2020

Annual Report of Department of Robotics

Faculty of Mechanical Engineering

VŠB – Technical University of Ostrava

Czech Republic

27th January 2021

VSB TECHNICAL UNIVERSITY OF OSTRAVA | FACULTY OF MECHANICAL ENGINEERING | DEPARTMENT OF ROBOTICS

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Annual Report

2020

Department of Robotics

Faculty of Mechanical Engineering, VŠB – Technical University of Ostrava, Czech Republic

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https://vk.com/departmentofrobotics

1. CONTENT

2. DEPARTMENT PROFILE

Since its foundation (1989), the Department of Robotics has been focused on the issue of robotics at all levels of education, in science and research and in professional practice. In accordance with the current trends, the department staffs and PhD students develop the topics of service robotics and robotics and the application of robots outside of engineering. This is reflected in research, teaching and publishing. In this respect, grants, contract research and topics of diploma and doctoral theses are based on research. The department provides several fields of study - Robotics, as part of the bachelor's study program in Mechanical Engineering and subsequently also in the follow-up master's program in the study program Mechanical Engineering at the Faculty of Mechanical Engineering. The department also guarantees the doctoral program of the same name Robotics and the bachelor study program Mechatronics.

The Department also intensively focuses on new topics related to the Industry 4.0 concept, in particular the areas of collaborative robotics, IoT, digital twins, etc. In this area, it works closely with a number of automotive companies in our region.

The areas of interest of the Department of Robotics can be divided into: design, operation, construction, testing and diagnostics, simulation, measurement, control and sensors, dynamics, use of computer support to solve problems and innovations in the field. The Department also profiles students interested in the design and implementation of control systems designed for process and visualization control levels in mechatronic systems. Emphasis is mainly on industrial PCs and their properties, including methods of ensuring the required reliability of operation. The Department enables students interested in master and doctoral studies to complete selected courses at the Faculty of Electrical Engineering and Computer Science of our University in the form of an individual study plan.

Teaching and research activities of the department are also focused on mathematical modelling of mechanisms and their drives in terms of control, design of technical and software means of control systems of positioning mechanisms and sensory subsystems, including image processing technology for various applications, tools and methods - including optimization – design of mechatronic systems. The scientific and research activities of the department lead to the strengthening of the department's profile in the field of service and collaborative robotics, methods and tools for designing relevant systems, as an obvious trend of the coming years with wide application possibilities.

The Department actively offers study internships for foreign students under the Erasmus+, IAESTE, etc. programs.

The staff of the department and students solve the theoretical and application tasks corresponding to the given specialization. Teaching takes place in the Robotics Centre, in various types of industrial and collaborative robots and their subsystems, in service robotics laboratories and in CAD systems classrooms. Robotics and mechatronics are characterized by broad and comprehensive use of computer support for all areas of activity. Classrooms of CAD systems are equipped with appropriate software tools.

3. STAFF

Head of Department:	Prof. Dr. Ing. Petr Novák
Vice Head:	Assoc. prof. Zdenko Bobovský, Ph.D.
Secretary:	Ing. Václav Krys, Ph.D.
Assistant:	Ing. Petra Pišťáčková
Professors:	Vladimír Mostýn, Petr Novák
Associate professors:	Zdenko Bobovský, Tomáš Kot, Milan Mihola
Assistant professor:	Ing. Ladislav Kárník, Ph.D..
	Ing. Václav Krys, Ph.D.
	Ing. Aleš Vysocký, Ph.D.
	Ing. Stefan Grushko
	Ing. Robert Pastor
	Ing. Jiří Suder
	Ing. Michal Vocetka
Researchers:	Ing. Ján Babjak, Ph.D.
	Ing. Dominik Heczko
	Ing. Jakub Mlotek
	Ing. Petr Oščádal
	Ing. Zdeněk Zeman
	Bc. Vyomkesh Jha Kumar (until 2020-08-31)
Technicians:	Karel Ranocha

4. EDUCATION ACTIVITIES

4.1. Guaranteed study fields

4.1.1. Bachelor Fields of Study

Title: **Robotics**

Item number: B0715A270011/S07 (Czech), B0715A270012/S04 (English)

Guarantor: Associate professor, Ing. Milan Mihola, Ph.D.,

Graduate Profile:

Bachelor graduates in this field will be employed as designers of robot elements, manipulators and peripheral devices of robotized workplaces / conveyors, bins, heads of industrial robots etc./, but also as designers of these devices and especially operational technicians ensuring operation, adjustment, programming, diagnostics, maintenance and repair.

Application possibilities are not limited to mechanical engineering, as robots are applied in a number of other sectors such as agriculture, healthcare, glass, food, textile and shoe industries, services etc. Due to this trend, one can speak of the possibility of universal promotion of this technique.

In addition to the necessary theoretical background, graduates will gain practical experience at robotized workplaces in newly built laboratories of industrial robots. The direct part of the study is the mastering of computer work for the whole spectrum of activities, starting with the use of text editors, spreadsheets and designing using CAD systems, to the use of computers in robot control systems and automated devices.

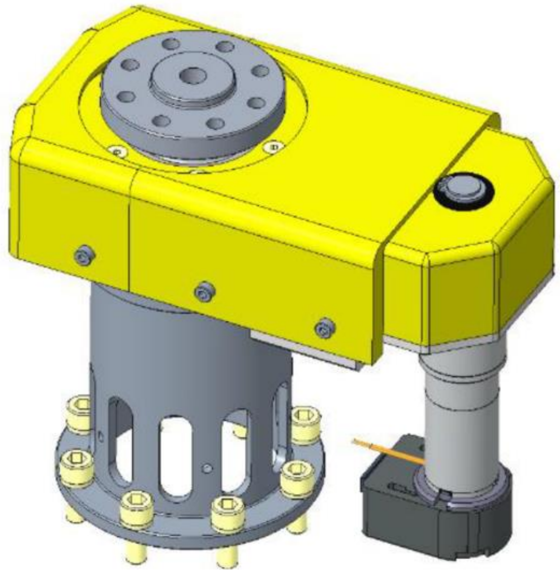

Fig. (Bc.) Jan Maslowski, Structural modification of the first joint of the K3P4 robot manipulator, bachelor's thesis, supervisor: Ing. Dominik Heczko

Title: **Mechatronics**

Item number: B0714A270002

Guarantor: Assoc. prof., Ing. Zdenko Bobovský, Ph.D.

Graduate Profile:

The aim of the three-year Mechatronics study program is to educate graduates with broad practical skills and basic theoretical knowledge in the multidisciplinary field of Mechatronics. Students will acquire the necessary targeted knowledge and skills by completing a number of courses from the Faculty of Mechanical Engineering and also from the Faculty of Electrical Engineering and Computer Science, especially in the areas of automation, electrical engineering and electronics, mechanical engineering and robotics. Graduates of the bachelor study program Mechatronics have the knowledge needed to work with complex structure systems that they are interconnected mechanical, electrical and control subsystems. They have knowledge of measurement, synthesis of control systems, design knowledge of the properties and applications of actuators and sensors. Knowledge of mechanics, measurement and signal processing allows them to solve application tasks in the field of control systems with high dynamics and high demands on the resulting utility machine properties. They know basic methods of synthesis of mechatronic systems and they know the tools of computer support of their design.

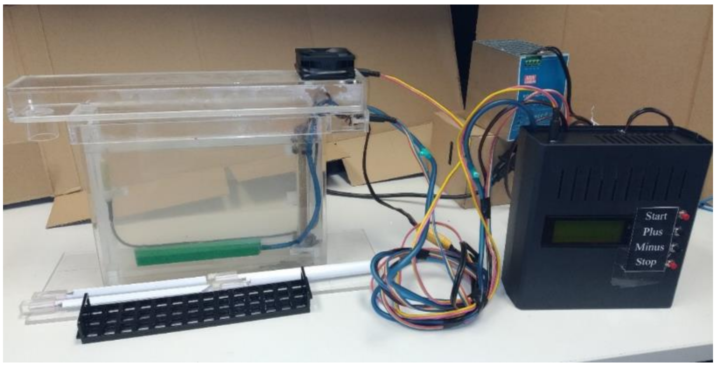

Fig. (Bc.) Mateusz Łuński Application of Two Position Control with the Arduino Control Board Usage, bachelor thesis, supervisor: Assoc. prof.. Jaromír Škuta, Ph.D. – Department of Control Systems and Instrumentation.

Graduates are prepared to carry out activities within the design, commissioning and operation of mechatronic systems with applications in various types of production with different technologies. They are able to solve the links between mechanical, electrical and control subsystems with respect to the Industry 4.0 concept.

4.2. Magister Fields of Study

Title: **Robotics**

Item number: 23 01T013-00

Guarantor: Prof. Ing. Dr. Ing. Petr Novák

Graduate Profile:

The specialisation “Robotics” is focused on design, construction and control of industrial robots and manipulators and their subsystems. The field is also focused on designing robotized technological workplaces, including their control, and issues of current legislation and safety regulations. In connection with current trends in robotics, the course is also focused on the issue of service robotics and for those interested in biorobotics. Part of the study of the field is a comprehensive mastery of powerful computer-aided design systems such as Creo Parametric and other computational and simulation systems, suitable for advanced modelling and simulation in the field of industrial and service robotics. Considerable attention is paid to the methodology of creating technical systems and the methodology of support of the innovation process based on TRIZ technology, including computer support of these activities. The field of Robotics is therefore very complex, the primary machine focus has a large overlap into related areas such as control, sensor technology, drive systems and computer science. In the final phase of their studies, students learn about the latest developments in the Industry 4.0 concept, such as IoT, augmented reality and the digital twin. They can apply these new skills in the development of their theses.

Graduates of the Robotics field of study have knowledge in the design of industrial robots and manipulators, design of robotized technological workplaces and creation of service robotic systems, including their deployment. The knowledge in the field of mechanical engineering is complemented by the necessary knowledge in the field of control and sensor technology, software engineering, design of control systems both in software and hardware, as well as knowledge in the field of electronics, machine vision and drives. Graduates are ready to solve engineering tasks in the field of automation and robotics of engineering production, application of service robots in production or services. In the field of designing production systems with industrial robots, graduates have the necessary knowledge of securing their operation, maintenance, reliability, safety, adjustment and programming of robotized workplaces.

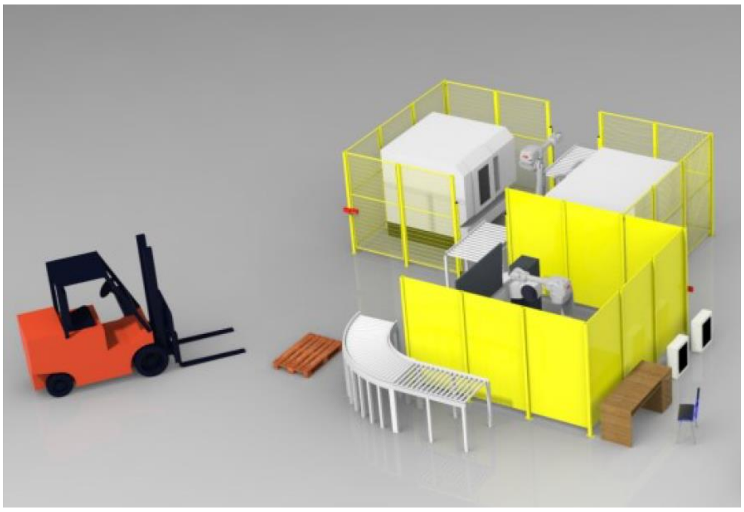

Fig. (Ing.) Bc. Jiří Vojtíšek „ Library of models of common elements of robotic workplaces, supervisor Ing. Daniel Huczala

Also gained is the knowledge gained in the use of high-performance computer support systems for design, design, modelling, simulation, programming, control, etc., which are fully usable outside the studied field. Graduates will be employed as designers, designers, operation engineers, specialists for various areas of computer applications - CAD, CAI, covering in addition to design activities and design and the entire field of technical preparation of production and product life cycle management (PLM systems).

4.3. Doctoral fields of study

Title: **Robotics**

Field of Study: 2301V013

Guarantor: prof. Dr. Ing. Vladimír Mostýn

Graduate Profile:

Graduates will learn the methodology of scientific work in the area of applied research and development of industrial and service robots and their applications with a significant application of the mechatronic approach to the development of these complex technical systems. In the area of creation and solution of innovative tasks the graduates will acquire basic methodological and scientific procedures, in the area of construction the graduates will acquire relatively extensive knowledge in the area of creation and optimization of mechanical subsystem with computer support, perception of the environment and communication with humans and in the field of propulsion subsystems are knowledge of new electric, hydraulic and pneumatic drives and their applications. The aim of the study is to deepen the theoretical knowledge of the master's degree, to understand the context and to combine this knowledge to acquire a mechatronic complex approach to the creation of robot-engineering systems in the area of production and service activities.

4.4. Newly accredited study

Accreditation of the follow-up master's study program Robotics in the Czech and English version for the full-time form of study has been obtained.

Title: **Robotics**

Field of Study: NFS0008 (Czech), NFS0009 (English)

Guarantor: prof. Dr. Ing. Petr Novák

Characteristics of the study program:

The study program Robotics contains three specializations:

Design of Robotized Workplaces

Within the specialization Design of robotic workplaces, the graduate has professional skills in the design of robotic workplaces, including relevant peripherals, can use top design, simulation software tools for design, can communicate professionally with other experts in individual specializations in creating the whole workplace and its connection to the environment. She or he has basic professional skills in robot programming and can choose a suitable concept of robotization of the workplace with regard to the input requirements.

Construction of robotic technology

Within the specialization Construction of Robotic Technology, the graduate has the professional skills necessary for designing, constructing robotic technology, including the synthesis and analysis of kinematic structures, taking into account dynamic parameters in design and construction. She or he is able to use and understand top computational, design, construction, simulation and optimization software tools. She or he has the professional skills needed to implement other subsystems such as control, sensory and action and the links between them.

Service robotics

Within the specialization Service Robotics, the graduate has professional knowledge of designing and constructing service robots and their subsystems, including their mechanical, hardware and software parts. She or he has knowledge of modern materials and technologies, including additives. He has knowledge of individual subsystems, such as control, sensory and action, including the links between them. She or he has knowledge of locomotor systems, navigation and orientation. She or he has knowledge and can use it in the field of modern 3D design, simulation and innovation systems and can apply the outputs of these systems.

Furthermore, the accreditation of the doctoral study program Robotics in the Czech and English versions was also obtained, for full-time and part-time study.

Title: **Robotics**

Field of Study: P0714D270003 (Czech), P0714D270004 (English)

Guarantor: prof. Dr. Ing. Petr Novák

Professional knowledge of the graduate

The field is focused on comprehensive professional knowledge of graduates, especially in the field of robotic equipment design, the field is strongly interdisciplinary and graduates will gain relatively extensive knowledge in creating and optimizing a mechanical subsystem with computer support, in the field of control and sensors, management, perception of the environment and communication with humans.

Professional skills of the graduate

Graduates will master the methodology of scientific work in the field of applied research and development of industrial and service robots and their applications, with a significant application of the mechatronic approach to the development of these complex technical systems.

General competencies of the graduate

Graduates are able to evaluate new knowledge and ideas in the field, taking into account the long-term social consequences of their use, plan large-scale activities of a creative nature and obtain and plan resources for their implementation, solve ethical problems related to creative activity or use of its results. They can clearly and convincingly communicate their knowledge in the field to other members of the scientific community at the international level and the general public.

4.5. List of defended theses

4.5.1. Bachelor theses

	Student	Supervisor	Topic
1.	Radim Bednárik	Ing. Václav Krys, Ph.D.	SW Tools for Creation of Complex Simulation Models of Robotic Workstations and their Basic Characteristics
2.	Jan Filip	Ing. Aleš Vysocký, Ph.D.	Multipurpose table for the UR3 robot
3.	Tereza Hanáková	doc. Ing. Milan Mihola, Ph.D.	Pneumatic Power Units for Robotics
4.	Vojtěch Hanke	Ing. Zdeněk Zeman	Creating metal structures using the Creo Parametric Framework
5.	Jakub Chlebek	Ing. Aleš Vysocký, Ph.D.	Proposal of Demonstration Tasks with the Robot UR3
6.	Michal Jarka	Ing. Ladislav Karník, CSc.	Mobile Robotics in Security Forces
7.	Martin Kantor	Ing. Jiří Suder	Proposal of the Rotary Table for 3D Scanning
8.	Jan Kelar	prof. Dr. Ing. Petr Novák	Safety Systems for Robotized Workplaces
9.	Jiří Klus	Ing. Jakub Mlotek	Design of the Educational Robotic Cell with a Pair of Mitsubishi Industrial Robots

10.	Václav Kožušník	doc. Ing. Milan Mihola, Ph.D.	Jaw Effectors for Material Handling
11.	Jan Maslowski	Ing. Dominik Heczko	Mechanical Redesign of the K3P4 Robot's First Joint
12.	Ondřej Moša	Ing. Václav Krys, Ph.D.	Library of Dynamixel Drive Unites and their Accessories for CAD and Simulation Systems
13.	Tomáš Poštulka	Ing. Robert Pastor	Soil sample storage device for the robot K3P4
14.	Petr Rais	Ing. Robert Pastor	Electronics and Control Program for a Soil Sampling Module
15.	Michal Zajíc	doc. Ing. Milan Mihola, Ph.D.	Roller Conveyors for Robotized Workplaces

4.5.2. Diploma theses

	Student	Supervisor	Topic
1.	Bc. Lukáš Hoza	doc. Ing. Milan Mihola, Ph.D.	Equipment for Wrapping Pallets
2.	Bc. Dominik Hrbáč	doc. Ing. Milan Mihola, Ph.D.	Modernization of the Lift for Patients Handling in the Balneo Units in the Darkov Spa
3.	Bc. Vít Kaštovský	doc. Ing. Milan Mihola, Ph.D.	Construction Design of Effector with Multi Fingers
4.	Bc. Milan Macek	Ing. Aleš Vysocký, Ph.D.	Analysis and Modification of the Glue Application and Clipping Station
5.	Ing. Michal Mitáček, MBA, Phd.	Ing. Václav Krys, Ph.D.	A Robotic Cell for Artistic Carving
6.	Bc. Radim Stanek	Ing. Ladislav Karník, CSc.	Design of The Carriage for Indoor and Outdoor Environment
7.	Bc. Václav Sýkora	Ing. Václav Krys, Ph.D.	Virtual Reality as the Supporting Tool for Designing and Operating of Robotic Workstations
8.	Bc. Jiří Vojtíšek	Ing. Daniel Huczala	The Model Library of the Common Elements in the Robotized Workplaces

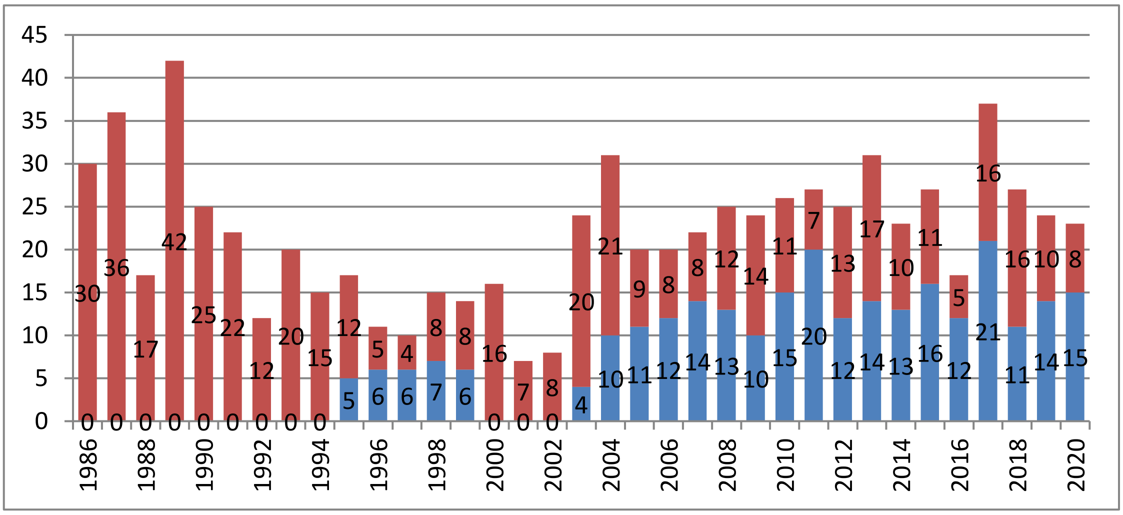

Fig. Overview of numbers of graduates (former Manufacturing Systems with Industrial Robots and Manipulators and now Robotics) Departments of Robotics: Bc.- Blue, Msc. - Red

4.6. List of PhD students

	Name	Dissertation	Year	Form	Tutor
1.	Ing. Stefan Grushko	Motion planning for manipulator in dynamic environment using RGB-D sensor	4.	P	doc. Ing. Zdenko Bobovský, PhD.
2.	Ing. Dominik Heczko	Increasing the accuracy of position and orientation of the objects placed by the manipulator	3.	P	doc. Ing. Zdenko Bobovský, PhD.
3.	Ing. Daniel Huczala	The Synthesis of Kinematic Structure of Robotic Manipulators	3.	P	prof. Dr. Ing. Vladimír Mostýn
4.	Ing. Jakub Mlotek	Shape Adjustable Links of Robotic Systems	2.	P	doc. Ing. Zdenko Bobovský, PhD.
5.	Ing. Petr Oščádal	Robot Arm Trajectory Optimization under Dynamically Changing Work Space	2.	P	doc. Ing. Zdenko Bobovský, PhD.
6.	Ing. Robert Pastor	Machine learning applications in robot kinematics design	4.	P	prof. Dr. Ing. Petr Novák
7.	Ing. Jiří Suder	The use of 3D printing in the design of robots	4.	P	doc. Ing. Zdenko Bobovský, PhD.
8.	Ing. Michal Vocetka	Manipulator accuracy improvement	3.	P	doc. Ing. Zdenko Bobovský, PhD.
9.	Ing. Zdeněk Zeman	Topological Design of Robotics' Arms	2.	P	prof. Dr. Ing. Petr Novák

4.7. Defended Dissertations

In 2020, no doctoral thesis was defended. However, Aleš Vysocký's dissertation, Ph.D., "**Robots working directly with humans**", defended in 2019, won the Werner von Siemens Prize in 2020 in the Industry 4.0 category, in which it defeated almost ninety graduate works dealing with this topic. . In total, eight hundred nominated works competed for prestigious prizes. The Werner von Siemens Awards have previously "earned" two doctoral and two diploma theses from our Department of Robotics, Faculty of Mechanical Engineering VŠB-TUO.

Fig. Receiving the Werner von Siemens Prize in the Bethlehem Chapel (Prague)

4.8. Student projects

Description of projects and activities implemented with significant involvement of students of the follow-up master's degree program and the doctoral study program Robotics.

4.8.1. Student grant competition 2020

The project of the student grant competition "Digital twins of robotic systems and their verification II" was divided into five main activities so that it was possible to involve as many doctoral and follow-up master's full-time students as possible in their solution. 22 doctoral students and a follow-up study program took part in solving the project. Within the solved project, the preparation of 7 articles in domestic and foreign journals was supported. Of these, 4 were published in impact factor journals (2x Q1 and 2x Q2).

Main project activities:

- Simulation models of robotic workplaces
- Simulation models of mobile robots and their subsystems
- VR and AR applications in robotics
- Application of the Internet of Things in robotic systems
- Simulation models of flexible materials and their applications in robotics

The possibilities of simulation tools available at the department for workplaces with industrial and collaborative robots in the design and operational phase of the life cycle of these workplaces were verified. These simulation tools are ABB RobotStudio, Robot Expert and Process Simulate from Siemens and CoppeliaSim (formerly V-Rep). These systems have been used to support decision-making processes in the design of robotic workplaces. Furthermore, to obtain the state parameters of robots and verify the impact on the automated process in workplace optimization. Based on the acquired knowledge, recommendations were formulated for the creation of simulation models and the preparation of materials for them.

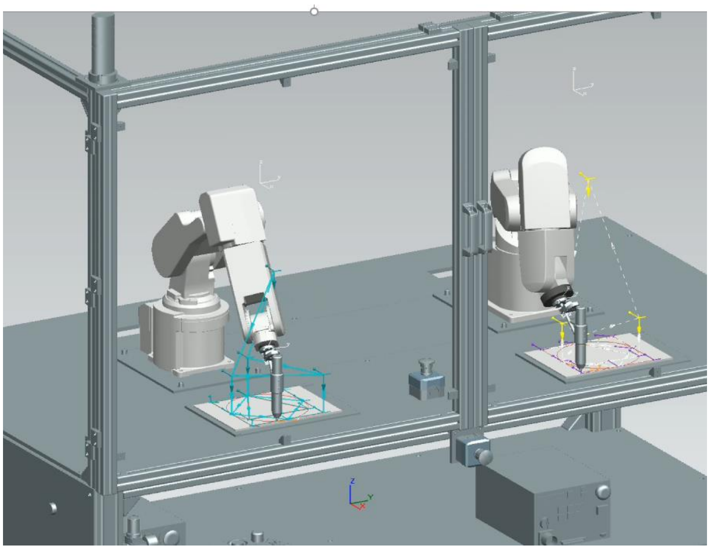

Fig. Preview of the workplace simulation model in the Process Simulate SW system

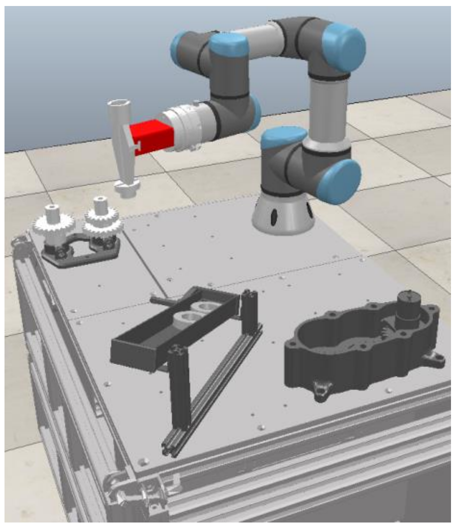

Fig. Preview of a simulation model of a workplace with a collaborative robot in the CoppeliaSim SW system

Experience in creating and working with simulation models and digital twins of mobile robotic systems and their subsystems proved to be a very good starting point for the **European Rover Challenge** (**ERC**) 2020, which took place virtually (see more below). The teams were provided with a simulation model of the robot in the Gazebo simulation system, for which it was necessary to prepare and debug control algorithms using ROS. These were then used for remote control of a real robot and the fulfillment of the assigned tasks was evaluated. Our RoverOva team placed 2nd in this international competition, which proves a very good mastery of the issue of off-line preparation of robot control algorithms using its digital twin.

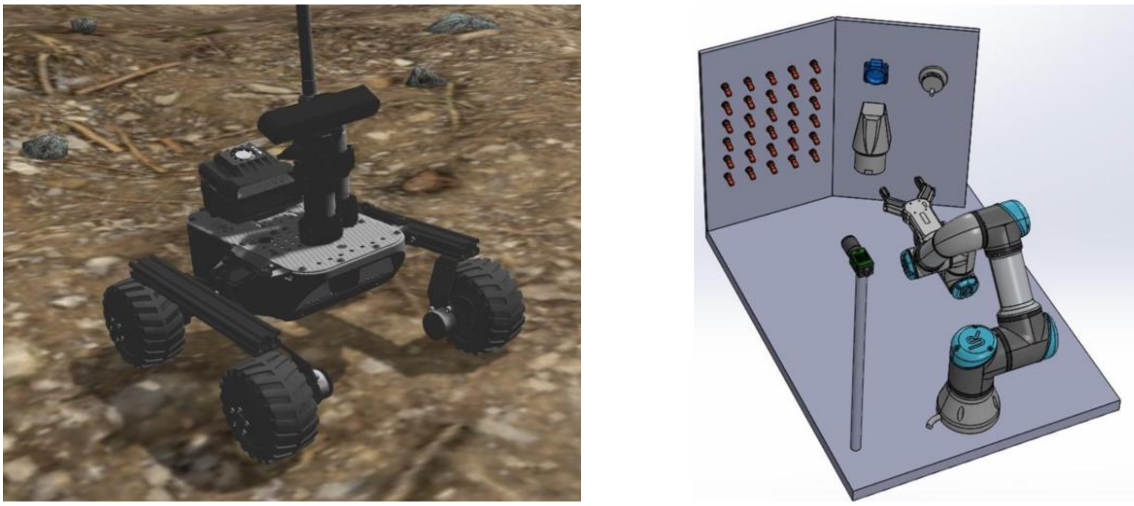

Fig. Preview of simulation models for the preparation of control algorithms for ERC 2020

During the activities of the solved project, the possibilities of using virtual reality in connection with the simulation system ABB Robotstudio for previews of designed workplaces and for accelerating the creation of basic waypoints of the robot program as another way of programming robots were verified.

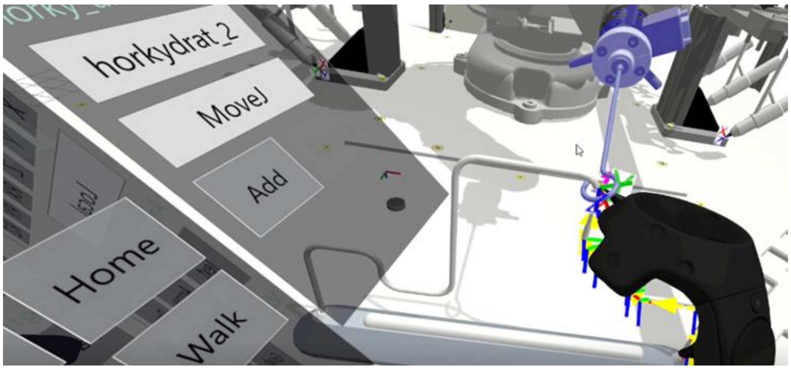

Fig. Demonstration of using a VR system driver for robot motion programming

Two case studies of the use of IoT in robotic workplaces in the laboratory were carried out, in which data were read into the SW tool ThingWorx, where they are further processed, archived and monitored. Gradual interconnection of SW tools from PTC prepares data for the use of AR and VR for monitoring the status parameters of real workplaces. Assignments for other activities in this area were specified, both in the field of visualization of the current state of the workplace and its systems in SW Vuforia, and statistical evaluation of long-term collected data for their use for predictive maintenance in SW ThingWorx. Other application possibilities of SW Vuforia and AR are support of operation and maintenance of workplaces, which we will also deal with further.

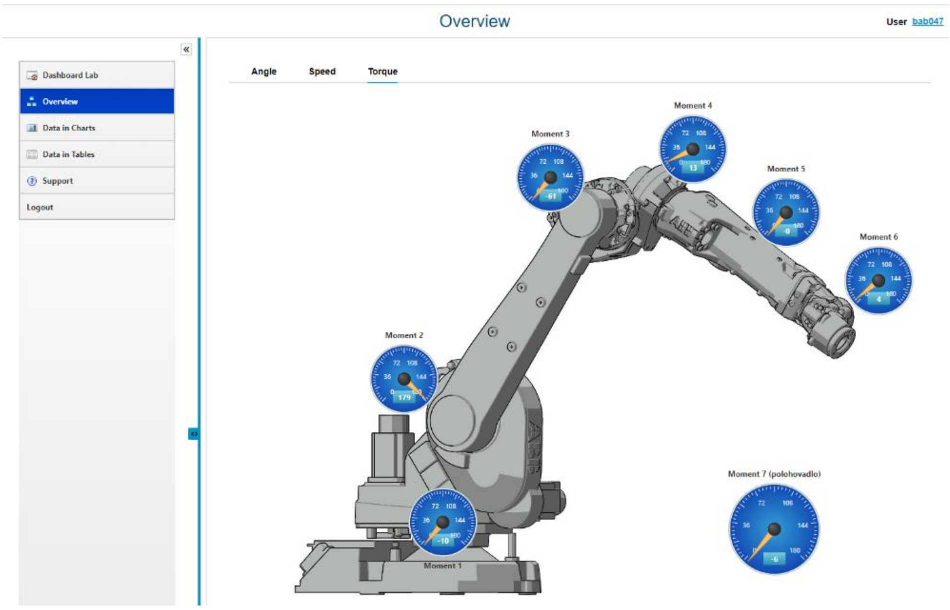

Fig. Preview visualization of current status parameters of the IRB 1660 robot in the ThingWorx SW

The project also supported activities in the field of creation and verification of simulation models of flexible materials for use in robotics. Analyzes of material properties of samples produced by additive FDM technology from available flexible materials were performed. Cyclic load tests of the designed experimental jaws of the end effector made of flexible material were performed using a robot with a force-torque sensor.

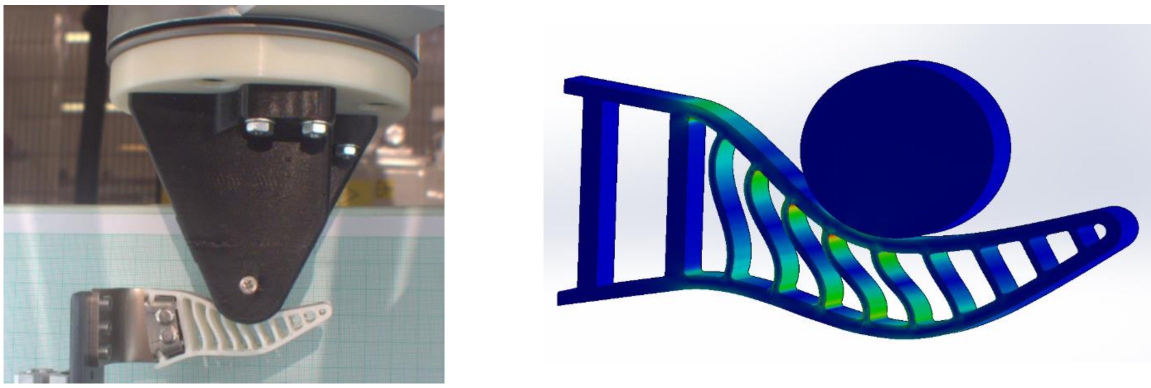

Fig. Implemented experiment and simulation model of an elastic part

In 2020, 1 diploma and 5 bachelor's theses supported or related to the SGS project were defended:

- Bc. Sýkora V. – Use of virtual reality in the design and operation of robotic workplaces
- Bednárik R. – SW tools for creating complex simulation models of robotic workplaces and their basic characteristics
- Chlebek J. – Design of demonstration tasks with UR3 robot
- Maslowski J. – Design modification of the first joint of the K3P4 robot manipulator
- Moša O. – Dynamixel drive library and its accessories for CAD and simulation systems
- Postman T. – Equipment for storing soil samples for the K3P4 robot

4.9. European Rover Challenge

Participation in the European Rover Challenge (ERC) 2020 - A twelve-member team of Rover's doctoral, master's and bachelor's students has participated in an international robotic competition for the third time. They improved the previous bronze position this year and won silver. The team also won two special awards: for best analysis and best autonomous navigation. A total of 46 teams from all over the world took part in the competition.

Due to the Covid-19 epidemic, this year's competition took place in a different form than in previous years, the competition was now held at a distance and all participants competed with the same rover. The task was not to design the best possible design of the robot, the team members focused more on the competition disciplines simulating the geological exploration of Mars and the creation of software for the platform provided by the organizers.

Classically, they compete in four practical tasks, presentation skills, and also in the processing of documentation for the robot. Due to the modifications of the rules, of the original five competition tasks (presentation, navigation, manipulation, collection, science), only the presentation, which just took place via a video call, remained unchanged. The collection task was completely eliminated from the competition. The task of manipulation was solved by controlling the UR3 robot remotely using several cameras, and the team had to use precise positioning using a joystick to complete the tasks on the control panel in front of the robot. This year's navigation and scientific task was combined into one, where the robot had to first pass through the given points and then examine the surface and find the artefact in the field.

The ERC has been held in Poland since 2014 and is supported by the European Space Agency (ESA). Practical demonstration tasks take place in an environment reminiscent of conditions on the surface of the Moon or Mars. Truck operators cannot have visual contact with the rover and all communication must be handled by the control system. Competition website: http://roverchallenge.eu/

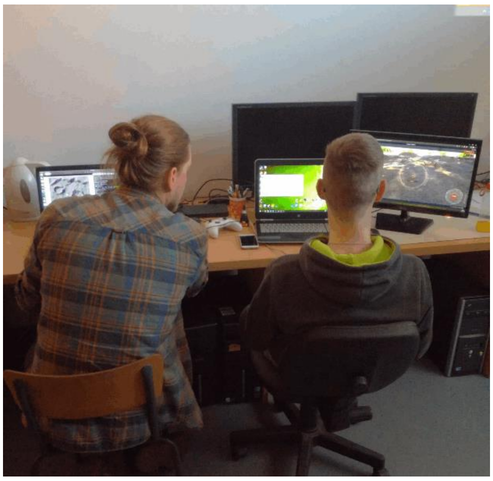

Fig. Photos from the competition ERC 2020 - Control of a robot located in Poland from the laboratory of the Department of Robotics

Fig. Photos from the ERC 2020 competition - View available to the competition teams: on the left from the Leo Rover camera for the Science task, on the right from the camera watching the robot workplace for the Maintenance task

Fig. RoverOva during the preparations for the ERC2020 competition

The project is financially supported by SGS and IRP projects, as well as by the Faculty of Mechanical Engineering and the home department of robotics.

5. PEDAGOGICAL COOPERATION

5.1. Significant cooperation with subjects in the Czech Republic

Within the solution of DMS projects - Platform for research focused on Industry 4.0 and robotics in the Ostrava agglomeration, cooperation was established / deepened with:

- HELLA Autotechnik Nova, s.r.o.,
- Brose CZ,
- VOP CZ (Military repair company),
- Moravskoslezský automobilový klastr,
- Brano,
- Varroc,
- Continental,
- Vitesco Technologies,
- ABB
- And others…

A cooperation agreement was signed with SoliCAD s.r.o. within which the simulation system Visual Components is provided to the department for teaching purposes. The SW will be used in teaching the design of robotic workplaces for conceptual design of workplaces and verification of sequences of operations performed on them.

As part of the long-term cooperation of the department with AV ENGINEERING a.s., which is a supplier of SW tools from PTC, we managed to extend the licenses of ThingWorx and Vuforia tools for educational purposes at a significantly reduced price for 3 years. This will allow us to further gain experience and create case studies of the use of IoT, augmented and virtual reality in the fields of industrial and service robotics.

5.2. Significant cooperation with foreign partners

- Ton Duc Thang University – Vietnam – contract on teaching Vietnamese students - PhD students, self-payers, in the field of Robotics.

- Deepened cooperation between TU Košice - Department of Mechatronics, Department of Manufacturing Engineering and Robotics, Department of Applied Mechanics and Mechanical Engineering.

- Deepened cooperation with SUT Gliwice Department of Fundamentals of Machinery Design.

- Deepened cooperation with STU MFT Trnava.

- Established cooperation with the University of Innsbruck.

5.3. Abroad stays of teachers and students

At the beginning of the year, we managed to implement a number of stays. Due to Covid-19 restrictions, a majority of planned events had to be cancelled or postponed.

- Assoc.prof. Bobovský, Ing. Krys – TU Košice
- Ing. Vocetka, Ing. Oščádal – TU Košice,
- Assoc.prof. Bobovský, Ing. Krys, Ing. Huczala, Ing. Mlotek – Joanneum research – Robotics, Klagenfurt,
- doc. Bobovský, Ing. Krys – SUT Gliwice
- Ing. Pastor, IT University, Kodaň, Danmark
- Ing. Heczko, Tampere, Finland,
- Ing. Huczala – University of Innsbruck

5.4. Foreign guests and students

Justinas Miseikis, Nelija Borisenko

Fig Lecture: Robot perception and social robotics

F&P Robotics

Lecture: Robot perception and social robotics

Eugeniusz Piechoczek, Wawrzyniec Panfil, Piotr Przystałka

SUT Gliwice

Meeting in order to establish deeper cooperation in the use of robotic technology for maintenance of power lines

Prof. Ing. Jozef Svetlík, PhD.

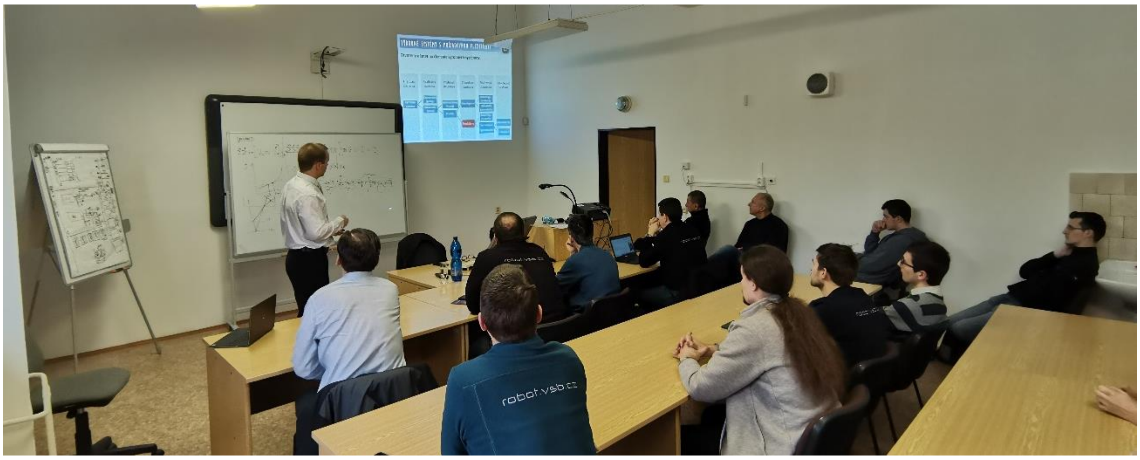

Fig.. Lecture: Production systems with flexibility requirements

TU Košice, Department of Manufacturing Engineering and Robotics

Lecture: Production systems with flexibility requirements

Internships:

Mateusz Kosior, January 2020, Collaboration on ERC – Design of simulation system for K3P4 simulation in unknown environment.

6. SCIENCE - RESEARCH ACTIVITIES

6.1. Currently solved projects

Name	Period	Budget (Euro)
Robot for participation in competitions	2020	0,1M
Research Centre of Advanced Mechatronic Systems	2018 - 2022	2,6M (from 9,6M)
Research Platform focused on Industry 4.0 and Robotics in Ostrava Agglomeration	2018 - 2022	0,64M (from 3,2M)
Digital twins of robotic systems and their verification II	2020	0,1M
National Competence Centre of Mechatronics and Smart Technologies for Mechanical Engineering	2019 - 2020	0,6M

6.2. Main directions of R&D

The following chapters present selected topics from the field of R&D, which were solved mainly by the employees and doctoral students of the Department of Robotics within the above-mentioned projects. (*Only already published outputs are listed*.)

6.2.1. Increasing the accuracy of the manipulator

In the first phase, this research aims to focus the current state of the manipulator and the dependence of its repeatability on the direction of arrival to the measured target point. Within this research, a number of measurements were performed under different conditions (at different carried weights, distances, number of starting points, etc.). The analysed data were measured by DIC cameras, collected by our own application written in C # and evaluated by Istra 4D and MatLab software. The research is described in detail in the article Influence of the Approach Direction on the 2 Repeatability of an Industrial Robot (https://doi.org/10.3390/app10238714) This research was carried out in close collaboration with doc. Huňady and Ing. Haga, Ph.D. from the Technical University in Košice, Faculty of Mechanical Engineering, Department of Applied Mechanics and Mechanical Engineering.

Fig. Use of DANTEC DIC cameras to measure the repeatability of the manipulator

Furthermore, the structures of two identical robots (ABB IRB1200) were measured with a FLIR Ax5 thermal imager and a set of thermometers (52 pcs). The result of these long-term measurements (under different conditions, a total of 64x 8h) is a detailed description of the dependence of the heating of the individual axes of the robot, under the given conditions, on time. In the future, this information will be used to increase the accuracy of the manipulator, as temperature changes have a major impact on this.

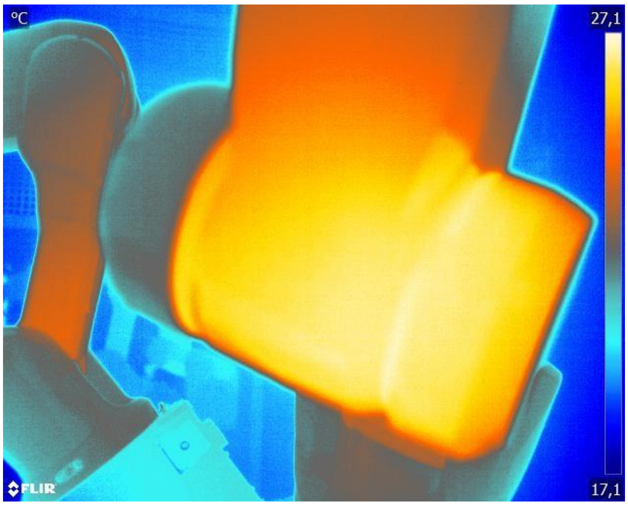

Fig. Axis of the IRB1200 robot, in the background on the left a robot of the same type with a warming up II. axis

6.2.2. Methodology and theory of conceptual design of robotic manipulators with computer support

Computer generated designs of robotic manipulator concepts draw on research in the field of evolutionary robotics. This area often focuses on the simulation of natural evolution for the design of robot controllers (motion generators), robot morphology or kinematics, or both of these properties simultaneously. Often the subject of this research is a mobile walking robot, but focusing on manipulators is no exception. Evolutionary robotics mostly focuses on the construction of robots from predefined building elements or modules. At our department, we investigated what concepts of link modules in optimized manipulators are beneficial to use. We have prepared four types of link modules, which a genetic algorithm uses to construct manipulators, always in combination with a drive joint module. The tested modules were of the following types: basic (predefined modules with a given length), linear (modules with variable length in one direction), rounded (modules with variable length, radius of curvature and twist angle) and curved using a Hermit curve. From the results of our simulations, we found that the benefits of curved modules are not high enough to justify their use. Manipulators with simpler (straight, with fewer parameters) modules not only converged faster, but achieved better overall results even with a longer optimization run.

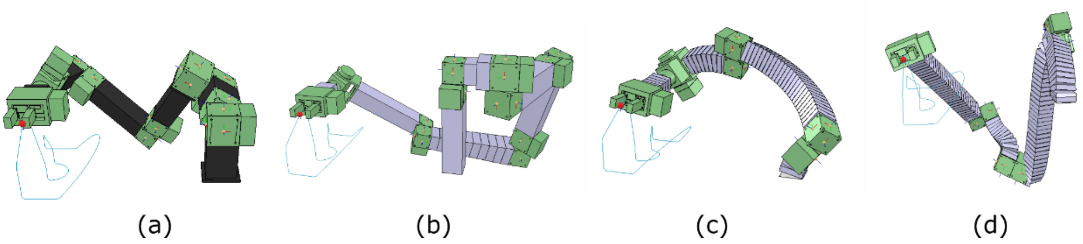

Fig. Manipulators after optimization composed of modules: a) basic, b) linear, c) rounded, d) Hermit curves

6.2.3. Research and development of multi-chamber insulating glass of a new type and its production

The project within the OP PIK was solved in cooperation with the company Energy In. s.r.o. Research and development of technical means for a robotic production line of an insulating glass assembly, consisting of a foil stretched in a steel frame (FIS) and two glasses, was carried out. The concept of the production line, its layout and the design of handling equipment, solution of inter-operational storage facilities and workplace management equipment were solved. At the same time, in cooperation with the staff of the Department of Power Engineering, the optimization of the product - insulating glass with a divided chamber and very low thermal conductivity for individual variants of foil fixation solution was solved and a number of experimental measurements of thermomechanical and sound properties of functional samples of insulating glass were performed. A computational algorithm was designed to calculate the heat transfers for different numbers of chambers, and thus for the various numbers of the dividing foils in the insulating glass. A test robotic workplace with a wide-range gripper for handling foil frames was implemented.

Fig. Robotic workplace for testing

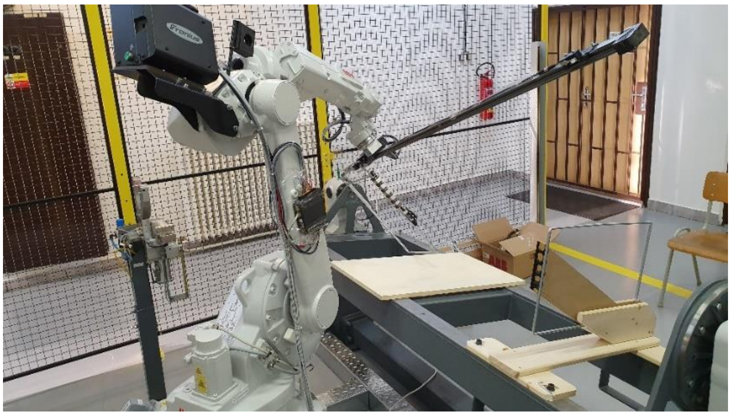

Fig. Robotic workplace for testing with magnetic holder of the frames

6.2.4. Automated assembly of pipe sleeves

In cooperation with the FEI (beneficiary), applied research of the system is carried out within the project "Research of possibilities of robotization of technology of assembly of metal products with rubber" (TAČR EPSILON TH04010428), which could fully automate assembly of pipe sleeves. The project contractor is Optimont 2000 s.r.o. The main challenge is the application of a rubber DGL profile on the body of the sleeve, a process whose automation is very complicated. Work on the project began in January 2019. A prototype feeder was designed and implemented for dividing the profile and applying it to the sleeve. The project will be completed at the end of 2021.

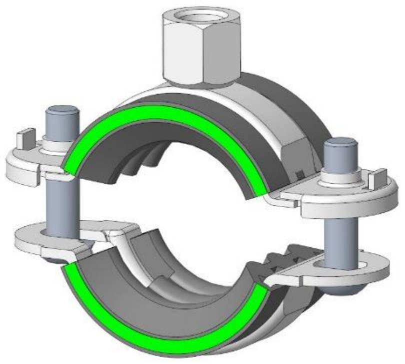

Fig. Pipe clamp

Fig. Upcoming test robotic workplace for assembly of rubber profile on sleeve molding to verify the functionality of the feeder prototype

6.2.5. Electronic catalogue of industrial and collaborative robots

As a part of one project, the department is creating an electronic catalog of conditions and principles for the effective deployment of industrial and collaborative robots. Based on this catalogue, it is possible to determine or recommend a suitable type of robot or cobot, while the parameters for robot selection are, for example, load capacity, working space, positioning accuracy, safety conditions, etc.

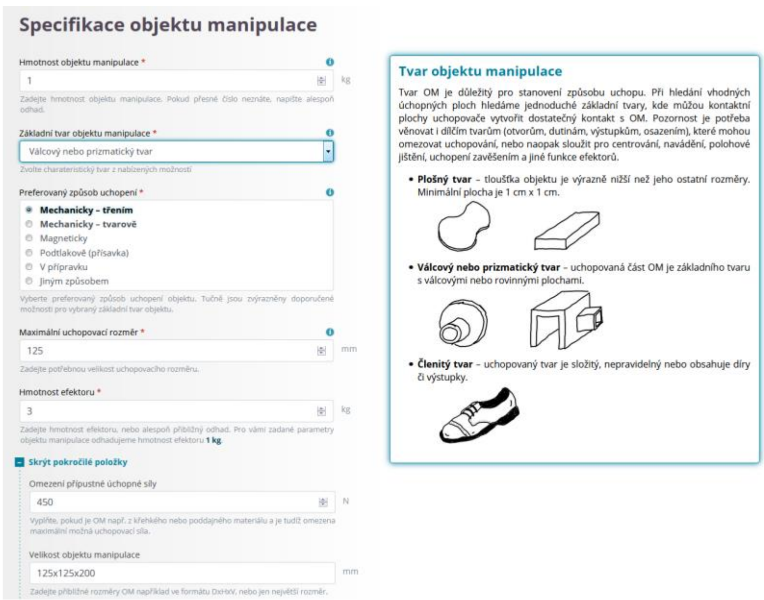

Fig. Example of a part of one page of the e-catalog input form

6.2.6. System for finding the optimal robot placement

The Department of Robotics is further developing a complex software simulation system providing support in the design of robotic workplaces – especially the selection of suitable robots and finding their suitable locations in relation to the trajectory of the end point. The newly designed method takes into account the wear of the robot when choosing the location of the robot, and the optimal position is sought in order to reduce the overall wear of individual joints and at the same time to prevent disproportionate wear of one joint (or several) relative to others. This should extend the life of the robot and prevent in practice relatively frequent situations where the industrial or collaborative robot fails after a short time because of one extremely stressed joint.

The criterion for evaluating joint wear is based on the calculation of the integral of the mechanical work performed by each joint during the entire work cycle and thus includes both the speed of movement and the torque. Not only the minimum of these values of joint wear is sought (reduction of total wear), but also the minimum of their standard deviation (ensuring balanced joint wear).

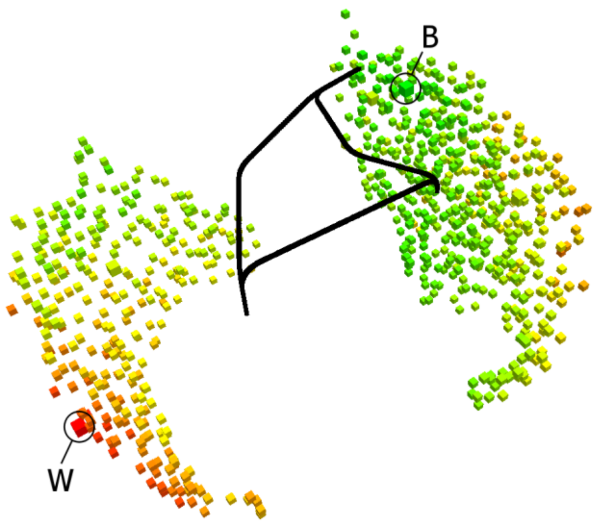

Fig. Evaluation of possible UR3 robot locations relative to the trajectory according to joint wear (W = the worst location, B = the best location)

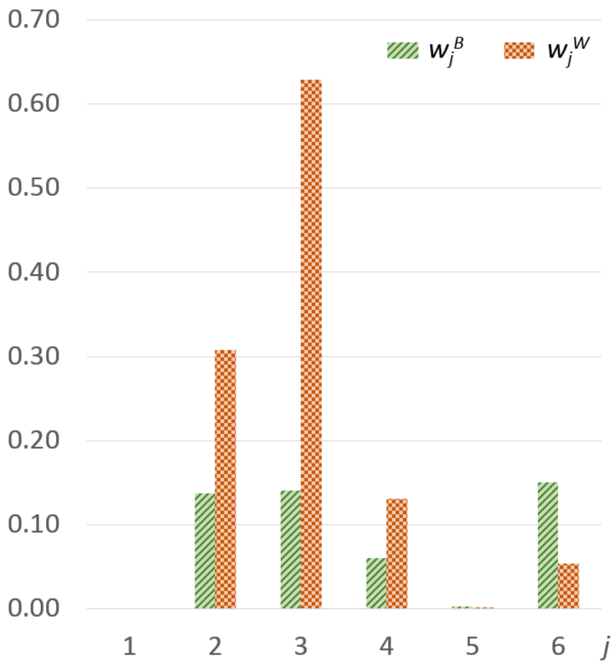

Fig. Values of the chosen wear factor for individual joints (1, 2, ... 6) of the UR3 robot for the best (B) and worst (W) location

6.2.7. Finding optimal manipulator arm shapes to avoid collisions

In situations of a confined workplace with a lot of obstacles and a complicated required trajectory of the endpoint of an industrial or collaborative robot, it may be impossible to find a suitable robot and its position within the workplace to fulfill the given task. In some cases, it could be favorable to design a custom manipulator arm with an unusual kinematic structure or shapes of some of its links.

The research focuses on finding a novel way of finding the optimal lengths and shapes of two crucial links of a manipulator arm, where the target lengths are as short as possible to reduce mass, and the shape in the form of a Bezier curve is chosen to avoid collisions.

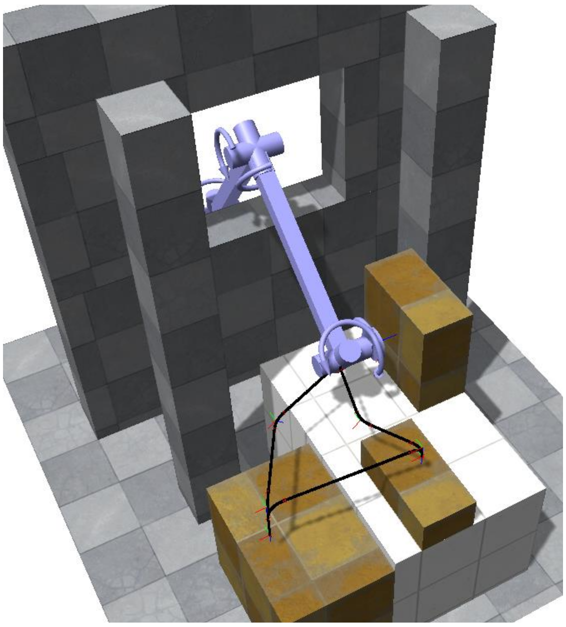

Fig. A sample confined workplace, a robot with straight arm links is in collisions

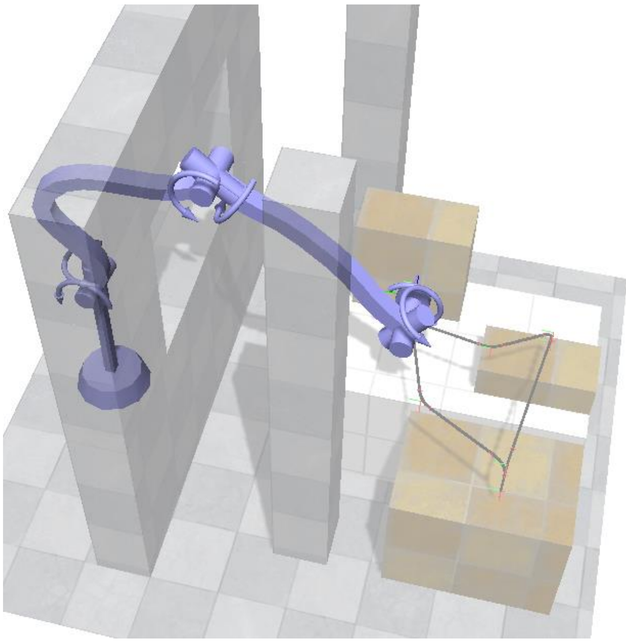

Fig. Proposed solution – a robot with curved arm link can fulfill the task without collisions

6.2.8. COBOTs

Within the project, three workplaces with collaborative robots for member companies of the Moravian-Silesian Automotive Cluster were solved. It was the integration of the two-handed collaborative robot ABB 14000 YuMi in the assembly production line, as a replacement for the manual assembly operation, which saved one worker. Within the project, a number of simulations were first performed, which showed a possible way to solve the assigned assembly task. On this basis, the entire assembly workplace was designed, manufactured and adjusted, including the vibrating conveyor and the control PLC (B&R).

Fig. Assembly station with the YuMi collaborative robot

For other workplaces, the issue of Bin Picking was solved, i.e. the selection of non-oriented objects from crates. These are plastic boxes, where the upper and lower part of the plastic box is loaded into the system pallet on the production line and this operation was previously performed manually. The solution was performed using a visual 3D system from Fanuc.

Fig. Test workplace for bin-picking

In the next part of the project, an automatic testing device for car door components was solved, where the robot manipulates the internal mechanisms of the door using a specially developed measuring head with a load cell and the tripping force is measured during movement. As part of the solution, the measuring head device, support points for stabilizing the measuring head position and software for measuring and visualizing the measured values were structurally solved.

Fig. Functional sample of the measuring effector on the UR10 robot

6.2.9. Precision of LeapMotion sensor

To find optimal devices for hand tracking which will lead to development of HMI to control the robot with operator's gestures we designed and performed a measurement of precision of hand-tracking ability of LeapMotion sensor which can track the human hand and its parts. Measurement was performed with the industrial robot UR3 which was used to position artificial hand. Position of the fingertip was compared with detected by the sensor which was mounted above the scene. The result is a precision map of the sensor in its operating space and also beyond it for setting corrections and limiting of the detection space.

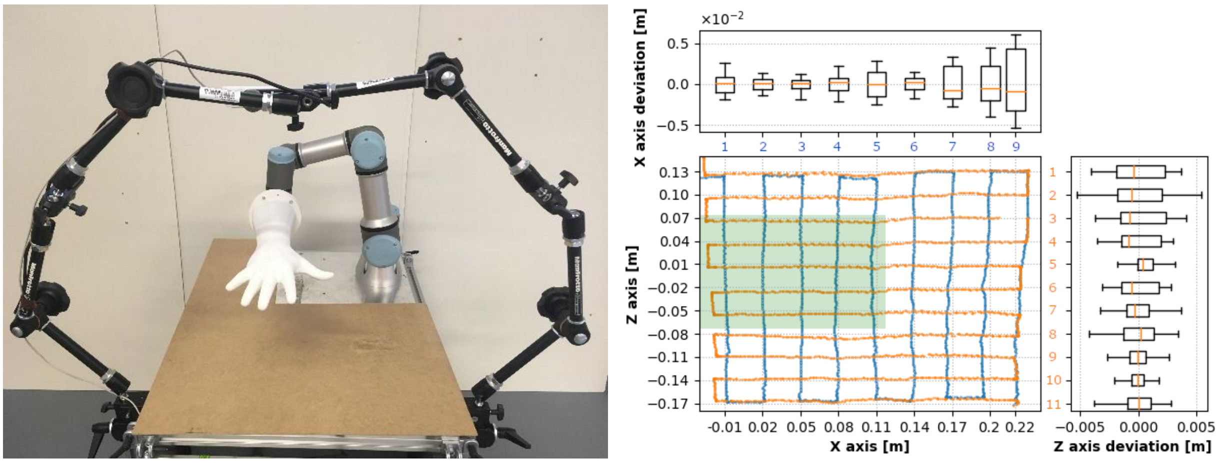

Fig. Precision measurement of LeapMotion sensor

6.2.10. Trajectory planning of non-technological moves

The subject of the research was to discover more energy-saving movement of the robot than the default movement created by the standard trajectory planner developed by the robot manufacturer. With optimization algorithms (PSO) were found more efficient trajectories for measured movements and these were experimentally verified using the real UR3 robot. Results may be used for energy optimization of robot movements between different technological positions.

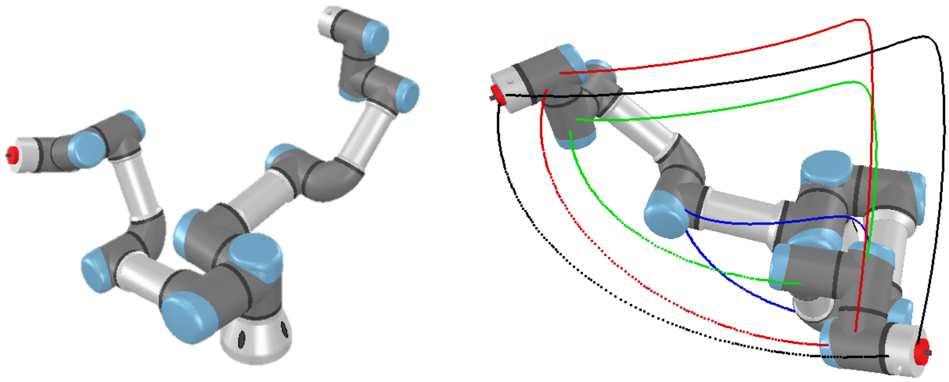

Fig. Different trajectories of non-technological moves

6.2.11. Determination of the influence of tensile strength on annealing temperature and annealing time for PLA samples produced by Fused Filament Fabrication

3D printing is widely used in our department for making prototypes of various devices, especially robots. When designing such devices, it is important to know the mechanical properties of the materials used. Due to the fact that 3D printing is a relatively new method, some important properties are not available from the manufacturers of printing filaments, especially if they are newer materials, or if the properties depend on the print settings. Therefore, at the department in cooperation with the Department of Applied Mechanics, we also test the mechanical properties of printed parts.

One of these tests was to determine the effect of annealing on the tensile strength of printed plastic samples. The purpose of annealing is to reduce the internal stress in the material, which was created by the printing of the part itself. In this testing, we focused on the effect of the size of the annealed temperature and the total annealing time. All samples were printed by Fused Filament Fabrication on a PRUSA I3 MK3S printer from three different PLA materials (classic PLA, PLA PLUS and PLA-HD). The physical properties of the materials were used for testing, and therefore temperatures from 60 (at this temperature the material softens) to 160 °C (around this temperature the material melts) were chosen. The annealing time that was tested (from 15 to 240 minutes) is based on the size of the samples. For our purposes, a sample was selected, the dimensions of which are shown in the following figure. The position of the samples on the printing bed is also shown in the following figure.

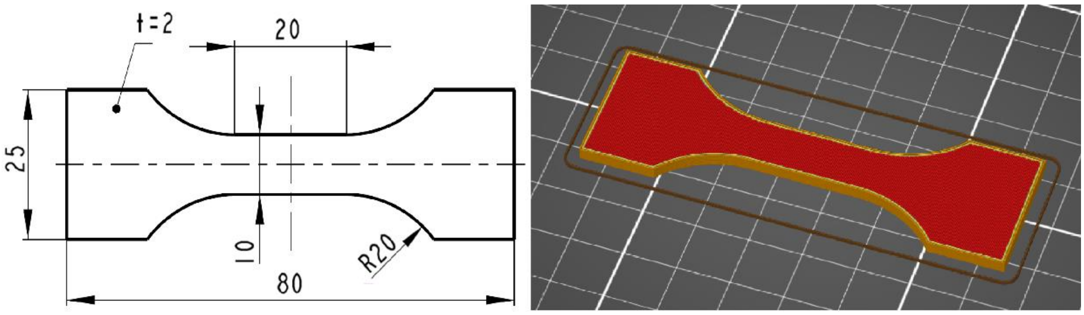

Fig. Sample dimensions (left), sample position on the printing bed (right)

Due to the fact that the samples deformed due to the relaxation of the material during annealing, this deformation was evaluated for all samples. The samples changed not only their dimensions but also their shape, however, the change in shape was not measured in this test. The annealing was performed in a Memmert Universal Oven UN30 industrial oven. The samples were tested on a Testometric M500 / 50 CT machine to determine the tensile strength. Along with the annealed samples, unannealed samples were also tested to show an increase in strength due to annealing.

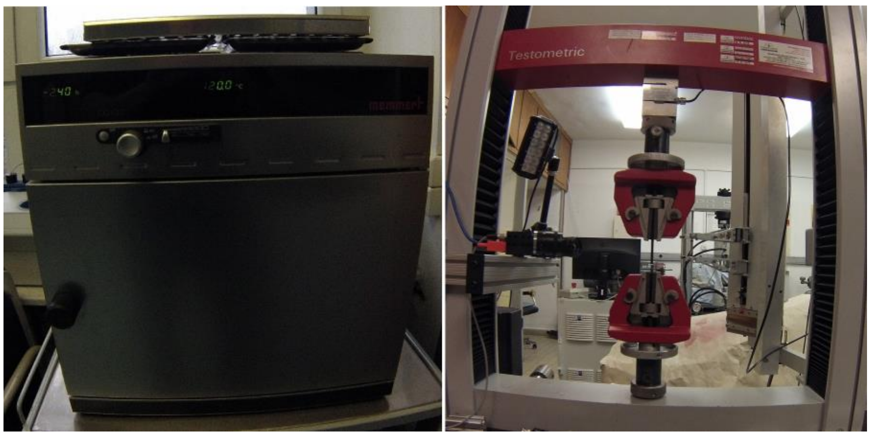

Fig. Industrial oven (left), test machine with tearing test sample (right)

All annealed samples changed their dimensions. This change depended on the orientation of the printed part relative to the bed. All dimensions perpendicular to the bed (print height) increased after annealing, dimensions parallel to the bed were shortened. Several samples melted due to the high temperature, while others showed only minor variations in shape and size. All annealed samples showed an increase in tensile strength, the magnitude of which was dependent on the annealing temperature. When measuring the annealing time, no difference was found between the annealing time of 15 minutes and 240 minutes. Once the material was heated to the required temperature in its entire volume and deformed due to relaxation, the further annealing time had no measurable effect on the tensile strength.

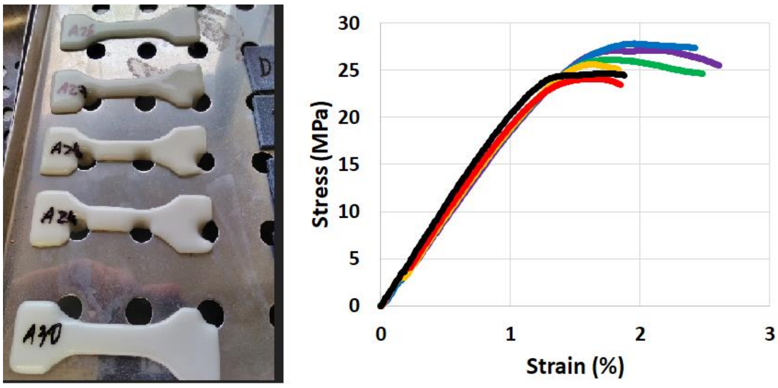

Fig. Melted samples (left), stress–strain diagram for different annealing temperatures (right)

6.2.12. Optimization of parameters for automatic trajectory planning of a 6-axis robot

In order to test the MoveIt! Framework, which represents the current state of the art in the field of trajectory planning in a dynamic environment, a workplace with a collaborative robot UR3 was prepared. A workplace with a UR3 robot, monitored by one RealSense D435 depth camera and off-line simulation of the same workplace were prepared as a benchmark environments for motion planning algorithms were available in MoveIt!.

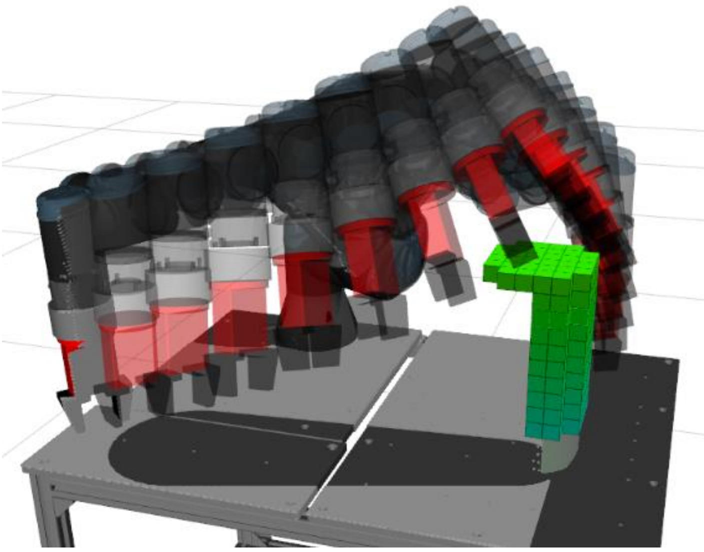

Fig. Visualization of the robot's trajectory planned around the obstacle. Trajectory generated by the RRTConnect planner

The goal of tuning the parameters of perception and planning is to find such a combination of parameter values in which the time of both planning and execution of all movements will be minimized simultaneously with reaching the maximum ratio of successfully performed attempts with respect to the total number of attempts. To assess the effects of individual settings on the planning speed and trajectory length, the following virtual benchmark was performed, where an obstacle was placed in the simulation model in the robot's workspace. A total of 31 variants of system settings were measured, including the default. 30 simulation cycles were performed for each setting (i.e. a total of 930 cycles).

Subsequently, based on the determined effects of individual parameters on the overall performance of the system, 3 parameters were selected to optimize their settings using the Particle Swarm Optimization. The optimization process was performed 2 times, each consisting of 625 measurement cycles. To verify the optimization results, benchmarks were performed in a simulated and real environment.

