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

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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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Master's Thesis

Study programme:	Intelligent Software Systems
Study field:	Informatics
Training workplace:	Institute of Computer Engineering and Applied Informatics
Thesis supervisor:	Ing. Marcel Baláž, PhD.
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Návrh zadania diplomovej práce

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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

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Annotation

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Anotácia

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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 Physics of rotating machines

2.1.1 Vibration fault types

There are a few methods of machinery fault identification in vibrational signals based on domain expertise. Data points can be viewed in the time domain and frequency domain. Either as individual stationary profiles obtained during the short duration in the time of measurement, or multiple spaced-out observations with the intent to highlight the long-term trend, e.g. shown in a waterfall plot [1]. The descriptor variable can be any meaningful statistical quantity, e.g. peak-to-peak, RMS, crest factor, kurtosis, which can be applied to recorded samples or frequency bands.

Mechanical faults manifest themselves in the vibration signal at various frequencies. In the low-frequency range (up to 1 kHz) shaft's unbalance, misalignment, bend, crack, and mechanical looseness is present. High frequencies (up to 16 kHz or more) contain bearings faults and gear faults.

Under fault-free circumstances, shaft speed appears as the strongest frequency component. In case of shaft and gear imbalance or damage, synchronous multiples of shaft frequency (harmonics) are amplified. When rub, bad drive belts and chains, or looseness is occurring in the machine then sub-synchronous harmonics or even non-synchronous frequencies appear [2]. Therefore it is useful to rescale the horizontal axis to RPM or orders of rotational speed. Complementary methods of fault symptom identification are phase and orbital analysis [3].

2.1.2 Band saw anatomy

2.2 Condition monitoring

2.2.1 Maintenance strategies

2.2.2 Technical standards

The maintenance procedure usually involves data acquisition cards inside handheld devices with accelerometer sensor probes then mounted firmly to the machine frame by either screwing in, magnets or wax [1]. The probe placement in axial and perpendicular radial directions is standardized in ISO 20816. The severity of vibrations is mostly assessed in units of velocity (mm/s), but acceleration (m/s^2) and displacement (μm) are also used. Based on the observed vibration intensity and one of the four classes of machines (I, II, III, IV) by output power and size, zones (A, B, C, D) for accepted levels are proposed. It is customary to establish operational limits in the form of alarms and trips [**iso_20816**].

Standard ISO 13373 categorizes three types of vibration monitoring systems: permanent, semi-permanent, and mobile. More importantly, a structured diagnostic approach is developed here complete with recommendations for formalizing diagnostic techniques [**iso_13373**]. The next step is the signal analysis with the use of proper units and transformations is the subject of the ISO 18431 [**iso_18431**].

2.2.3 Sensor placement

2.3 Feature engineering

Feature selection vs. extraction

2.3.1 Signal denoising and filtering

Blind source separation, PCA, ICA

2.3.2 Time-frequency features

Time Synchronous Averaging of Real FFT vs. FastCWT - Synchrosqueezing

2.3.3 Harmonics identification

Cepstrum + Harmonic Product Spectrum + Peak identification

2.3.4 Feature importance ranking

2.4 Semi-supervised learning in diagnostics

Label propagation

2.4.1 Clustering techniques

BIRCH, DBSCAN, SVM

2.4.2 Sketch streaming algorithms

2.5 IoT in Industry 4.0

2.5.1 Microcontrollers

2.5.2 Wireless protocols

Cite [**sample**].

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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. Meeting schedule is established.
2^{nd} week	Outline of key sections of the analysis part of the thesis.
3^{rd} week	Match supporting literature with analysis sections. Further invesigation on the feature engineering in condition monitoring.
4^{th} week	TBD (Descibe machinery physics and maintanance strategies.)

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: