to reach wider acceptance, and not remain just a quirk/trend system has to be sufficiently independent, reliable, and as self-sufficient as the model design allows it to be.

The thesis is structured in a following manner. In Chapter 1 we explore the theoretical (analytical) model view, mechanical maintenance approaches, and industry standards where common fault identification is described. Chapter 2 is all about taking vibration measurements (procuring) and transforming them into features meaningful in automatic fault pattern recognition. The methods for ranking are reviewed to obtain the most important and correlated features with machine health status. We delve into modes of diagnosis based on reduced relevant indicators in chapter 3. Chapter 4 takes a look into IoT communication infrastructure limiting the data throughput and devices that can be deployed (accommodate) in the factory environment. Chapter 5 defines measurement vectors and proposes processing steps to diagnose the reoccurring failure, RUL (remaining useful life), and fault types. The approach taken is evaluated and deployed in Chapter 6.

2 Problem analysis

2.1 Condition monitoring

Why monitor with vibrations, Wear process curve, Fault - failure, Levels are dependant on load and lifecycle stage

2.1.1 Maintenance strategies

Reactive

Preventive

Predictive - value for the factory and assess risks asociated with potencial fault to assign them importance

Diagnosis indicators - what we montitor? - when it fails and early signs of faulty component - RUL (Remaining useful life) models - disadvantage lot of similiar machines (homogenous) or lots of runns until failure

- Similarity
- Degradation - used by standards
- Survival

2.1.2 Vibration fault types

- frequency ranges 1 - 300 Hz (shaft), 300 - 1000 Hz, 1000 - 10000 Hz (early bearings) - Base analytical models: Jeffcott rotor - rotor dynamics, Bearnings model - Resonance frequencies of each part - machine must run at speeds not aligned with resonance frequencies - Campbell diagram - task for mechanical engineers - Faults - reasons and frequency content

- Synchrounous response - based on RPM
- Mass unbalance
- Misalignment
- Eccentricity
- Bent or bow shaft
- Cracked shaft
- Rotor rubs - friction
- Looseness
- Auxiliery mechanical systems: Gearbox, Bearings, Belt

2.1.3 Technical standards

ISO 20816 Part 1

- Measurement units - displacement, velocity, acceleration
- RMS, and max. amplitude = severity
- Measurement points for sensors (axial, radial) - image, and 45 degrees
- Evaluation zones - A, B, C, D - Severity chart (Annex B) - Degradation model
- Opeartional limits - Alarm, Trips

ISO 13373

- Sensor mount type in relation to sensor resonance
- Data presentation - standard display formats for analysis - trends, watefall plots ...
- Potencial causes for faults (p. 45) - use in vibration fault types

2.2 Feature engineering

Large domain knowledge with compared to other areas of machine learning (mechanics - physics)

2.2.1 Preprocessing

- Detrending - DC removal filter
- Denoising
  - Gaussian smoothing filter
  - Adaptive FIR filter with LMS algorithm
  - Wavelet thresholding with coif2 or db2
- Time synchronous averagings

2.2.2 Feature extraction

Statistical measures

- Standard Deviation
- Max. amplitude
- RMS amplitude
- Skewness
- Kurtosis

  —

- Spectral centroid
- RMS frequency
- Root variance frequency
- Spectral kurtosis / Fast kurtogram

- Harmonic spectral deviation

  —

- Energy

- Spectral negentropy

- TKEO - Teager-Kaiser energy operator

Signal decompositions - sparse approximations Matching pursuit algorithm optimalization problem

- FFT - Short Time Fourier Transform with Hamming window and Welch averaging

- CWT-SST - Synchrosqueezing Wavelet Transform (vs. Transient-extracting transform)

- EEMD - Ensemble Empirical Mode Decomposition - to IMF - mode mixing problem

- WPD - Wavelet Packet Decomposition - to approximation and detail coef. (Fejer-Korovkin wavelet)

- EWT - Empirical Wavelet Transform - (Meyer wavelet)

2.2.3 Feature transformation

- Principal Component Analysis (PCA)

- Log transformation (Box-Cox Transform) to normal distribution

- Normalization (min-max, standardize)

2.2.4 Feature selection

Filter method - SelectKBest in evaluation phase

- Variance Threshold

- Pearson correlation

- ANOVA F-value
- Mutal information
- Fisher score
- Spectral feature selection algorithm (SPEC)

2.3 Diagnostics techniques

Idenification of faulty states in data streams in semi-supervised learning

2.3.1 Novelty detection

- DenStream (Density based clustering - DBSCAN)
- Half-space Trees (Isolation forest)

2.3.2 Classification

- kNN + Metric Tree (M-Tree for neighbourhood queries) + Mahalanobis distance / Cosine similarity
- Naive Bayes + Count-min sketch
- Label propagation (Temporal label propagation, LabelRankT) - RBF similarity

2.4 Evaluation Datasets

MAFAULDA

CWRU

2.5 Sensor and microcontroller

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Appendix A: Resume

Appendix B: Plan of work

B.1 Winter semester

Period	**Work**
1^{st} week	Consultation with the supervisor on directions of the future work based on literature review during previous semester.
2^{nd} week	Outline the key sections of the analysis part in the thesis.
3^{rd} week	Match supporting literature with analysis sections. Further invesigation on the feature engineering methodology in condition monitoring.
4^{th} week	Summarize notes from condition monitoring articles and video-recordings of tutorials and conferences.
5^{th} week	Research transformation of vibration signal to feature space using time-frequency, harmonic and energy statistical metrics. Progress report meeting with the supervisor.
6^{th} week	Find articles and take notes about unsupervised and semi-supervised techniques in streaming data for machinery diagnostics, in order to gather information about suitable features.
7^{th} week	TBD (Narrow down wide variety applicable methods for signal decomposition)
8^{th} week	TBD (Write thesis section on condition monitoring and machinery fault types)

B.2 Summer semester

Appendix C: Digital medium

Evidenčné číslo práce v informačnom systéme: FIIT-xxxx-xxxxxx

Obsah digitálnej časti práce (archív ZIP):

Názov odovzdaného archívu: