

A vertical stack of five horizontal bars in red, green, blue, orange, and green from top to bottom.

## Sensors, Testing and Measurement





22. Juni 2022

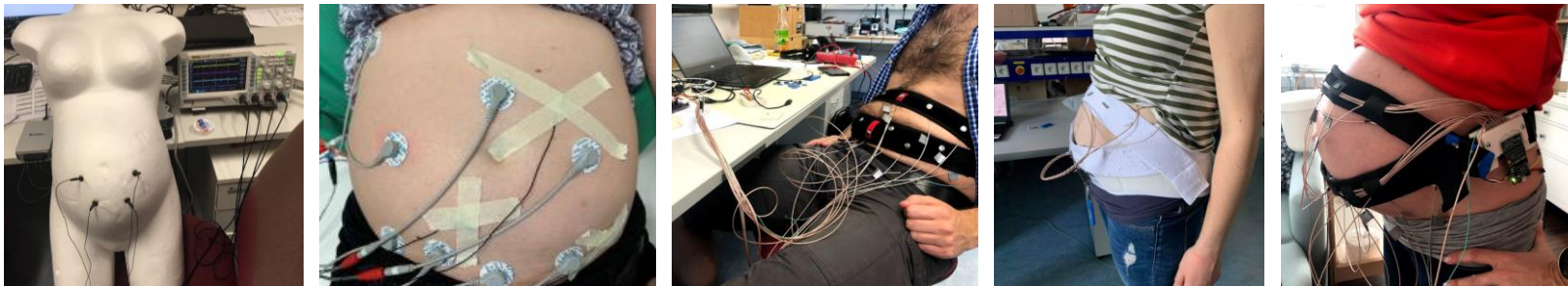
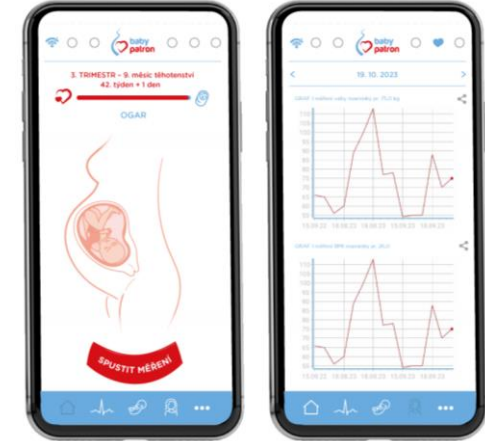
Radek Martinek & Petr Bilík, VSB - Technical University of Ostrava

5<sup>th</sup> WORKSHOP Forming and Punching

# Projects

## A Comprehensive System for the Development of the Field of Non-Invasive Fetal ECG Monitoring

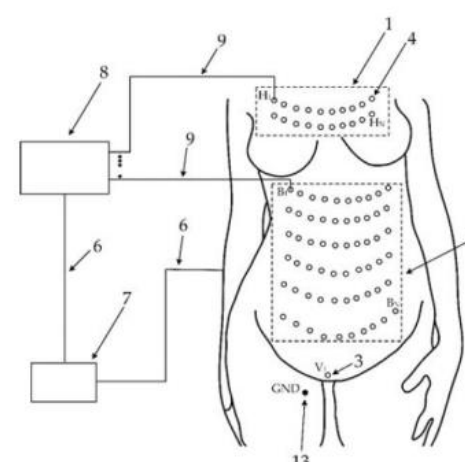
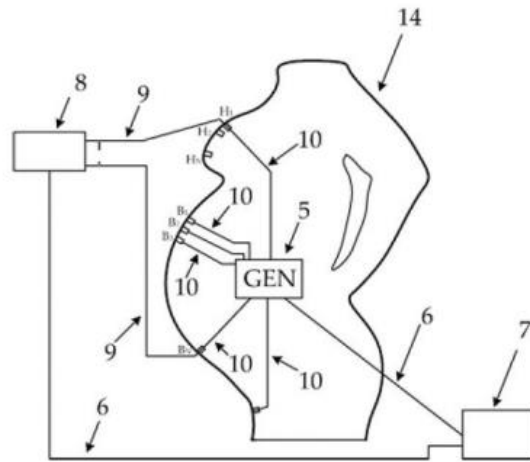
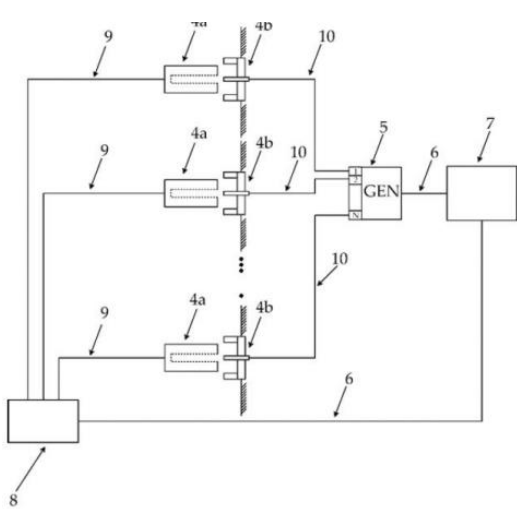
-  TREND - Technology Agency of the Czech Republic
-  1 million EUR
-  2021–2024
-  Non-Invasive Fetal ECG Home Monitor



# Application Outputs

## A Comprehensive System for the Development of the Field of Non-Invasive Fetal ECG Monitoring

- Patent PV 2016-518 307183, A device for monitoring vital functions of a pregnant woman's fetus
- Patent PV 2019-240 308074, Phantom for continuous generation of foetal and maternal electrocardiogram



**PATENTOVÝ SPIS**

(11) Číslo dokumentu: **308 074**

(13) Druh dokumentu: **B6**

(15) ČESKÁ REPUBLIKA

(21) Číslo přihlášky: **2019-240**

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(40) Zveřejněno: **11.12.2019**

(Věstník č. 50/2019)

(47) Uzávěrka: **30.10.2019**

(24) Ochranná lhůta: **11.12.2019**

(Věstník č. 50/2019)

OBAD PŘEMYSLOVÉHO VLASTNICTVÍ

(56) Kvalifikační dokumenty: Oborník, R., et al. Physiol. Mon. 37 (2004) 238 - 256. 13.10.03 (37:099 A).

(73) Místní pobočka: Vysoká škola báňská - Technická univerzita Ostrava, Ostrava, Poruba, CZ

(72) Přidružení: doc. Ing. Radek Martiněk, Ph.D., Nedbálův, CZ; Ing. Jan Nedoma, Ph.D., Koutelba na hlásku, CZ; Ing. Jakub Kolář, Ostrava, Moravská Ostrava, CZ; Ing. Lukáš Souček, Karvina, Říš, CZ; Ing. Jiří Babiš, Ph.D., Ostrava, CZ; Ing. Radana Kahánková, Háj ve Slezsku, Chabotov, CZ

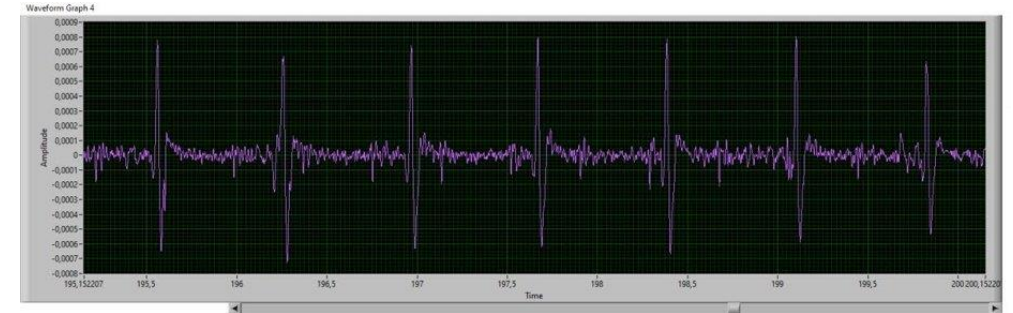
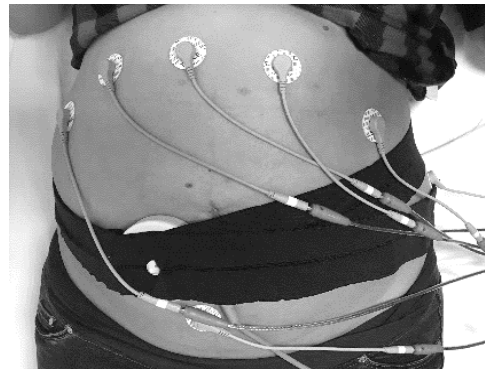
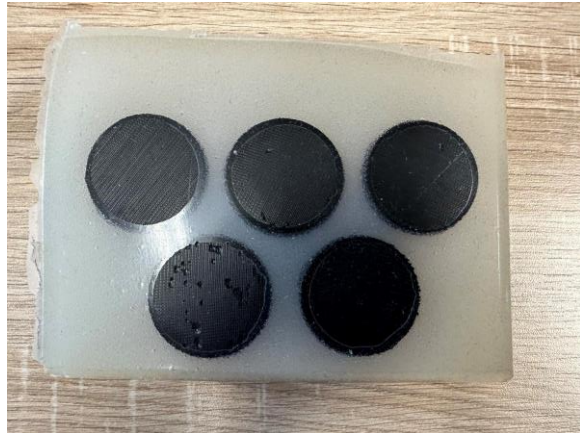
(54) Název vynálezu: **Fantom pro kontinuální generování fetálního a mateřského elektrocardiogramu**

(57) Anotace: Vynález se týká oblasti elektrocardiografie. Zařízení popsané v této přihlášce je známo pod pojmem „fantom“. Jedná se tedy o fantom pro kontinuální měření fetálního a mateřského elektrocardiogramu, který přebírá tvar torza (14) gravida. Je to sestava, která se nachází v oblasti hrudníku a generátorem (5) umělečného srdce. Plocha torza (14) je rozdělena do oblastí pro měření, kterými jsou hrudní oblast (1), břichová oblast (2) a vaginální oblast (3) přičemž existují kabely (10) a desky torza (14) sítě na povrchu torza (1, 2, 3) v podobě elektrických konektorů (4b) pro napojení měřících (4a) konektorů měřícího systému (8) nebo přípravkové jednotky (11). Tyto oblasti (1, 2, 3) jsou propojeny s signálními jednotkami (7) pro zpracování a vysílání signálů z generátora (5) umělečného srdce. Připojení jsou realizována prostřednictvím kabelů (6, 9) nebo bezdrátově. Toto zařízení je určeno pro modelování a monitorování přirozeného elektrocardiogramu při výuce zdravotnického personálu.

**CZ 308074 B6**

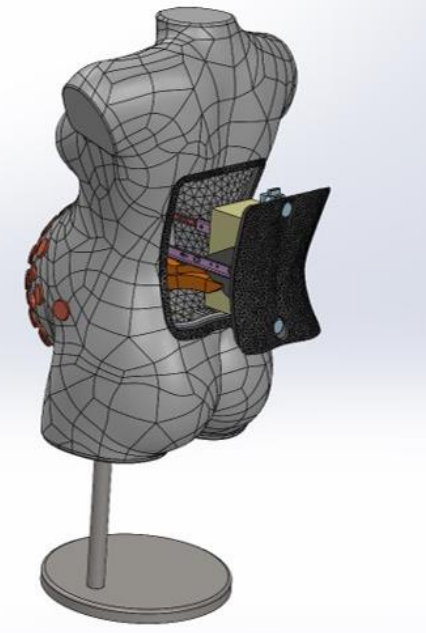
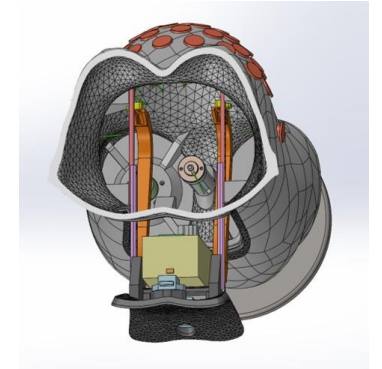
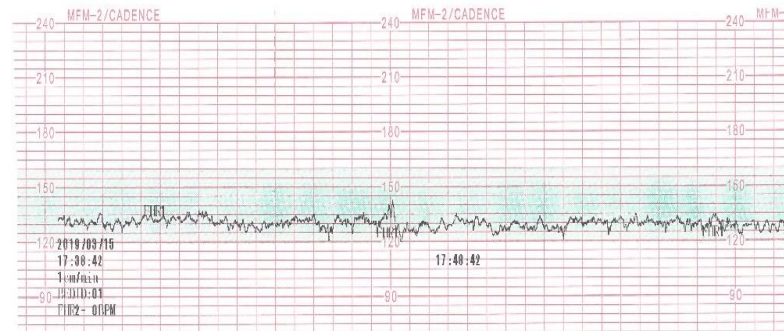
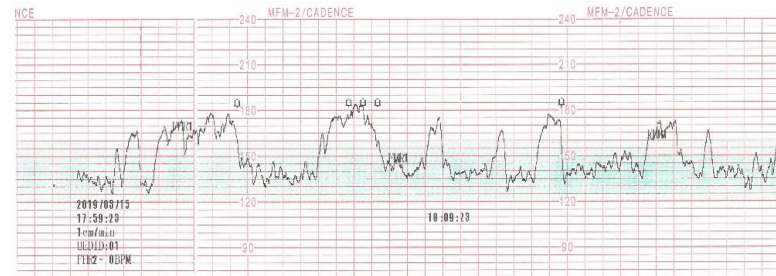
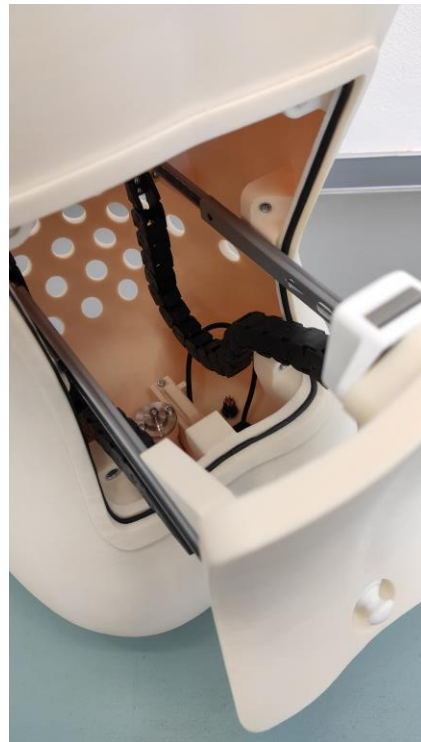
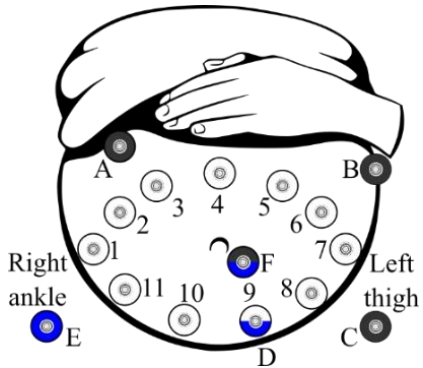
# Project Development

A Comprehensive System for the Development of the Field of Non-Invasive Fetal ECG Monitoring



# Project Development

A Comprehensive System for the Development of the Field of Non-Invasive Fetal ECG Monitoring



# Publication Outputs

## A Comprehensive System for the Development of the Field of Non-Invasive Fetal ECG Monitoring

Applied Soft Computing 113 (2021) 107940

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: [www.elsevier.com/locate/asc](http://www.elsevier.com/locate/asc)

### System for adaptive extraction of non-invasive fetal electrocardiogram

Katerina Barnova<sup>a</sup>, Radek Martinek<sup>a</sup>, Rene Jaros<sup>a</sup>, Radana Kahankova<sup>a,\*</sup>, Khosrow Behbehani<sup>b</sup>, Vaclav Snasel<sup>c</sup>

<sup>a</sup> Department of Cybernetics and Biomedical Engineering, Faculty of Electrical Engineering and Computer Science, VSB-Technical University of Ostrava, 708 00, Ostrava-Poruba, Czechia

<sup>b</sup> Department of Biomechanics, University of Texas at Arlington, Arlington, TX, USA

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IF=8.7

ARTICLE INFO

ABSTRACT

This study aimed to find the most suitable combination of adaptive and non-adaptive methods for extraction of non-invasive fetal electrocardiogram (NI-FECG) using signals recorded from the mother's abdomen. Among the nine methods considered, the combination of independent component analysis (ICA), fast transversal filter (FTF), and complementary ensemble empirical mode decomposition with adaptive noise (CEEMDAN) proved to be the most effective for the extraction of FECG from abdominal recordings. This combined method was suitable due to both being effective in extracting FECG and being less computationally complex. Further, so far, FTF and CEEMDAN methods have not been extensively tested for FECG extraction, and in particular, have not been examined as a hybrid method. The ICA-FTF-CEEMDAN hybrid algorithm was tested on two patient databases: Fetal Electrocardiograms, Direct and Abdominal with Reference Heartbeats Annotations (FECGDARHA) and PhysioNet Challenge 2013. The evaluation of the accuracy of QRS complexes detection was performed using the following parameters: accuracy (ACC), sensitivity (SE), positive predictive value (PPV), and F1 score. The fetal heart rate (FHR) determination accuracy was evaluated using Bland-Altman plots and FHR traces. When testing on the FECGDARHA database, average values of ACC = 92.98%, SE = 95.33%, PPV = 96.4% and F1 = 95.86% for detection QRS were achieved. The error in estimating the FHR was  $-1.02 \pm 7.02$  ( $\mu \pm 1.96\sigma$ ) bpm. When testing on the Challenge 2013 database, average values of ACC = 78.47%, SE = 82.06%, PPV = 87.90% and F1 = 84.62% for QRS detection were achieved, and the error in estimating the FHR was  $-6.62 \pm 10.33$  ( $\mu \pm 1.96\sigma$ ) bpm. In addition, a non-invasive morphological analysis (ST analysis) was performed on the records from the FECGDARHA database, which was accurate in 7 of 12 records with values of  $\mu < 0.03$  and values of  $\pm 1.96\sigma < 0.04$ .

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IEEE REVIEWS IN BIOMEDICAL ENGINEERING, VOL. 13, 2020

### A Review of Signal Processing Techniques for Non-Invasive Fetal Electrocardiography

Radana Kahankova, Radek Martinek<sup>a</sup>, Rene Jaros<sup>a</sup>, Khosrow Behbehani<sup>b</sup>, Adam Matonia<sup>c</sup>, Michal Jezewski<sup>d</sup>, and Joachim A. Behar

(Methodological Review)

IF=17.6

Abstract—Fetal electrocardiography (fECG) is a promising alternative to cardiocardiography continuous fetal monitoring. Robust extraction of the fetal signal from the abdominal mixture of maternal and fetal electrocardiograms presents the greatest challenge to effective fECG monitoring. This is mainly due to the low amplitude of the fetal versus maternal electrocardiogram and to the non-stationarity of the recorded signals. In this review, we highlight key developments in advanced signal processing algorithms for non-invasive fECG extraction and the available open access resources (databases and source code). In particular, we highlight the advantages and limitations of these algorithms as well as key parameters that must be set to ensure their optimal performance. Improving or combining the current or developing new advanced signal processing methods may enable morphological analysis of the fetal electrocardiogram, which today is only possible using the invasive scalp electrocardiography method.

Index Terms—Fetal electrocardiography, noninvasive fetal (NI-FECG) monitoring, signal processing, electronic fetal monitoring, fetal heart rate, morphological analysis.

I. INTRODUCTION

FETAL heart rate (FHR) monitoring in its early form was based on the auscultation methods, i.e. intermittent observations of the fetal heart sounds [1]. Progress in electronics and computers science brought to the introduction of the

Almost simultaneous to the development of fetal electrocardiography (fECG), the ultrasonic fetal cardiocardiography (CTG), a non-invasive method for simultaneous monitoring of FHR and uterine contractions was introduced [11]. The popularity of this noninvasive method grew as it was accepted by the medical community throughout the 1960s with the first commercially available model (Hewlett-Packard 8020A) introduced into delivery rooms in 1968 [12]. Some practitioners noted the virtual disappearance of fetal death in labor following its introduction [13]. However, despite great expectations, application of CTG in clinical practice did not result in a rapid reduction of undiagnosed fetal hypoxia or a decrease in the incidence of cerebral palsy [14], [15]. This may be attributed to the fact that the first monitors were rather unreliable and suffered from considerable inter- and intra-observer disagreement since the data were difficult to interpret [16].

Additionally, in late 1970s and 1980s, several studies [17]–[23] suggested that CTG was one of the factors responsible for the significant rise of Cesarean section (C-Section) rates. However, some authors have pointed out that introduction of the CTG is only one of the factors causing this rise [24], [25]. Other suggested causes [24], [25] were new obstetrical methodologies

<sup>a</sup> In English-speaking countries, particularly in the United States, the term used instead of CTG is electronic fetal monitoring (EFM), the name given in the 1960s to describe this new technology. However, nowadays use of this term may be misleading. Therefore in 2015, the consensus promoted by the International Federation of Gynecology and Obstetrics agreed that cardiography is the term that best describes this monitoring technique. In this paper, the term FFM will only be used for the electronic fetal monitoring in general.

www.nature.com/scientificreports

scientific reports

IF=4.6





OPEN Nature inspired method for noninvasive fetal ECG extraction

Akshaya Raj<sup>1</sup>, Jindrich Brablik<sup>1</sup>, Radana Kahankova<sup>1,2,3</sup>, Rene Jaros<sup>1</sup>, Katerina Barnova<sup>1</sup>, Vaclav Snasel<sup>2</sup>, Seyedali Mirjalili<sup>3</sup> & Radek Martinek<sup>1</sup>

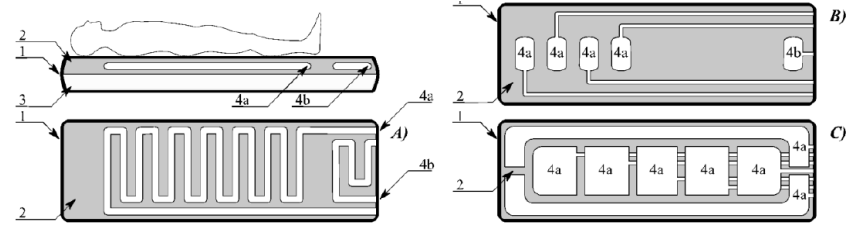
This paper introduces a novel algorithm for effective and accurate extraction of non-invasive fetal electrocardiogram (NI-FECG). In NI-FECG based monitoring, the useful signal is measured along with other signals generated by the pregnant women's body, especially maternal electrocardiogram (MECG). These signals are more distinct in magnitude and overlap in time and frequency domains, making the fECG extraction extremely challenging. The proposed extraction method combines the Grey wolf algorithm (GWO) with sequential analysis (SA). This innovative combination, forming the GWO-SA method, optimises the parameters required to create a template that matches the MECG, which leads to an accurate elimination of the said signal from the input composite signal. The extraction system was tested on two databases consisting of real signals, namely, Labour and Pregnancy. The databases used to test the algorithms are available on a server at the generalist repositories (figshare) integrated with Matonia et al. (Sci Data 7(1):1–14, 2020). The results show that the proposed method extracts the fetal ECG signal with an outstanding efficacy. The efficacy of the results was evaluated based on accurate detection of the QRS complexes. The parameters used to evaluate are as follows: accuracy (ACC), sensitivity (SE), positive predictive value (PPV), and F1 score. Due to the stochastic nature of the GWO algorithm, ten individual runs were performed for each record in the two databases to assure stability as well as repeatability. Using these parameters, for the Labour dataset, we achieved an average ACC of 94.60%, F1 of 96.82%, SE of 97.49%, and PPV of 98.96%. For the Pregnancy database, we achieved an average ACC of 95.66%, F1 of 97.44%, SE of 98.07%, and PPV of 97.44%. The obtained results show that the fHR related parameters were determined accurately for most of the records, outperforming the other state-of-the-art approaches. The poorer quality of certain signals have caused deviation from the estimated fHR for certain records in the databases. The proposed algorithm is compared with certain well established algorithms, and has proven to be accurate in its fECG extractions.

# Projects

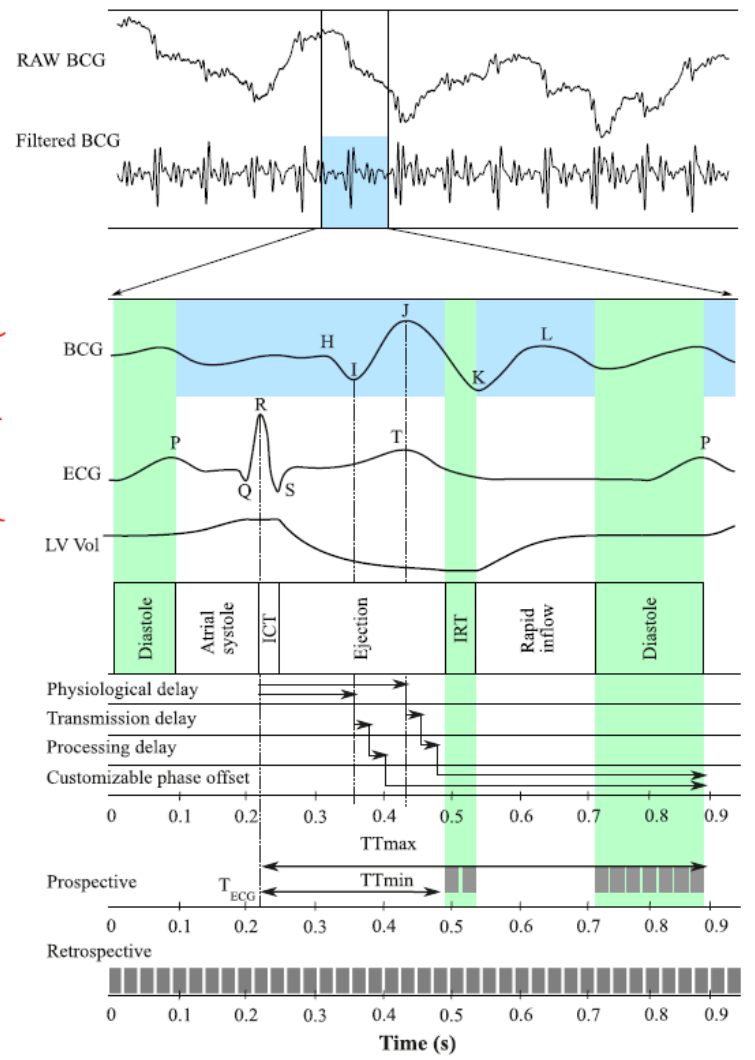
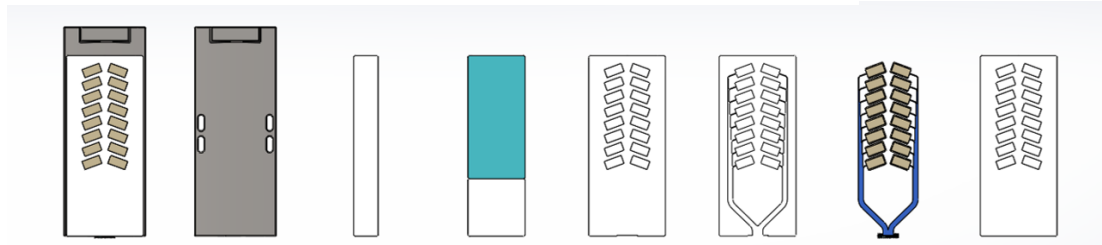
## Development of a Complex Sensory System for Effective MRI Control

-  APLIKACE – VÝZVA VII - Ministry of Industry and Trade
-  1.2 million EUR
-  2020–2022
-  Measurement pad for Cardiac and Respiratory Monitoring

First concept

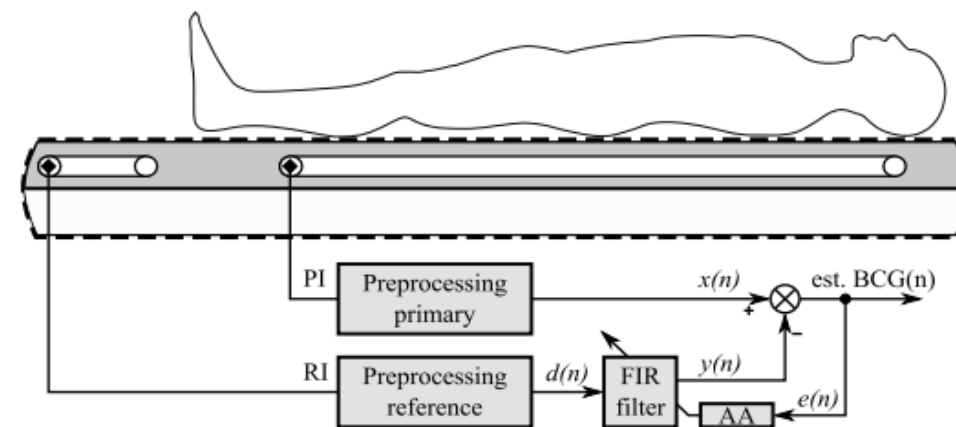
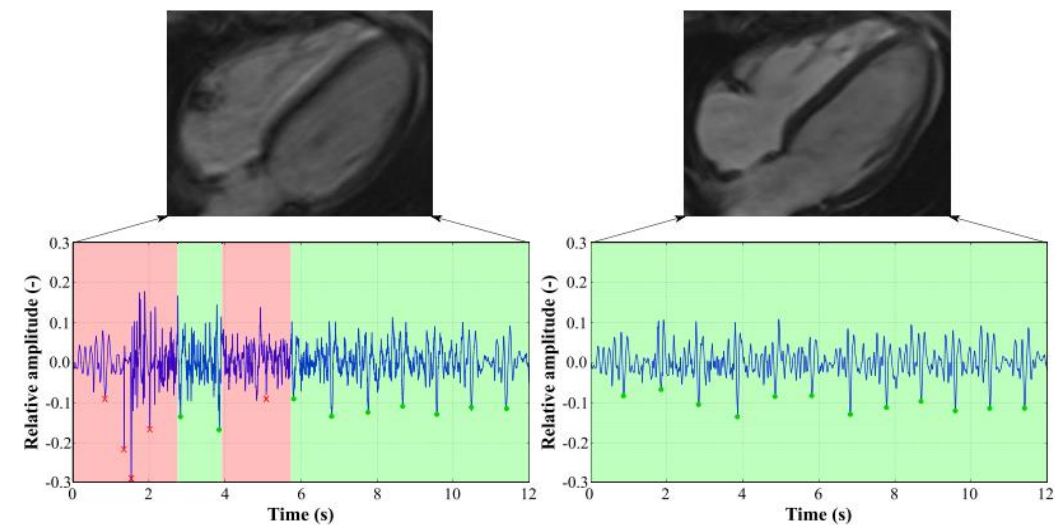


Final design



# Project Development

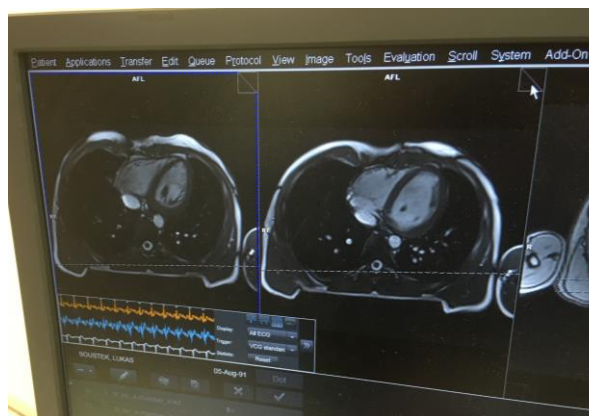
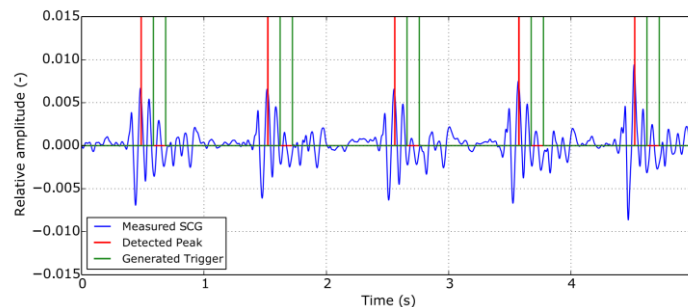
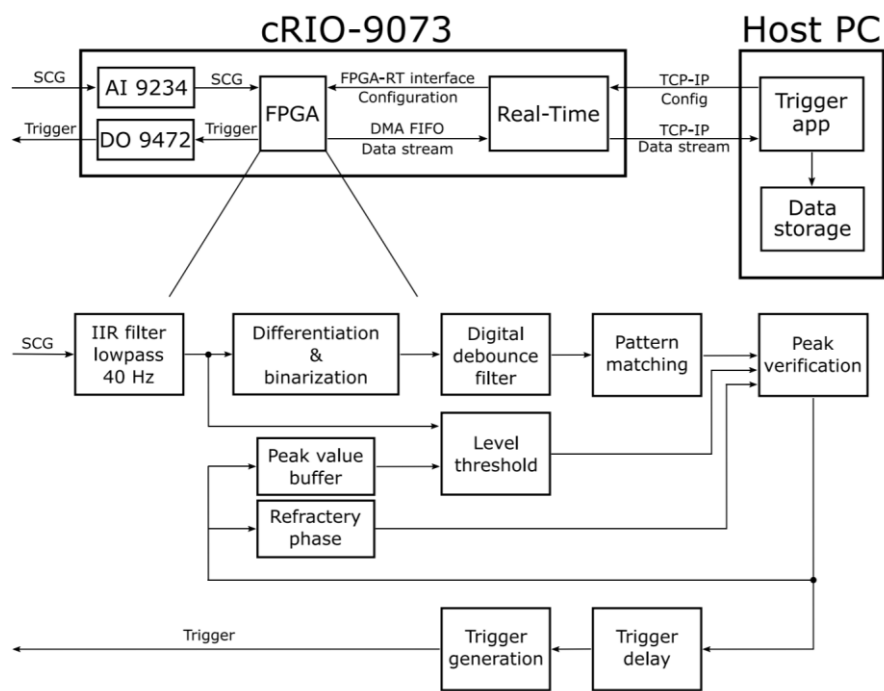
## Development of a Complex Sensory System for Effective MRI Control





# Project Development

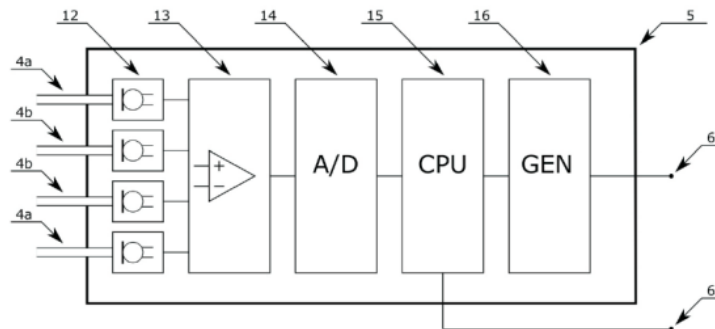
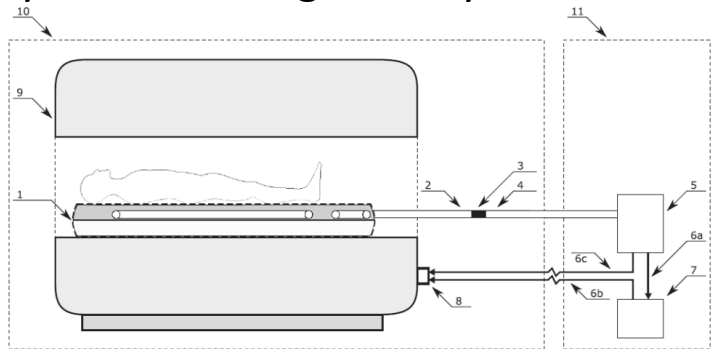
## Development of a Complex Sensory System for Effective MRI Control


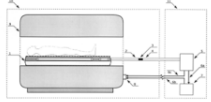


# Application Outputs

## Development of a Complex Sensory System for Effective MRI Control

- P** Patent PV 2019-762 08705, System for monitoring cardiorespiratory activities of the human body not only in magnetic resonance environments reducing the required length of examination
- P** Patent PV 2019-93 308261, System for monitoring cardiorespiratory activities of the human body in magnetic resonance environments
- P** Patent PV 2018-265 307778, Sensor for monitoring the vital functions of the human body in electromagnetically disturbed environments and how to produce it



<p><b>PŘÍHLÁŠKA VYNÁLEZU</b> Zveřejněná podle §31 zákona č. 527/1990 Sb.</p>		<p>(21) Číslo dokumentu: <b>2019-762</b></p> <p>(13) Druh dokumentu: <b>A3</b></p> <p>(51) Int. CL.: <b>A61B 5/11</b> (2006.01)</p>
<p>(19) ČESKÁ REPUBLIKA</p>  <p>ÚŘAD PRŮMYSLového VLASTNICTVÍ</p>	<p>(22) Přihlášeno: <b>10.12.2019</b></p> <p>(40) Datum zveřejnění přihlášky vynálezu: <b>10.03.2021</b> (Věstník č. 10/2021)</p>	
<p>(71) Přihlášovatel: Vysoká škola báňská-Technická univerzita Ostrava, Ostrava, Poruba, CZ Ostravská univerzita, Ostrava, Moravská Ostrava, CZ</p>		<p>laborator. JIP (jednotka intenzivní péče), lůžka pro dlouhodobě nemocné, hospici ale také monitoring novorozenců.</p>
<p>(72) Původce: doc. Ing. Radek Martinek, Ph.D., Nedvědice, CZ Ing. Jakub Kolařík, Ostrava, Moravská Ostrava, CZ Ing. Jindřich Bráhlík, Ph.D., Ostravice, CZ Ing. Jan Nedoma, Ph.D., Kostelec na Hané, CZ Ing. Radana Kahánková, Háj ve Slezsku, Chabíčov, CZ doc. MUDr. Petr Krupa, CSc., Brno, Černá Pole, CZ Ing. Martina Láčtová, Ostrava, Poruba, CZ MUDr. Pavla Hanzlíková, Ph.D., Děhylov, CZ Ing. Lukáš Šoustek, Karviná, Ráj, CZ</p>		
<p>(54) Název přihlášky vynálezu: <b>Systém pro monitorování kardiorepiračních aktivit lidského těla nejen v magneticky rezonančních prostředích snižující nutnou délku vyšetření</b></p>		
<p>(57) Anotace: Systém pro monitorování kardiorepiračních aktivit lidského těla nejen v magneticky rezonančních prostředích sestává z měřicího modulu (5) spojeného pneumatickým vedením (4) přes propojovací konektory (3) s nejméně jednou sadou pneumatického senzoru (2) společně s polstrovaním podložky (19), tvrdou podložkou (18) a podložkou pro tlumení vibrací (17) tvořící kompletní systém měřicí podložky (1). Systém slouží ke kontinuálnímu monitorování kardiorepiračních projevů aktivity lidského těla pomocí balistokardiografie. Hlavní účel jeho použití je zejména při vyšetření magnetickou rezonancí, ale lze jej využít pro monitorování v prostředí CT (počítačová tomografie), rentgen, spánková</p>		

# Publication Outputs

## Development of a Complex Sensory System for Effective MRI Control

LOGO GENERIC COLORIZED JOURNAL, VOL. XX, NO. XX, XXXX 2017

### A Comparison of Alternative Approaches to MR Cardiac Triggering: A Pilot Study at 3 Tesla

Jindrich Brablik, Martina Ladrova, Dominik Vilimek, Jakub Kolarik, Radana Kahankova, Pavla Hanzlikova, Jan Nedoma, Khosrow Behbehani, Marcol Fajkus, Lubomir Vojtisek, Radek Martinek

**Abstract**—This pilot comparative study evaluates the usability of the alternative approaches to magnetic resonance (MR) cardiac triggering based on ballistocardiography (BCG), fiberoptic sensor (FOS) and pneumatic sensor (P-BCG). The comparison includes both the objective and subjective assessment of the proposed sensors in comparison with a gold standard of ECG-based triggering. The objective evaluation included several image quality assessment (QA) parameters, whereas the subjective analysis was performed by 10 experts rating the diagnostic quality (scale 1 – 3, 1 corresponding to the best image quality and 3 the worst one). Moreover, for each examination, we provided the examination time and comfort rating (scale 1 – 3). The study was performed on 10 healthy subjects. All data were acquired on a 3 T SIEMENS MAGNETOM Prisma. In image quality analysis, all approaches reached comparable results, with ECG slightly outperforming the BCG-based methods, especially according to the objective metrics. The subjective evaluation proved the best quality of ECG (average score of 1.68) and higher performance of P-BCG (1.97) than O-BCG (2.03). In terms of the comfort rating and total examination time, the ECG method achieved the worst results, i.e. the highest score and the longest examination time: 2.4 and 19.0 min, respectively. The BCG-based alternatives achieved comparable results (P-BCG 1.35 and 8.06; O-BCG 1.9, 9.08). This study confirmed that the proposed BCG-based alternative approaches to MR cardiac triggering offer comparable quality of resulting images with the benefits of reduced examination time and increased patient comfort.

**Index Terms**—Alternative Sensors; Ballistocardiography; Fiberoptic Sensor; Magnetic Resonance Cardiac Triggering; Pneumatic Sensor.

**I. INTRODUCTION**

Cardiovascular magnetic resonance imaging (CMRI) is a significant imaging technique for evaluation of heart structure and function. This work was supported in part by the Ministry of Education of the Czech Republic under Project SP2022/18, in part by the European Regional Development Fund in the Research Centre of Advanced Mechatronic Systems Project within the Operational Programme Research, Development and Education under Project CZ.02.1.01/0.0/0.0/16.0/19/0:0/0067, in part by the Grant Programme Support for Science and Research in the Moravia-Silesia Region 2018 under Grant RHC102018, and in part by the MEYS CR (Czech-Biomed) to the Core Facility Multimodal and Functional Imaging Laboratory (MFL) of Central European Institute of Technology (CEITEC) under Grant LM201819.

R. Martinek, J. Brablik, M. Ladrova, D. Vilimek, J. Kolarik and R. Kahankova are with the Department of Cybernetics and Biomedical Engineering, and J. Nedoma and M. Fajkus are with the Department of Telecommunications, Faculty of Electrical Engineering and Computer Science, VSB-Technical University of Ostrava, 70103 Ostrava, Czech Republic (e-mail: radek.martinek@vsb.cz, jindrich.brablik@vsb.cz, martina.ladrova@vsb.cz, dominik.vilimek@vsb.cz, jakub.kolarik@vsb.cz, radana.kahankova@vsb.cz, jan.nedoma@vsb.cz, marcol.fajkus@vsb.cz).

K. Behbehani is with the Department of Bioengineering, University of Texas at Arlington, Arlington, TX 76019 USA (e-mail: kbe@uta.edu).

P. Hanzlikova is with the Department of Imaging Method, Faculty of Medicine, University of Ostrava, 70103 Ostrava, Czech Republic (e-mail: pavla.hanzlikova@osu.cz).

L. Vojtisek is with Central European Institute of Technology (CEITEC), Masaryk University 602 00 Brno, Czech Republic (e-mail: lubomir.vojtisek@ceitec.muni.cz).

Presently, the electrocardiogram (ECG) is usually used in clinical practice for cardiac triggering. As such, it is considered a gold standard in this purpose. Nevertheless, ECG sensing in the MR environment brings several challenges. Besides the common inconveniences associated with skin preparation and ECG electrodes

IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 71, 2022

### Fiber-Optic Cardiorespiratory Monitoring and Triggering in Magnetic Resonance Imaging

Martina Ladrova, Jan Nedoma, Senior Member, IEEE, Radek Martinek, Senior Member, IEEE, Khosrow Behbehani, Fellow, IEEE, and Radana Kahankova

**Abstract**—During the past decades, fiber-optic technology has become a very popular tool for vital signs monitoring. Thanks to its advantageous properties, such as noninvasiveness, biocompatibility, and resistance to electromagnetic interferences, this methodology started to be explored under the conditions of a magnetic resonance (MR) environment. This review article presents the motivation and possibilities of using fiber-optic sensors (FOSs) in MR environment and summarizes the studies dealing with experimental validation of their compatibility with MR. Several aspects of the presented issue are highlighted and discussed, such as suitability of the fiber-optic approach for MR triggering, precision of vital sign detection, development of sensor designs, and its application to patient's body. From the literature review, it can be concluded that FOSs have promising future in the field of cardiorespiratory monitoring in MR environment. This is mainly due to their advantages originating from sensing mechanical signals instead of electrical ones, which makes them resistant to MR interference and extrasystoles. Moreover, these sensors are easy to use, reusable, and suitable for combined monitoring. However, there are several shortcomings that should be solved in future research before introducing them to clinical practice, namely, signal's delay or optimal placement of sensors.

**Index Terms**—Cardiorespiratory monitoring, fiber-optic sensors (FOSs), magnetic resonance imaging (MRI), MRI triggering, vital sign monitoring.

**I. INTRODUCTION**

IN RECENT years, magnetic resonance imaging (MRI) has progressed significantly, as it now provides invaluable tissue composition, functional, and metabolic structure information. Simultaneously, advances in medical computing have enabled the advent of many advanced quantitative techniques

For enhanced disease diagnosis and administration of therapy. The development of magnetic field MR machines, nowadays reaching 7 T, is a rapid growing deployment in clinics have brought several challenges in MRI imaging. One such important and significant challenge is monitoring and compensating for movements resulting from patient's cardiorespiratory activity during imaging [1]. One such compensation method is timed-triggered imaging which is paramount for obtaining quality diagnostic information [2]. Such adjustments are even more essential for a relatively large percentage of patients who are noncooperative such as neonatal, pediatric, and mentally or critically ill patients [3]. However, the most commonly applied adjustment methods are adversely affected by high electromagnetic interference, acoustic noise, and vibration. These effects become even more prominent with the increase in the MRI's magnetic field strength [4], [5].

Fiber-optic sensors (FOSs) are advantageous to use in medical field, thanks to their noninvasive nature, biocompatibility, high sensitivity, small dimensions, and reduction of wires used. Since they are composed of dielectrics such as glass or plastics, the electrical isolation of the patient or elimination of voltage induction is not needed [6]–[9]. Moreover, their construction is characterized by high resistance to electromagnetic interference, which is suitable for making measurements in magnetic resonance (MR) environment [10], [11]. The FOSs use the changes in the light properties of the applied light (such as wavelength or frequency) due to cardiorespiratory or other physiological activities to detect the presence of such activities. Indeed, with this method resolution, heart rate (HR), blood composition, and body temperature can be monitored.

Previously, the role of FOSs in monitoring of cardiorespiratory activity and other vital signs and, particularly, their suitability for patient monitoring, including their integration into smart textile, have been reported [12]–[18]. This review article focuses on recent advances in monitoring of patient's cardiorespiratory activity during MRI with the option of MRI synchronization. This problem has been already outlined in our previous article [19] that provides a comprehensive summary of methods suitable for MRI gating and their comparison. In contrast, the focus of this article is more in-depth and only includes the overview of the sensors based on fiber optics that were successfully tested and validated in MR environment. It presents the application of various types of FOSs and discusses the finding of their latest experimental evaluations.

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### Monitoring and Synchronization of Cardiac and Respiratory Traces in Magnetic Resonance Imaging: A Review

Martina Ladrova, Radek Martinek, Jan Nedoma, Pavla Hanzlikova, Michael Douglas Nelson, Radana Kahankova, Jindrich Brablik, and Jakub Kolarik

(Methodological Review)

**Abstract**—Synchronization of human vital signs, namely the cardiac cycle and respiratory excursions, is necessary during magnetic resonance imaging of the cardiovascular system and the abdominal cavity to achieve optimal image quality with minimized artifacts. This review summarizes techniques currently available in clinical practice, as well as methods under development, outlines the benefits and disadvantages of each approach, and offers some unique solutions for consideration.

**Index Terms**—Magnetic resonance imaging (MRI), cardiac magnetic resonance imaging (CMRI), MRI triggering, cardiac triggering, respiratory triggering.

**I. INTRODUCTION**

MAGNETIC Resonance Imaging (MRI) is a powerful non-invasive tool for imaging human body structure and function. The main advantages of MRI include the absence of ionizing radiation, high contrast between different types of soft tissues, and its ability to image in arbitrary spatial orientations. In addition to providing high-resolution images of the body structure, MRI also provides novel pathophysiological insight into basic body functions (e.g., molecular water diffusion, tissue perfusion, or MR spectroscopy). Together, the information provided can help make more accurate diagnoses, and improves our ability to monitor treatment outcomes [1].

This review focuses on MRI applications that require vital sign synchronization, namely with the cardiac cycle and/or respiratory excursions. Indeed, triggering and gating devices and algorithms are necessary to ensure high image quality of regions within the chest and abdomen (e.g. heart, liver, pancreas). The task is to perform imaging during minimal movement of the heart and thorax, which causes motion artifacts, appearing as shadows or blurred contours on the image (referred to as "ghosting artifacts" see Fig. 1). Synchronization serves to suppress these artifacts but is not without several major challenges. In particular, synchronization of biological signals is limited by inherent high-frequency disturbances and extreme magnetic induction, which interferes with the measurement of vital signs, and ultimately compromises MRI sequence synchronization [2], [3].

**A. Abdominal MRI**

Abdominal MRI is widely used due to its ability to extract information at the level of tissue composition and to assess functional status, including the metabolic structure of the tissue. It allows clinicians to respond to tissue damage or dysfunction and to adapt the therapy or disease prevention strategy accordingly. Given the versatility of MRI, it can detect a plethora of abdominal disorders, such as steatosis, fibrosis, inflammation,

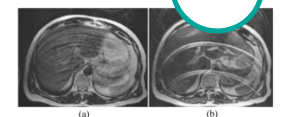



Fig. 1. Examples of MR motion artifacts: (a) blurring due to random respiratory motion and (b) ghosting artifacts caused by periodic breathing [3].

# Projects

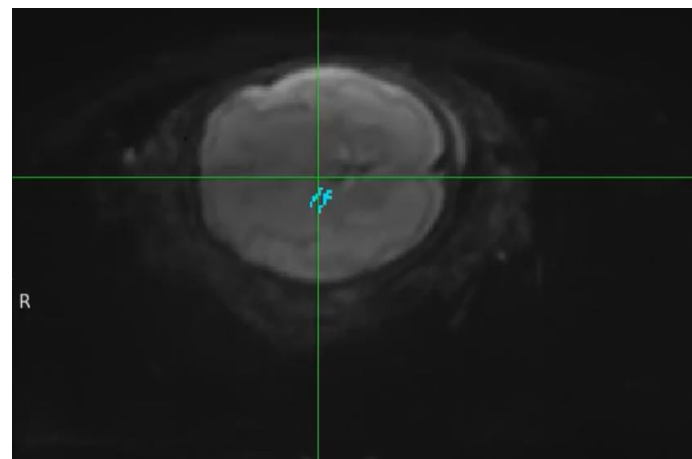
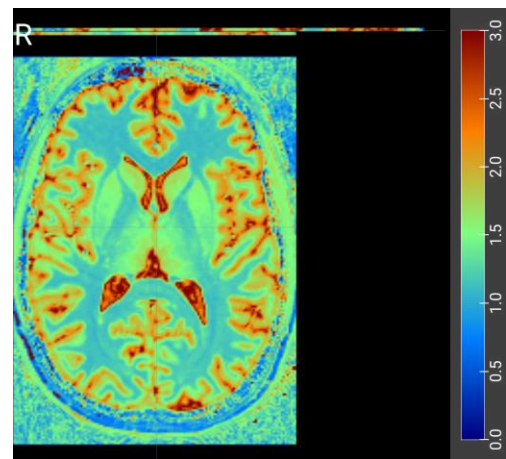
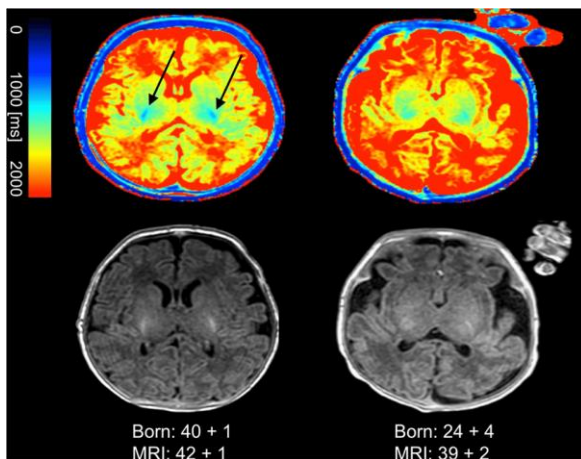
## MR Relaxometric Assessment of Basal Ganglia in Neonates with Hypoxic-Ischemic Encephalopathy (HIE)

 TREND - Technology Agency of the Czech Republic

 1.1 million EUR

 2023–2027

 Computer-Aided Diagnosis for Quantitative Evaluation of Brain Development Incorporating AI



# Projects






## MR Relaxometric Assessment of Basal Ganglia in Neonates with Hypoxic-Ischemic Encephalopathy

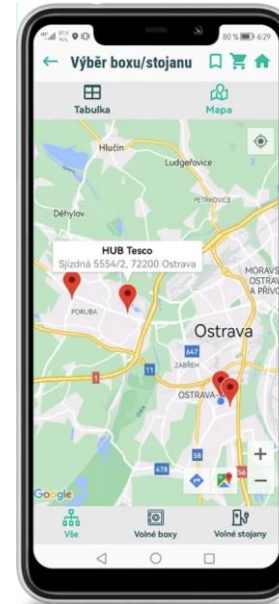
### Motion Detection During MR Examination



# Projects






## Development of Small Electric Vehicles for Intergenerational Urban E-Mobility Concepts Powered by Smart Infrastructure

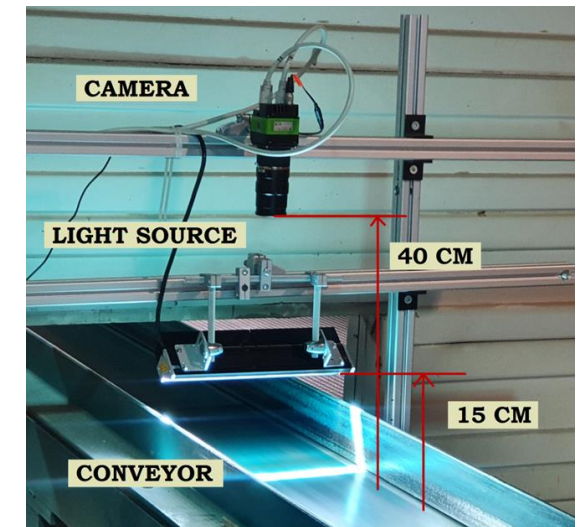
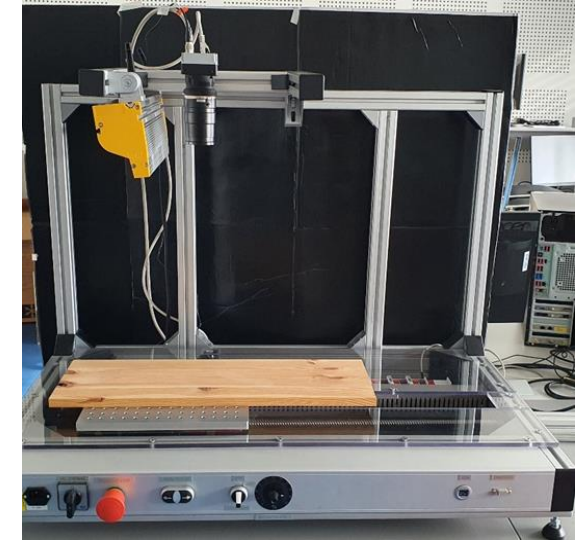
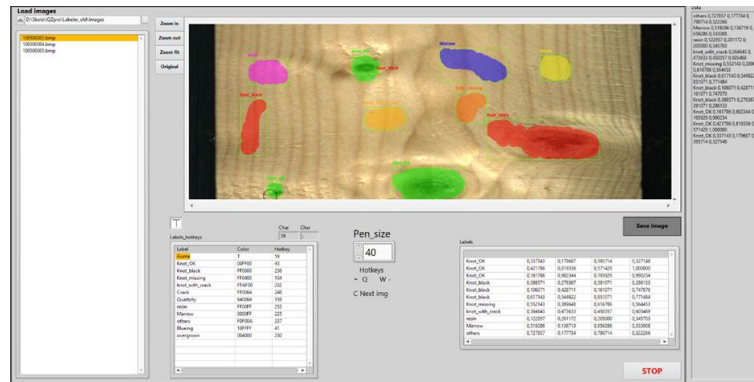
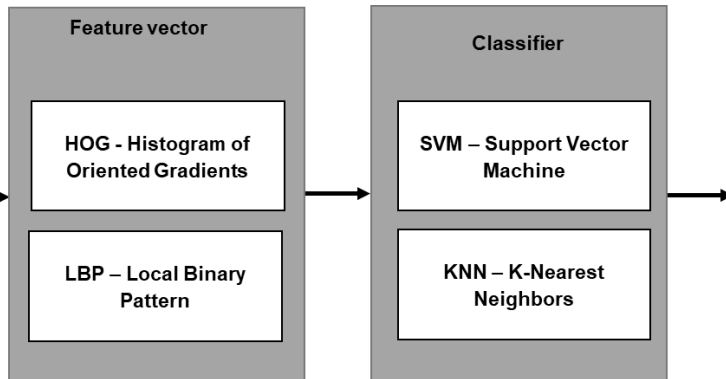
-  INTER-EXCELLENCE - Ministry of Education, Youth and Sports
-  620 000 EUR
-  2021–2022
-  Smart infrastructure for securing and charging e-scooters and e-bikes
-  Parameter tester for the same



# Projects






## IQZeProd - Inline quality control for zero-error-products

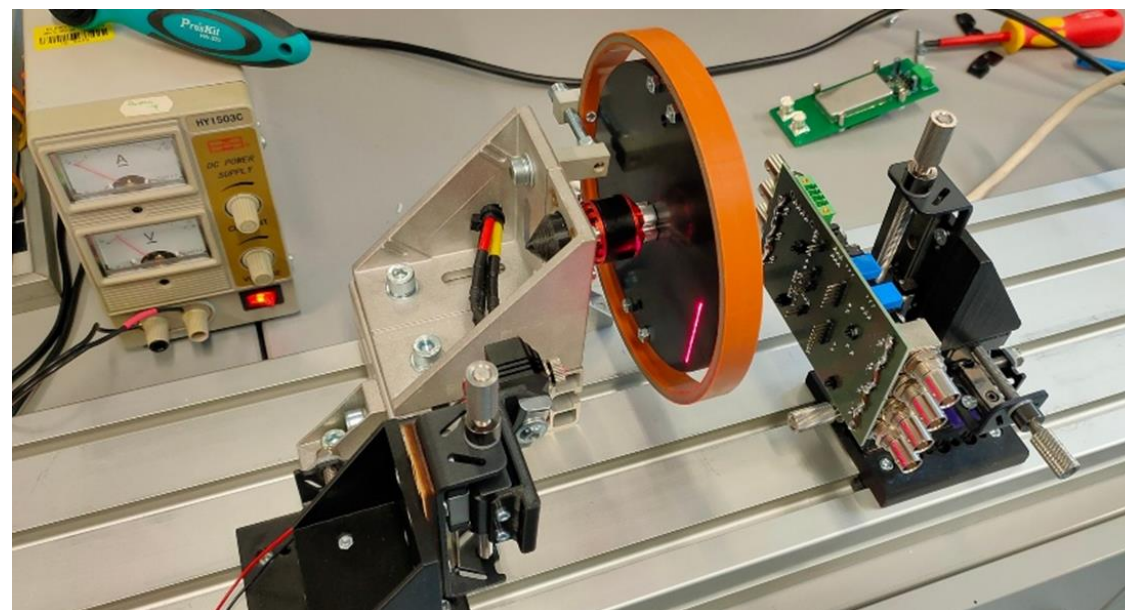
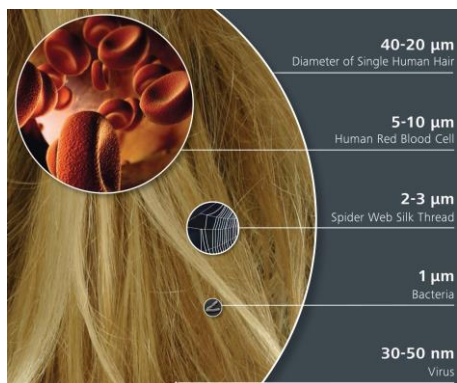
-  Ministry of Industry and Trade
-  300 000 EUR
-  2019–2020
-  A large-scale image dataset of wood surface defects
-  Classification algorithm based on NN



# Projects

**Research and development of innovative technology for the pin hole detection in the metal strip**





-  Ministry of Industry and Trade
-  480 000 EUR
-  2021–2023
-  Detectable hole diameter  $>5 \mu\text{m}$
-  Speed of sheet metal up to 25 ms<sup>-1</sup>

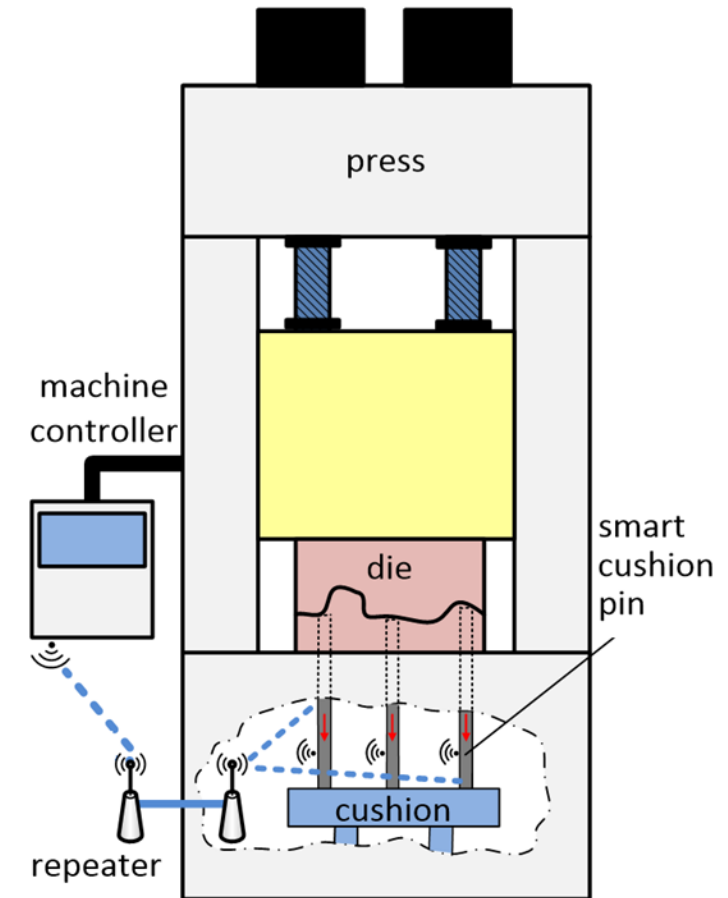




# Projects

## Research and development of the Smart Cushion Pin for machine presses


-  Ministry of Industry and Trade
-  440 000 EUR
-  2018–2019
-  Special sensor development for press machines





# Projects

## Smart Steam Valve – an automatic system for predictive maintenance

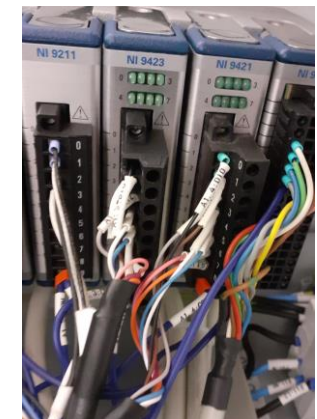
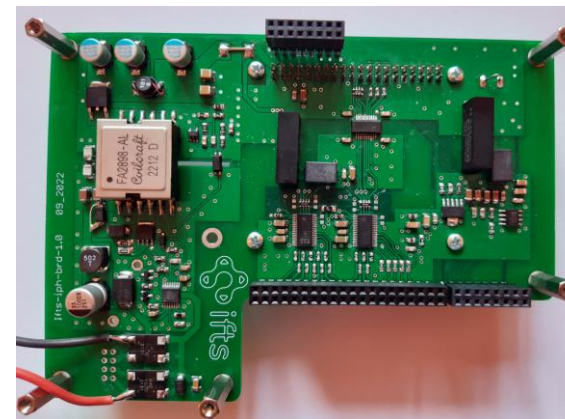
 DELTA 4 - Technology Agency of the Czech Republic

 440 000 EUR

 2021–2023

 Innovation of the blower used to clean the heat exchange surfaces of power plant boilers

 Prototype of a HW and SW for a monitoring system



# Geothermal Energy In Special Underground Structures (GeoUS)

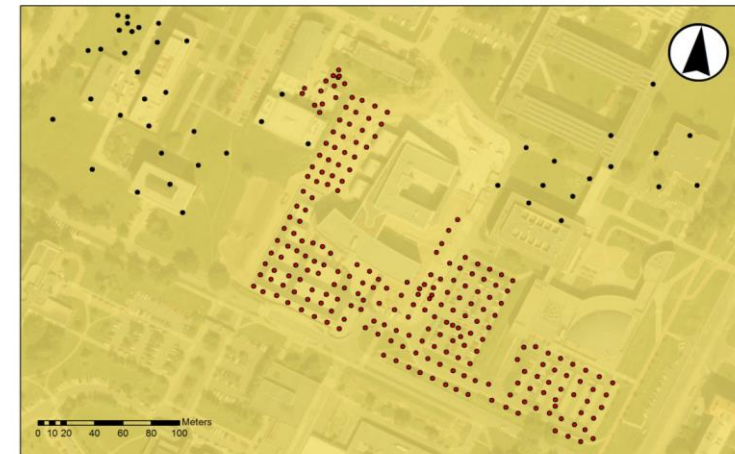
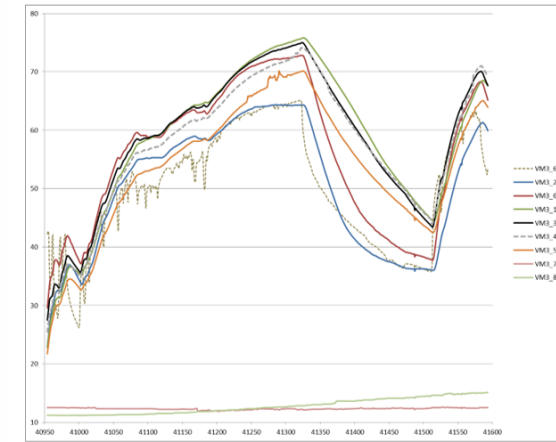
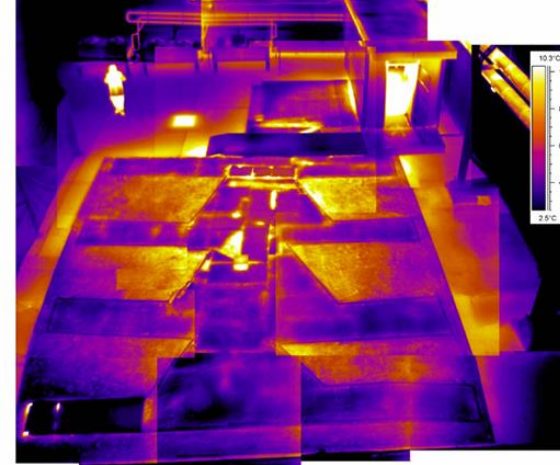
- H2020, Twinning, WIDESPREAD-03-2018
- VSb – TUO (coordinator), Fraunhofer Institute IWU, Germany, University of Vaasa, Finland

Experience in geothermal energy area:

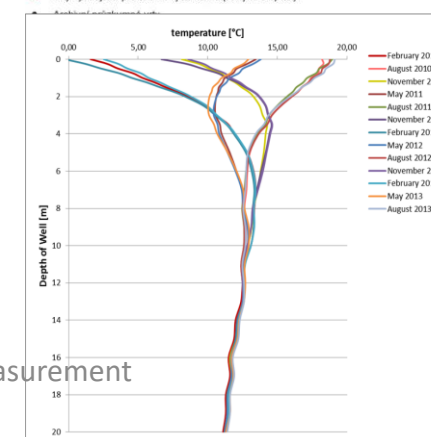
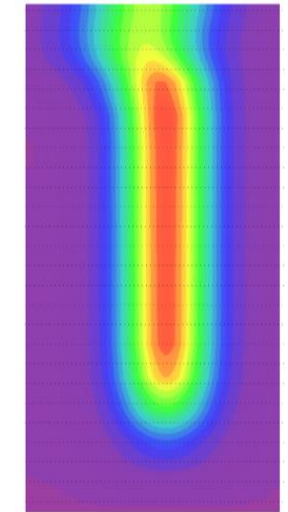
- Assessment of the rock environment.
- Comprehensive design of systems for the use of low-enthalpy geothermal energy.
- Simulation of heat transfer.
- Measurement and control of geothermal systems.
- Special measurements for geothermal systems design – TRT, Temperature profiles, long term measurements.

Research team of 3 faculties.

<http://geous.vsb.cz/>

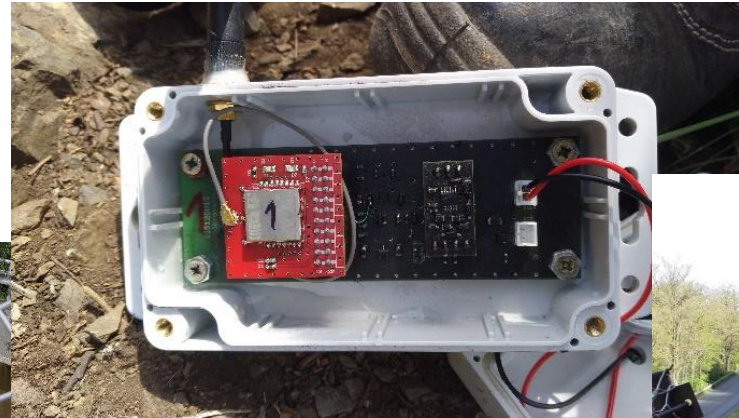
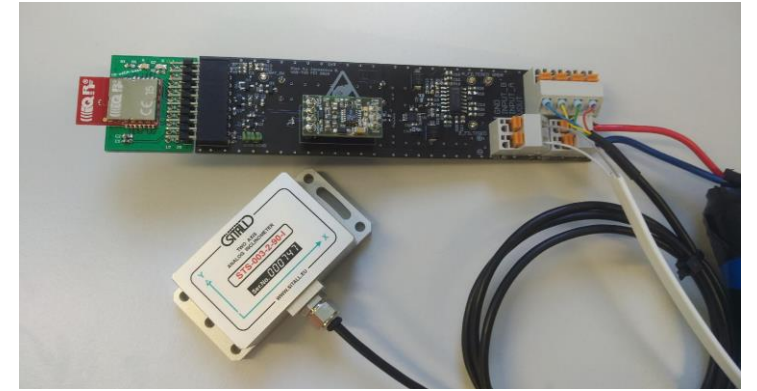


Legend  
• Vity vystrojené pro aktivní využívání tepelnými čerpadly  
Zdroj: Čos. ČÚZK



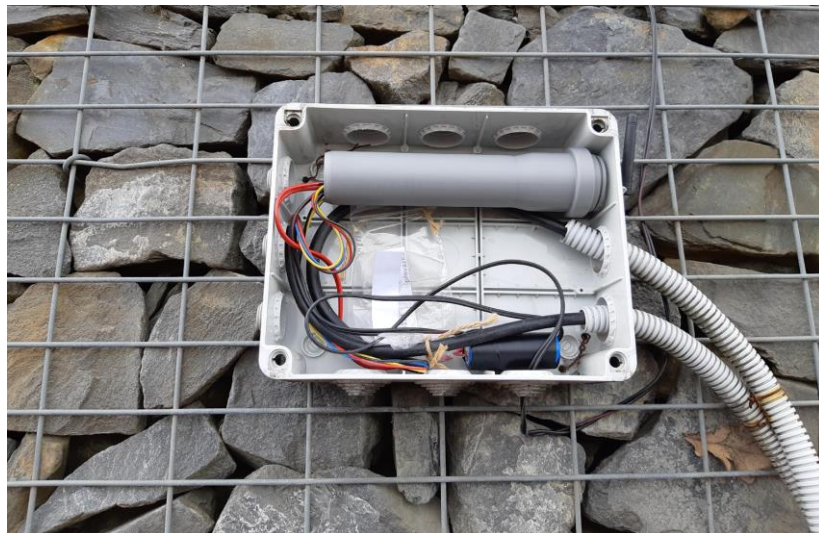
# Projects

- Development of wireless monitoring systems for monitoring the state of protective fences near rocky walls.
- Cooperation with STRIX Chomutov, a.s.



# Projects

- Development of wireless monitoring systems for slope stability monitoring.
- Cooperation with SG Geotechnika, a.s.



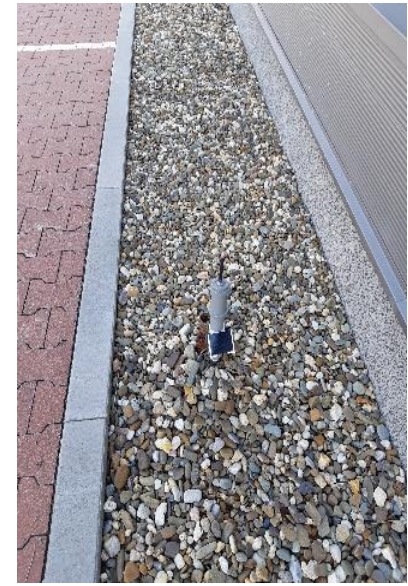
# Projects

- Development of wireless monitoring systems for monitoring of cracks in rocks massive.
- Cooperation with ČEZ (owner of pumped hydroelectric power plant)



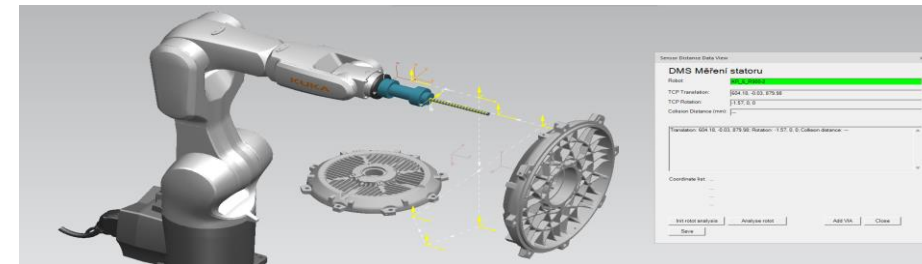
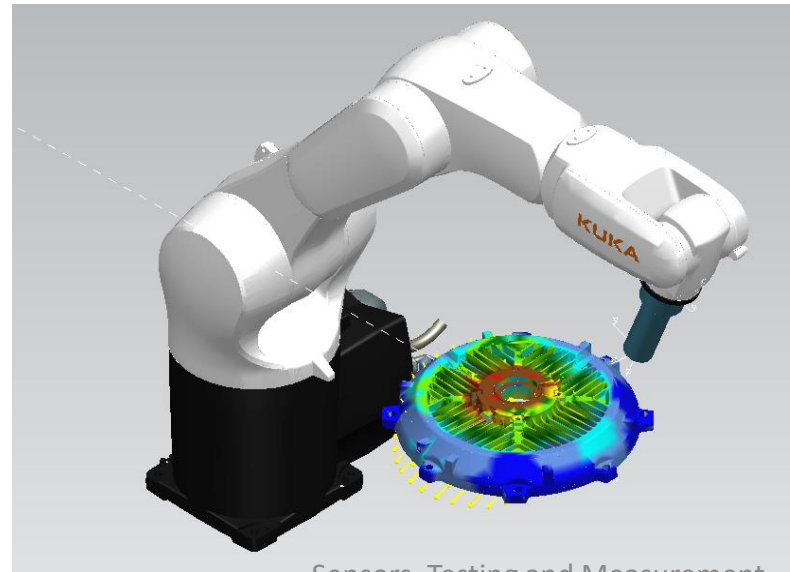
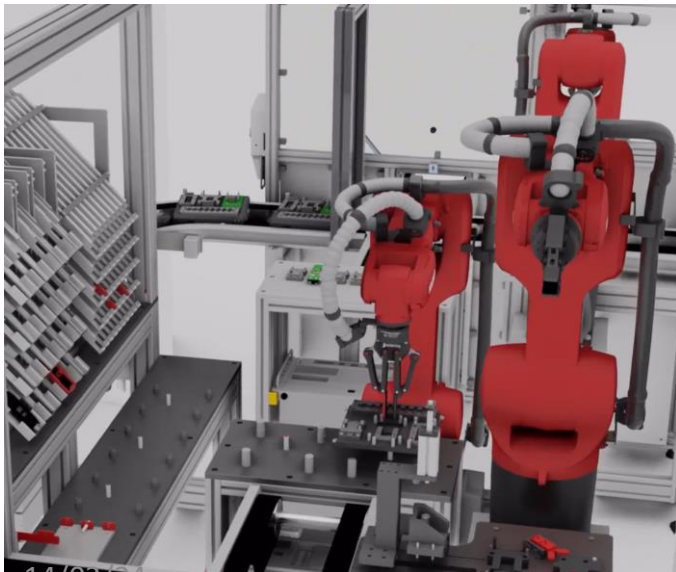
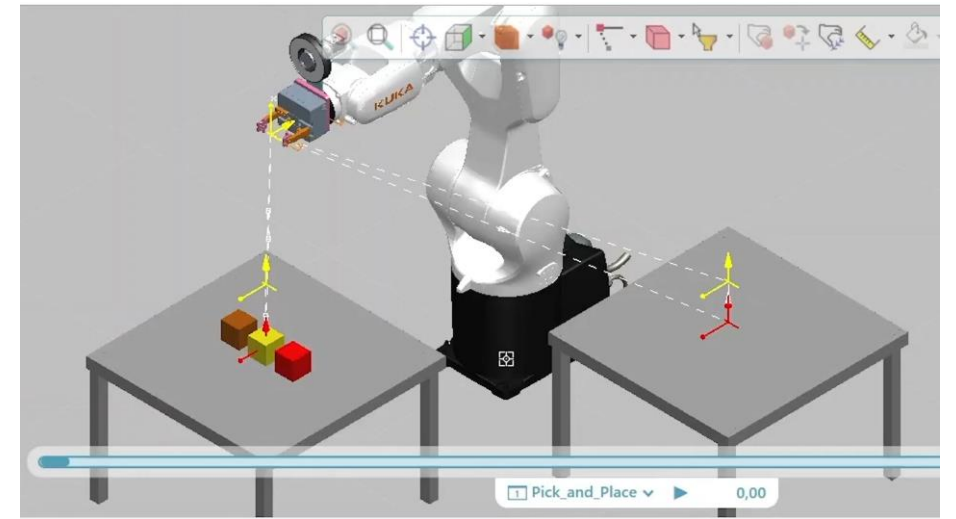
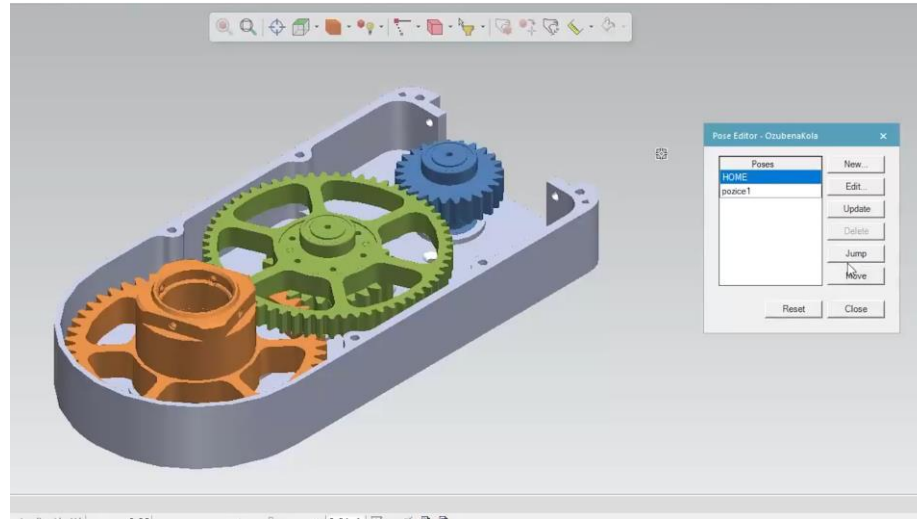
# Projects

- Development of wireless monitoring systems for thermal processes monitoring at mining dumps.
- Cooperation with DIAMO, s.p., SG Geotechnika, a.s., CANIS Safety, a.s.



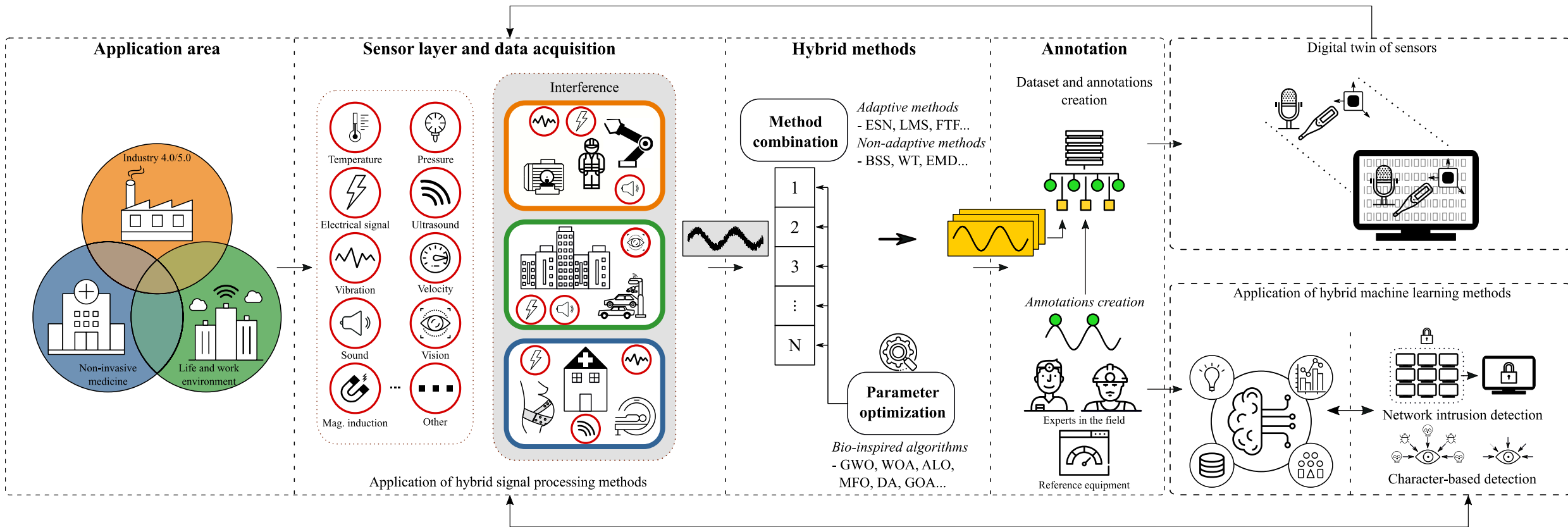
# Projects

- Digital Twin.





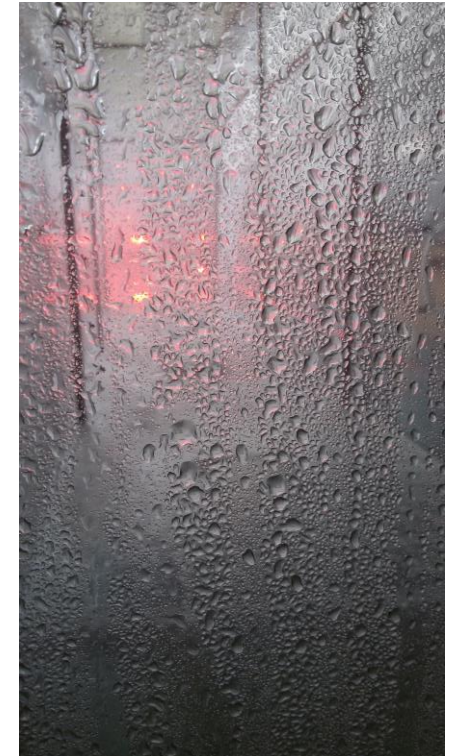
# Application Areas in General



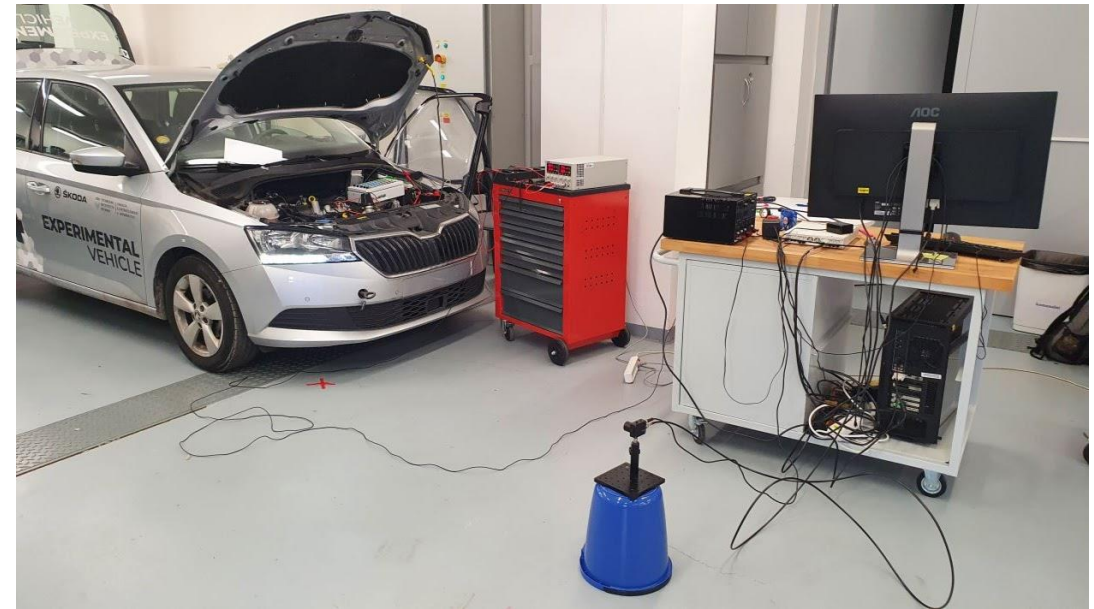
# Visible Light Communication



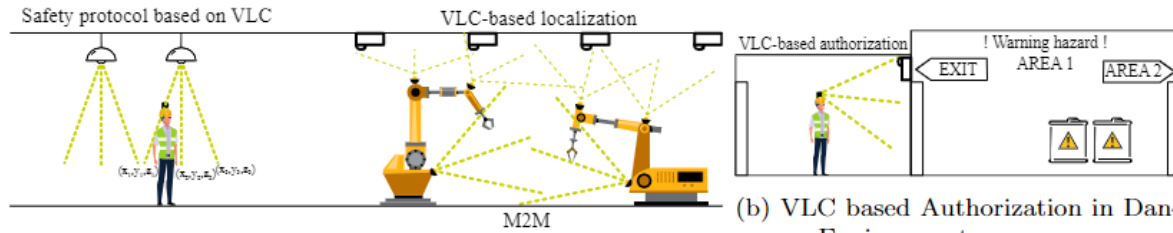
# Visible Light Communication



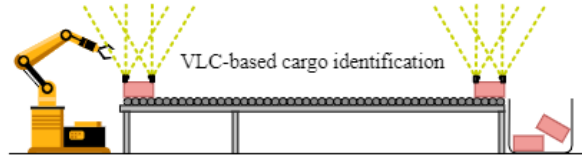
# Visible Light Communication



# Visible Light Communication

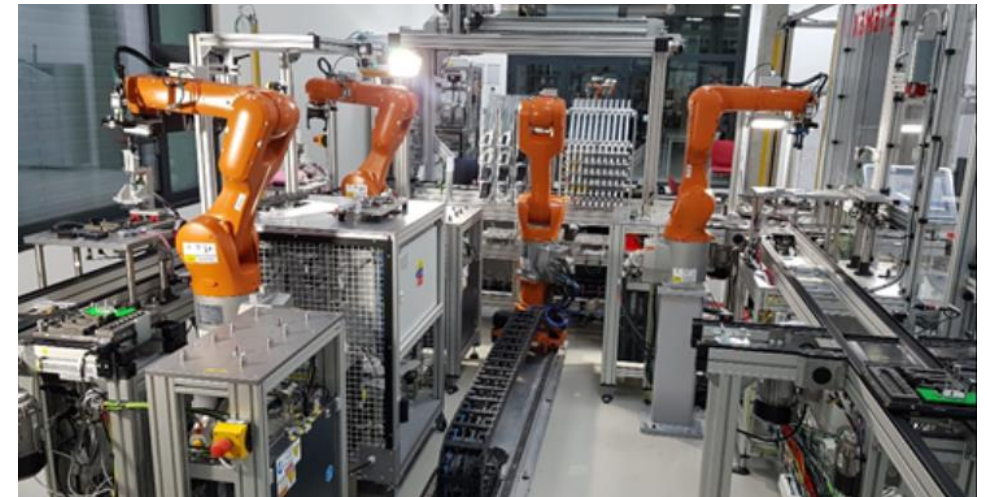
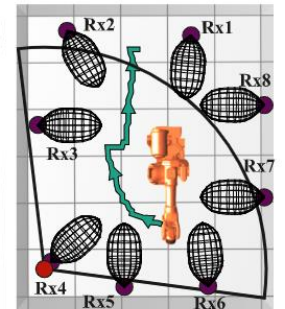
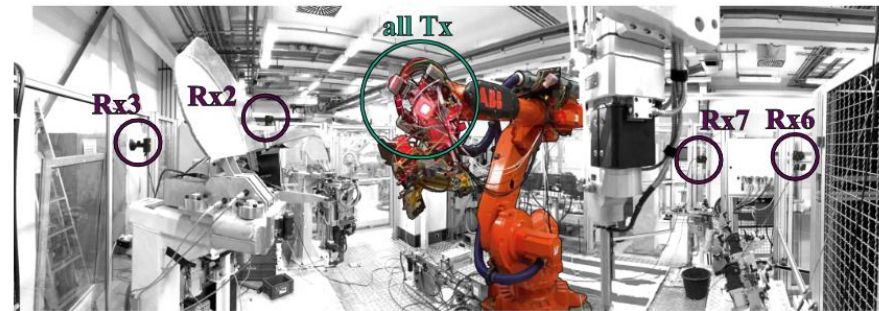


(a) Localization, Safety and M2M Protocols based on VLC.



(c) VLC based Cargo Identification and Localization.

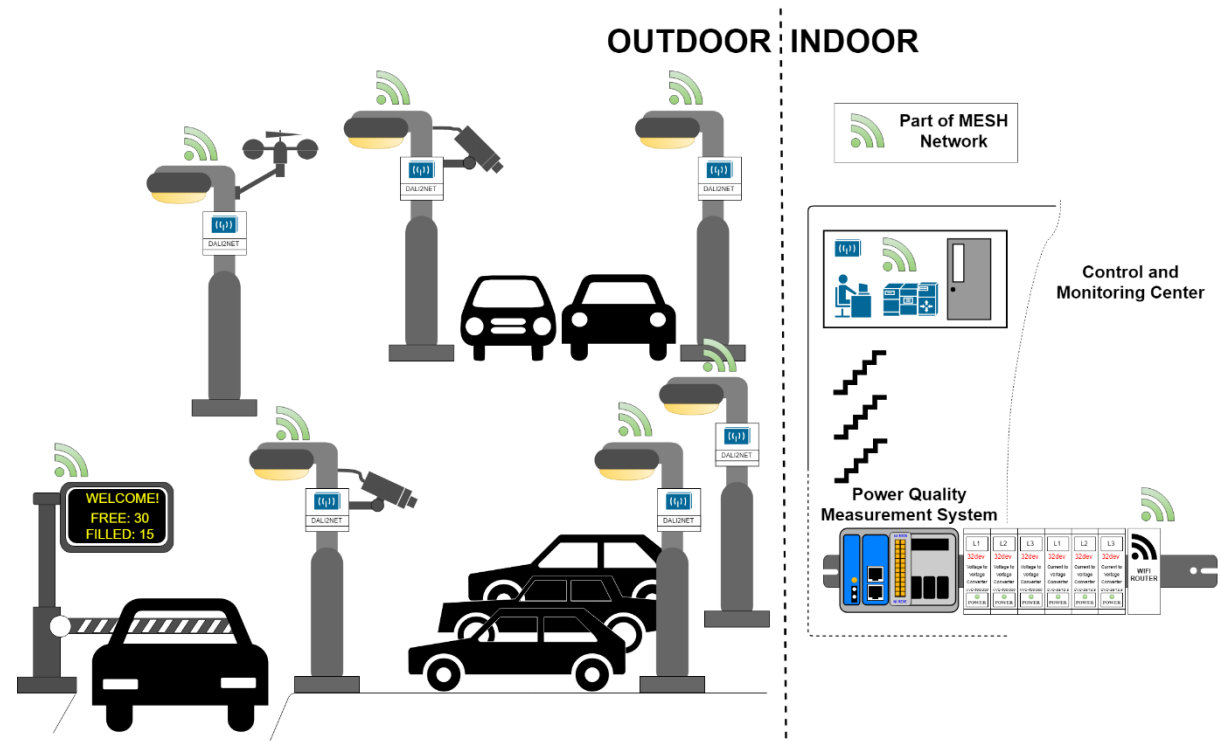
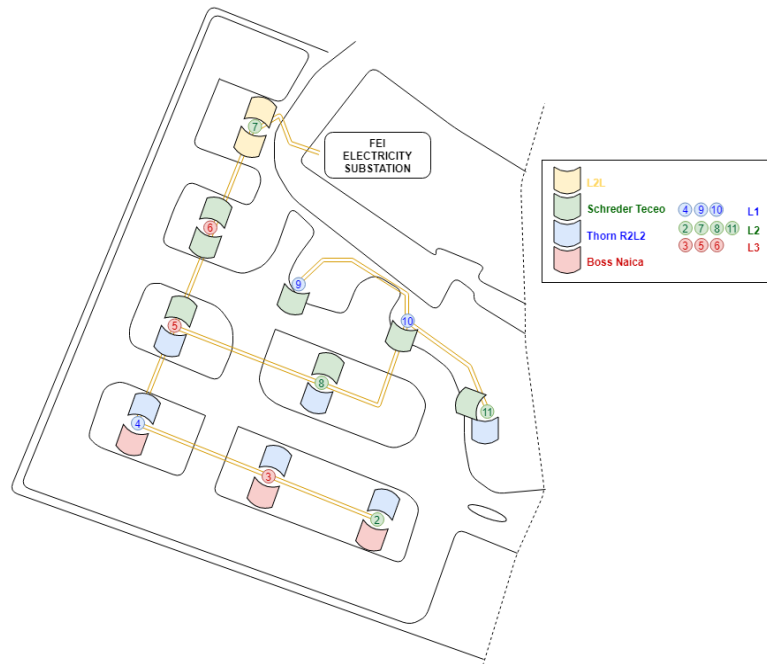
(b) VLC based Authorization in Dangerous Environments.



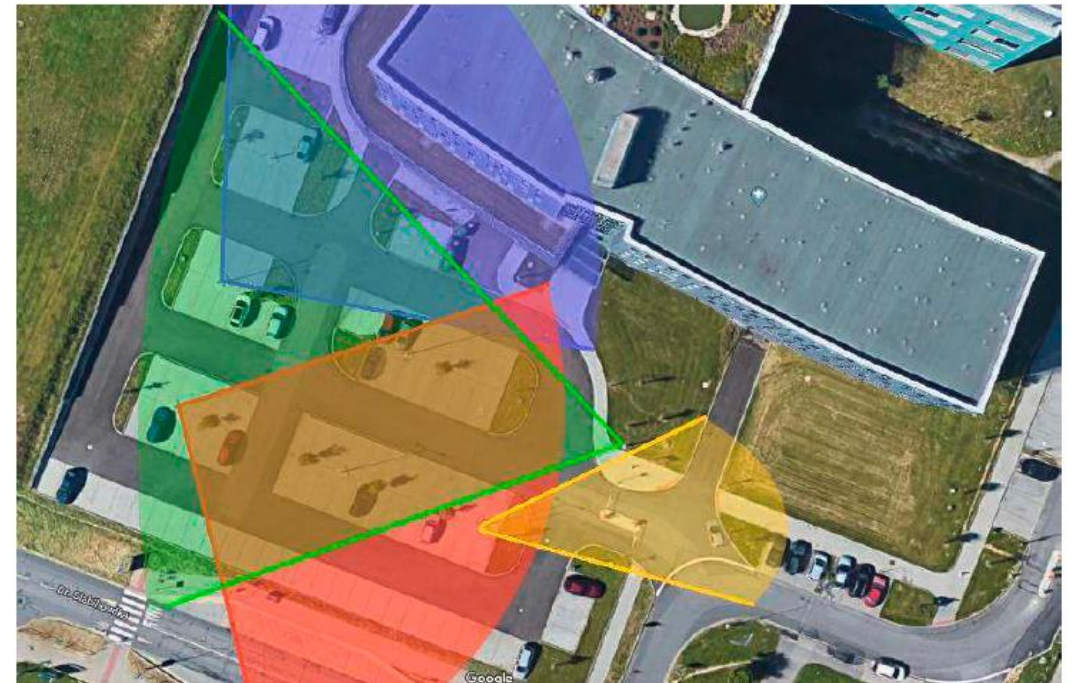
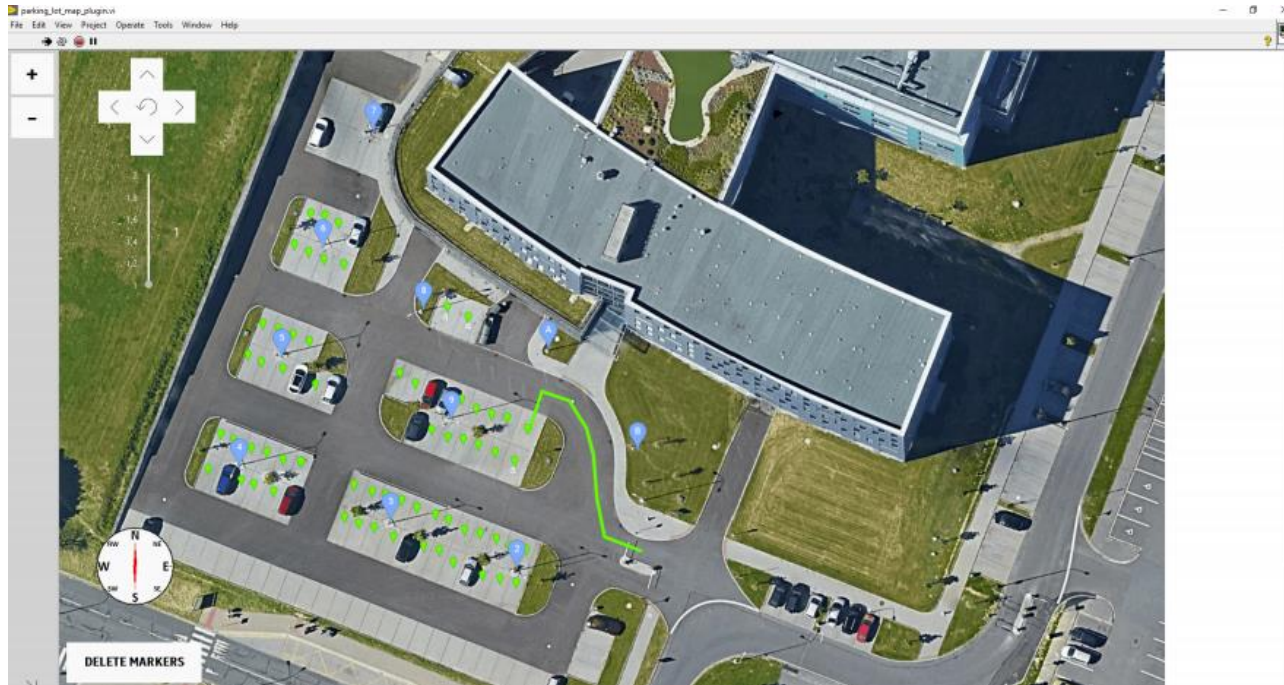
# Parking Lot Polygon



# Parking Lot Polygon



# Parking Lot Polygon





# Laboratory of Virtual Instrumentation

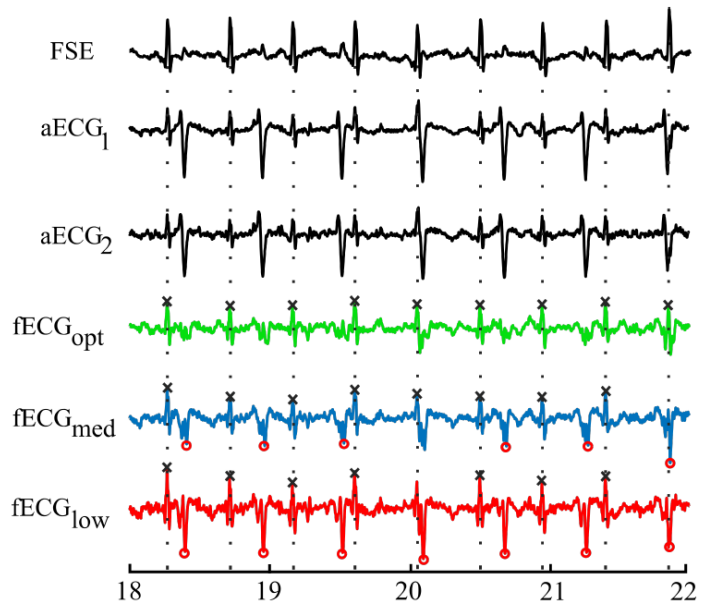
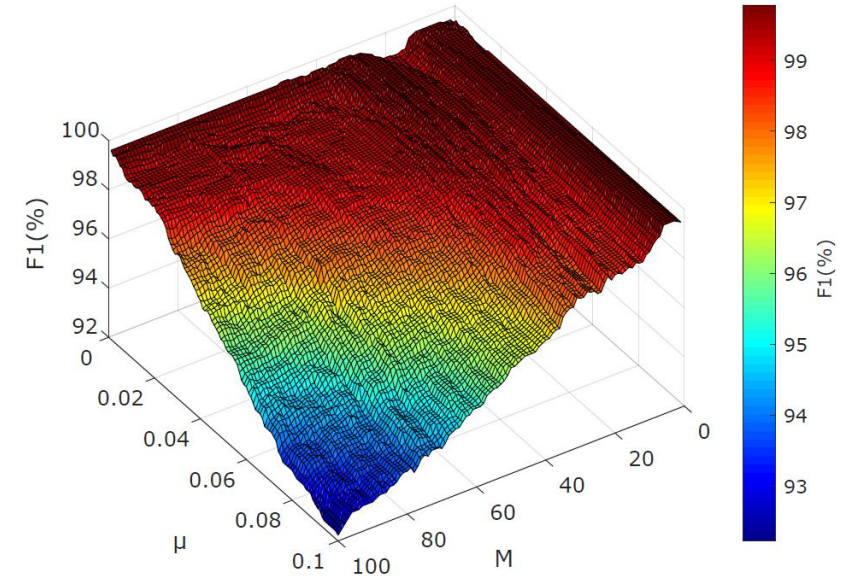
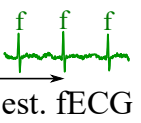
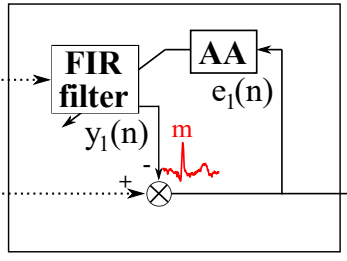
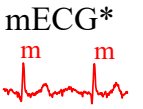
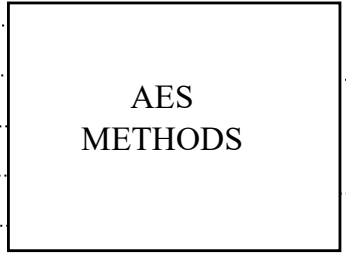
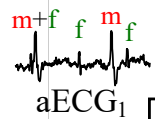
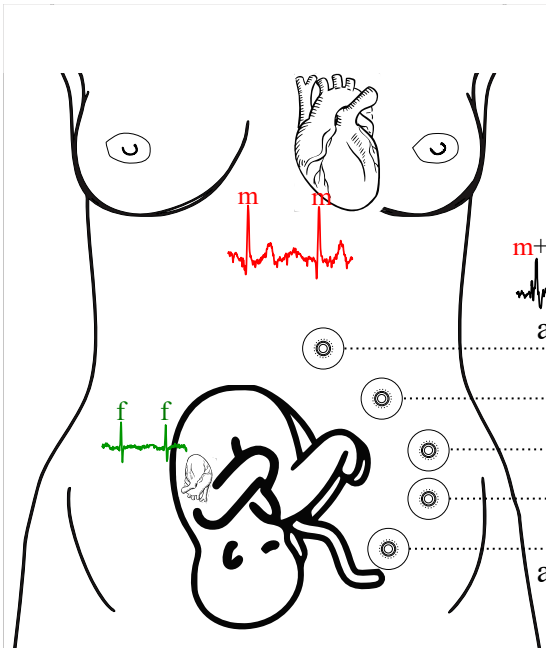


# Laboratory of Signals and Systems



# Extraction Algorithms

- Non-Adaptive, Adaptive and Hybrid Methods.
- Different parameters that need to be optimized.



# Bio-Inspired Optimization

Grey Wolf Optimizer



An algorithm that mimics the social hierarchy and navigation mechanism of grey wolves in nature to solve optimization problems.

Whale Optimization Algorithm

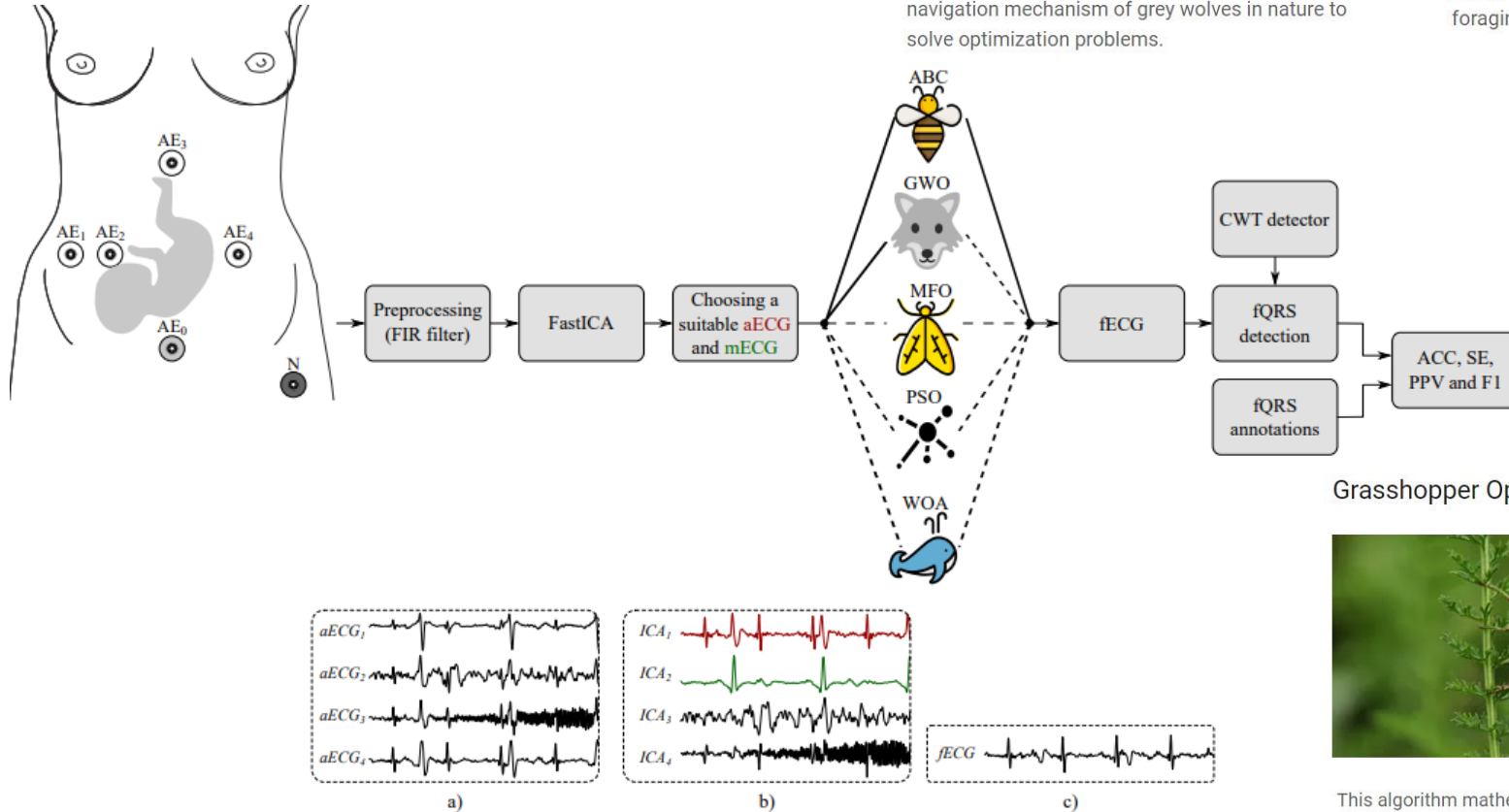


An optimization algorithm inspired from bubble-net foraging of humpback whales.

Moth Flame Optimizer



The main inspiration of this optimizer is the navigation method of moths in nature called transverse orientation. Moths fly in night by maintaining a fixed angle with respect to the moon, a very effective mechanism for travelling in a straight line for long distances. However, these fancy insects are trapped in a useless/deadly spiral path around artificial lights. This paper mathematically models this behaviour to perform optimization.



Grasshopper Optimization Algorithm

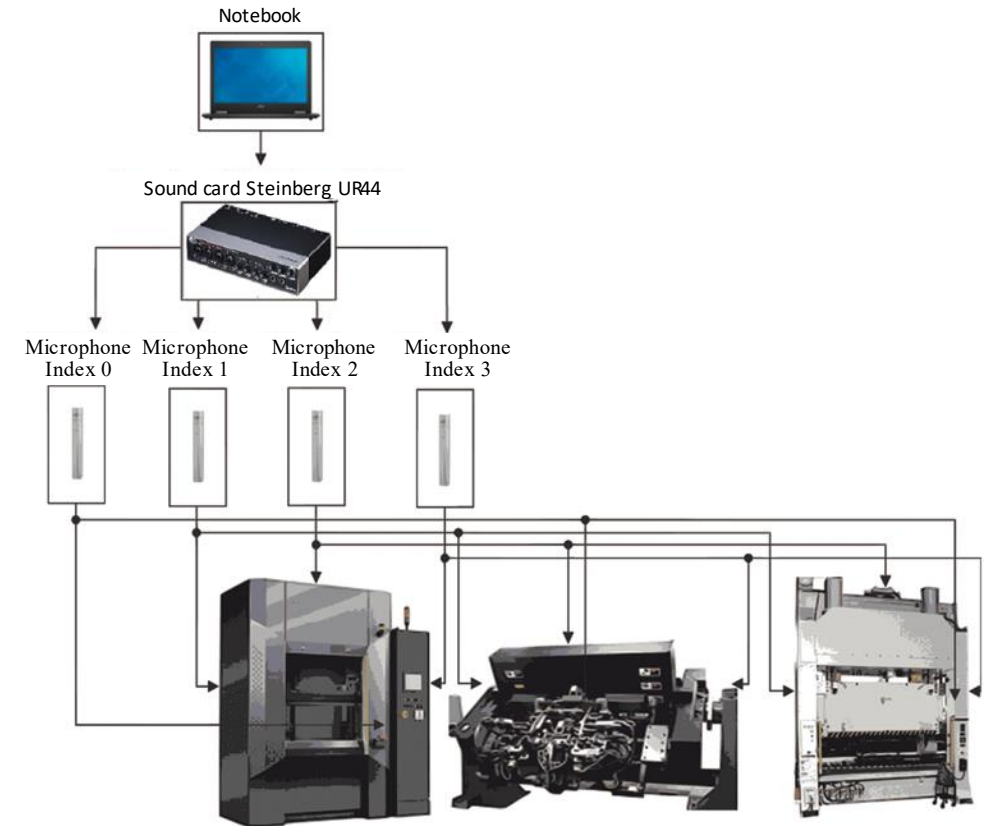
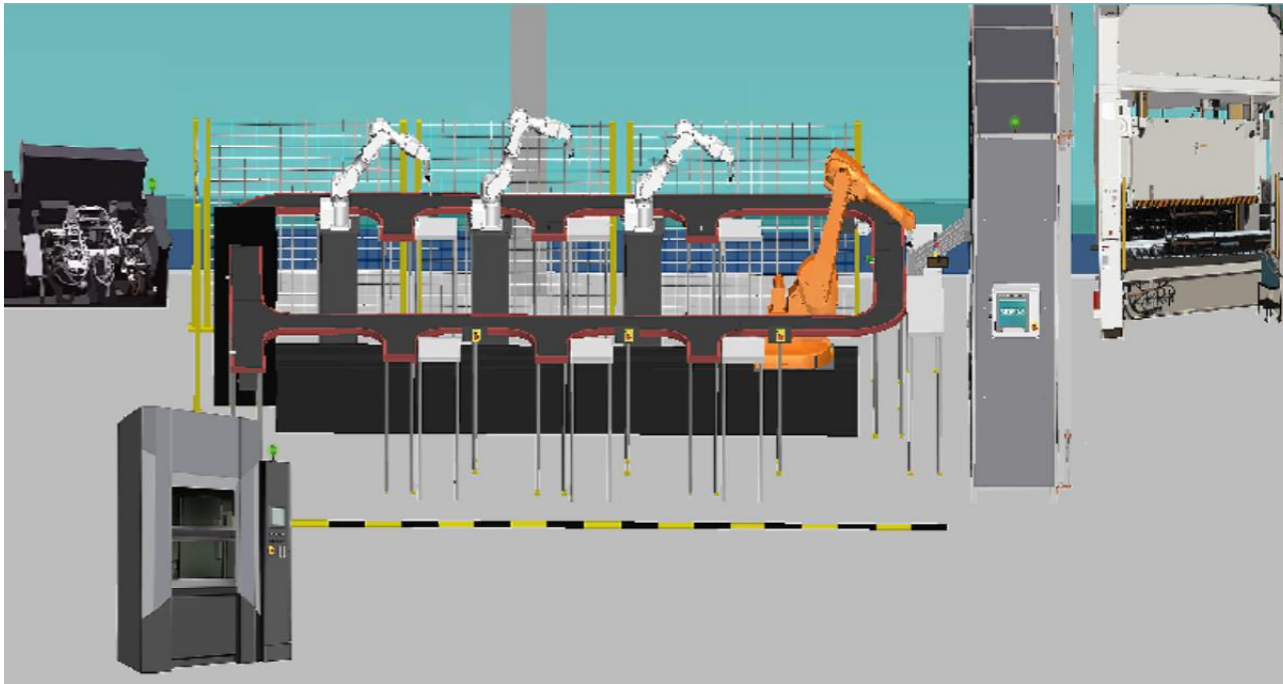


This algorithm mathematically models and mimics the behaviour of grasshopper swarms in nature for solving optimisation problems.

# Speech Processing

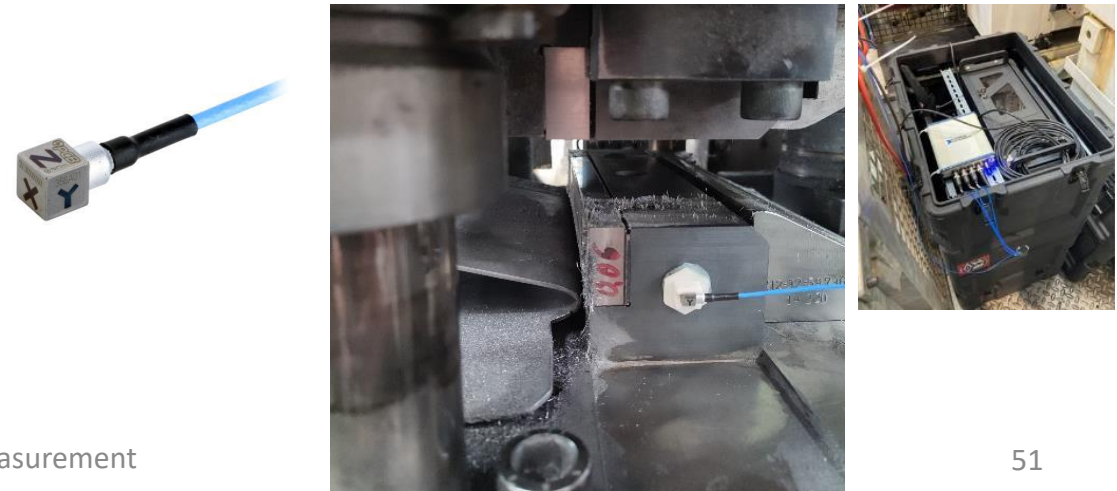
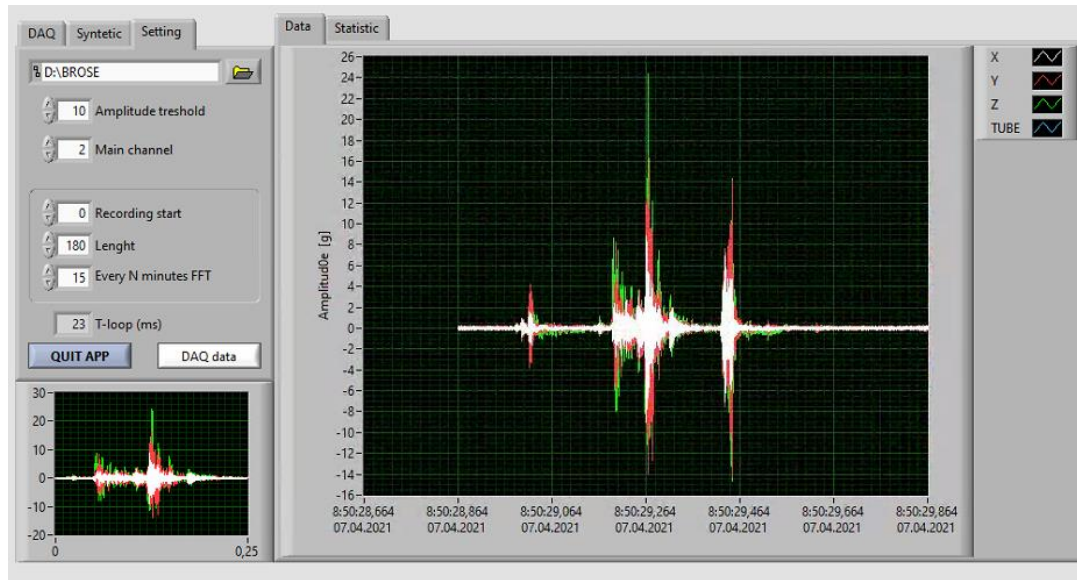


# Speech Processing



# Continuous Monitoring, Predictive Maintenance

- Long-term measurements in two industrial complexes.
- Metal cutting machine monitoring with tri-axial accelerometers.

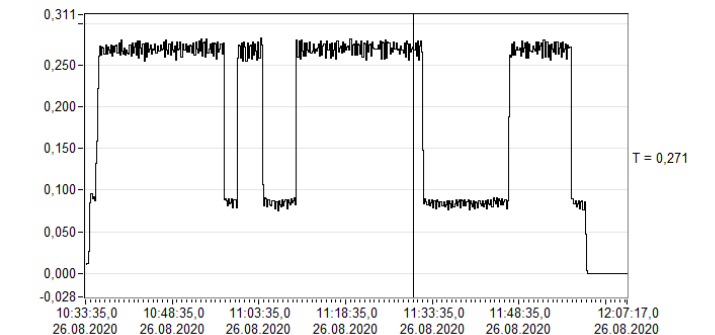
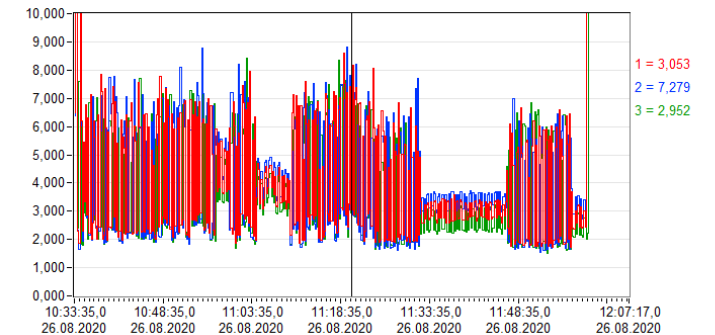


# Power Quality Measurement and Evaluation

- ENA330 with Rogowski coils for current up to 3000 A.



THDi (%), Total Harmonics Current Distortion

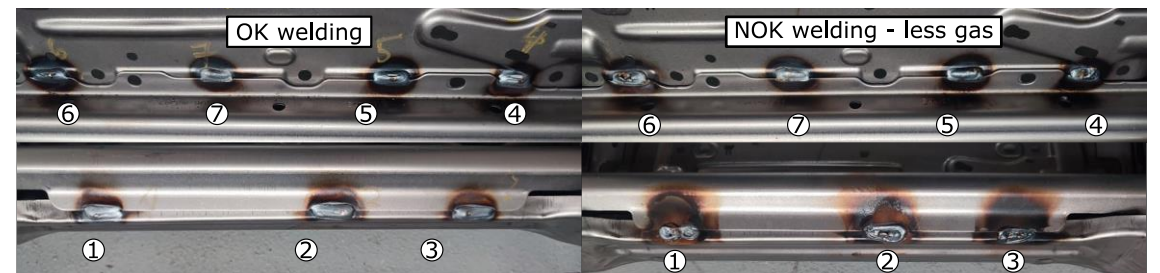
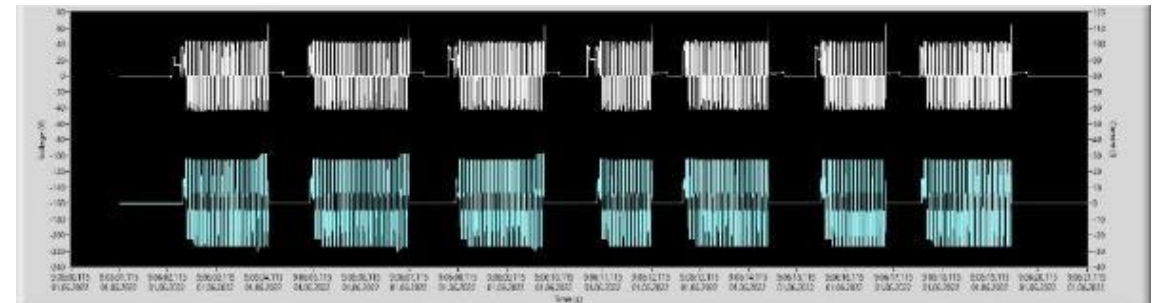
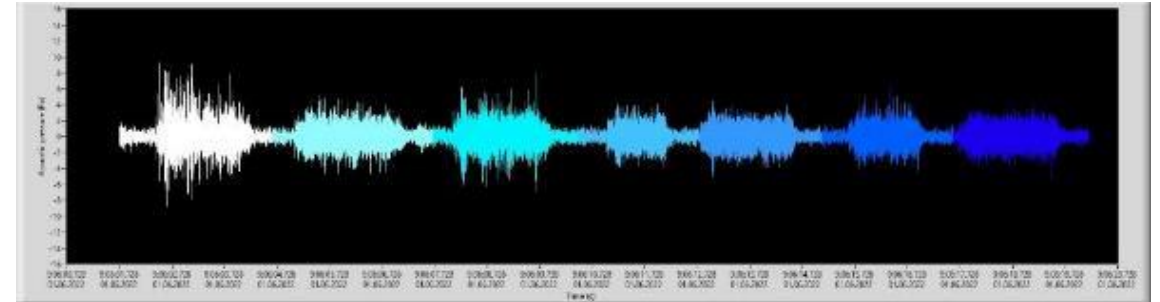
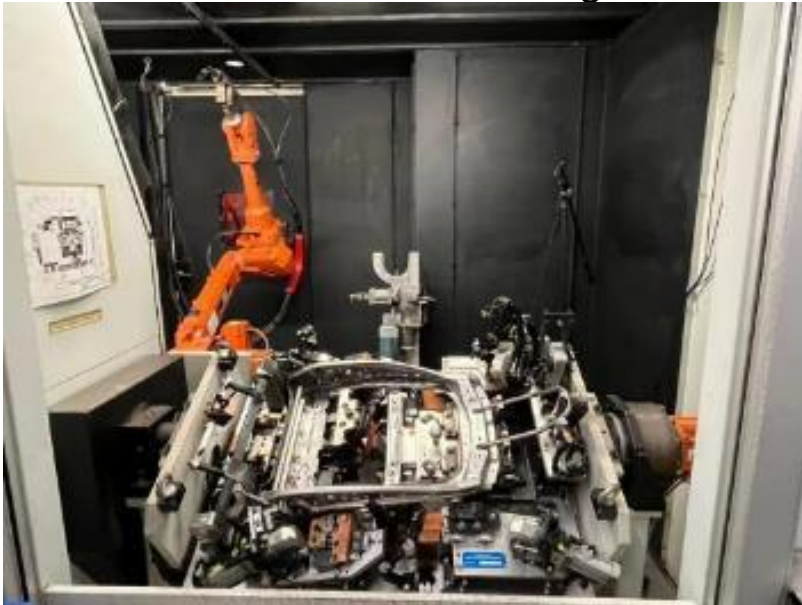


3-Phase Power (kW)



# Continuous Monitoring, Predictive Maintenance

- Feasibility study of welding monitoring using acoustic emission sensing.
- Measurement of electric signals and acoustic signals fields.





# NI PXIe Hardware

- PXIe chassis expandable with I/O, communication and FPGA modules.
- Can have a separate controller.
- Can be remotely controlled via PC/laptop.



# Cooperation with the Mendel University in Brno

- Using Solar and Geothermal Energy to Reduce the Energy Intensity of Automated Crop Production.



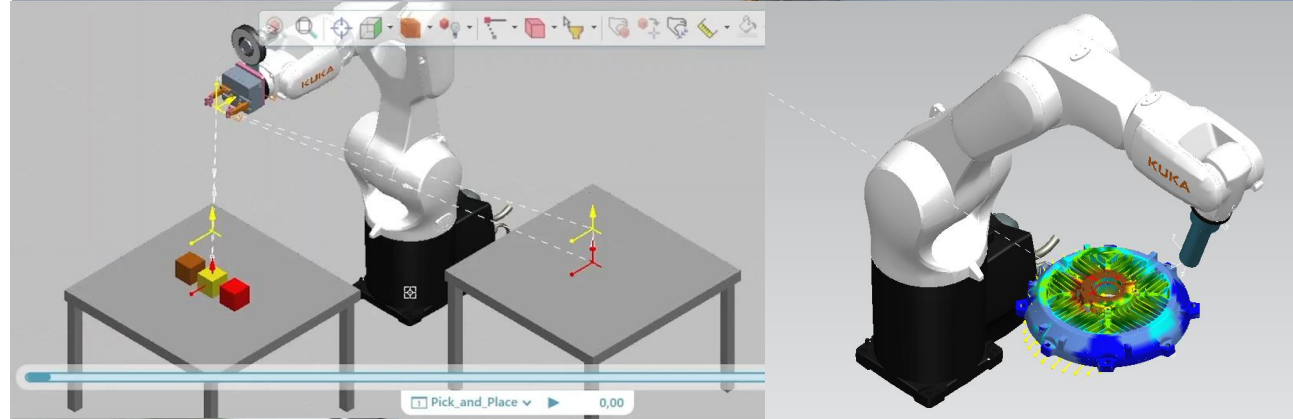
# Smart Factory

- Research and training testbed for Industry 4.0
- Test-Before-Invest cooperation

Expertise and research provided by Smart Factory:

- Industrial control systems design (PLC, HMI, SCADA).
- Measurement systems design (virtual instrumentation, condition monitoring)
- Digital twin design (Visual Components, Tecnomatix Process Simulate).
- Modelling and simulations (Comsol, Matlab, Simit)
- Edge computing, IoT
- Machine vision systems
- Implementation of advanced signal processing methods, artificial intelligence, control theory, advanced calculations etc.

<http://smartfactory.vsb.cz/>



# Faculty of Electrical Engineering and Computer Science



# Thank you for your attention

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Sensors, Testing and Measurement