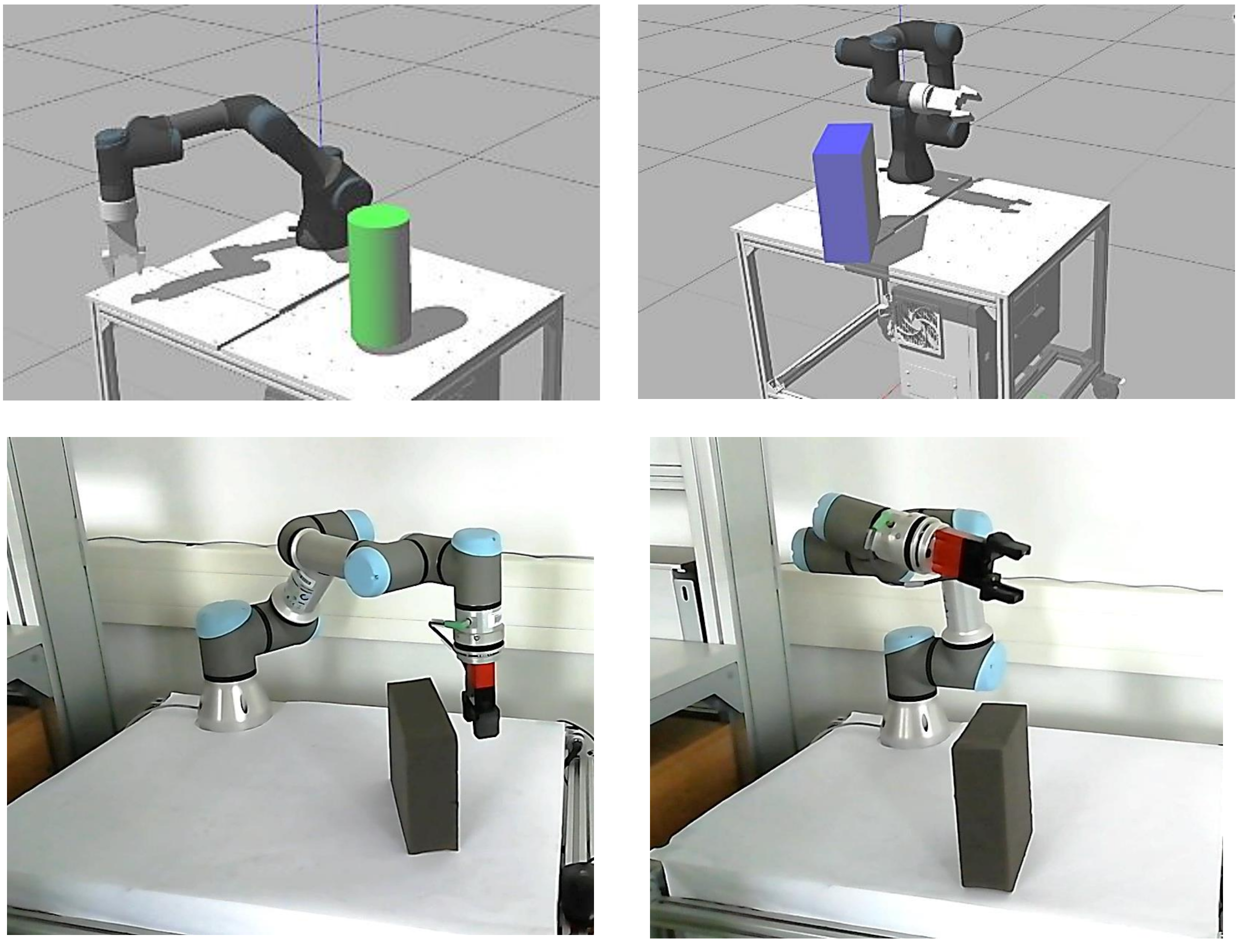

Fig. Performed benchmarks

During each benchmark, system performance was compared at optimized and default settings. To measure and compare the performance of these variants, each of them was measured 30 times. Both benchmarks performed in the simulation using the optimized settings show the improvement of the measured cycle parameters (planning and execution times). The results of benchmarks performed with a real workplace are similar to the results of benchmarks with a simulated model.

6.2.13. State of the art analysis of upper limb prostheses control and implementing natural proprioception

The loss of a hand has significantly affect one's work and social life. For many patients, an artificial limb can improve their mobility and ability to manage everyday activities, as well as provide the means to remain independent. Even though prosthetics as a field of medicine originated many centuries ago, it is still an area that is developing and largely dependent on the research of new technologies. Even the most modern innovations and discoveries in this area cannot provide an ideal replacement for lost limb functions. Multiple control topologies have been developed over the past seventy years with electromyography (EMG) being the most commonly used technology these days. However, there are other less-known and yet unproven techniques available, which may potentially represent a number of advantages such as simultaneous proportional control over multiple degrees of freedom (DOFs) and the possibility of enabling intuitive proprioceptive feedback. An extensive analysis of available biosensing methods of implementing the control system for hand prostheses was performed in order to map all the possibilities. The covered techniques include electromyography, magnetomyography, electrical impedance tomography, capacitance sensing, near-infrared spectroscopy, sonomyography, optical myography, force myography, phonomyography, myokinetic control, and modern approaches to cineplasty.

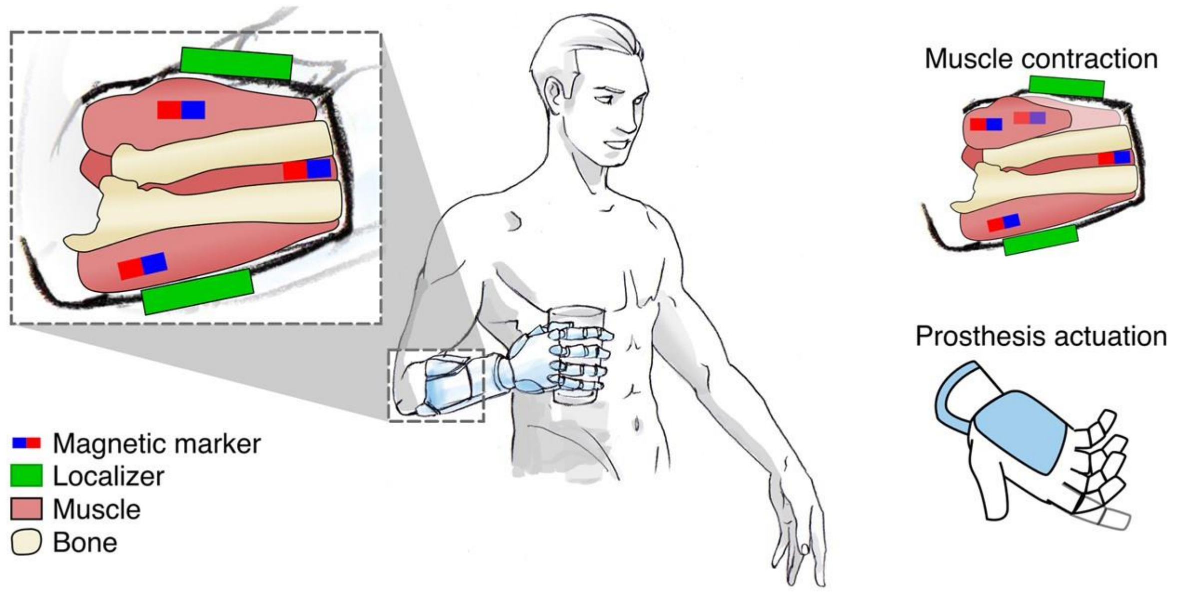

Fig. An example of perspective approach to prosthesis control – MYKI project

The paper also covers combinations of these approaches, which, in many cases, achieve better accuracy while mitigating the weaknesses of individual methods. The analysis is focused on the practical applicability of the approaches, and analyses present challenges associated with each technique along with their relationship with proprioceptive feedback, which is an important factor for intuitive control over the prosthetic device, especially for high dexterity prosthetic hands

6.2.14. Automation of design of industrial robots and manipulators

The design of industrial robots and manipulators, or their individual structural units, is a demanding process both in terms of the necessary expertise and in terms of the time required. For this reason, knowledge databases and software tools are being developed that would significantly facilitate and speed up these processes. In the figure is a scheme of developed knowledge base.

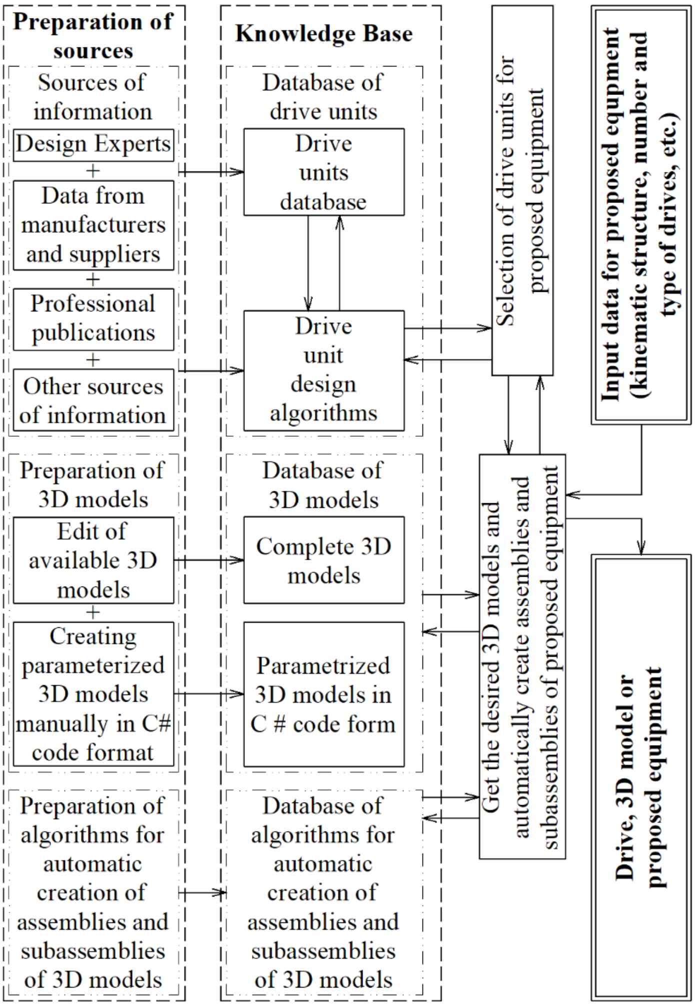

Fig. Knowledge database scheme

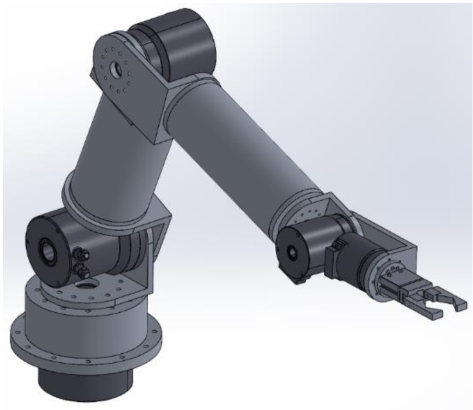

Fig. 3D model of a robotic arm

The knowledge base contains both pre-prepared 3D models of elements used in the construction of industrial robots and manipulators, and parameterized 3D models in the form of C # codes, based on which it is possible to create new 3D models using the API of the SolidWorks software. The database also contains code sequences that can also be used to create the required assembly models.

In order to simplify and shorten the development time, specialized software tools are being developed. Drive Picker software has been developed to selection of compact drive units. This tool has both a graphical interface, with which it is possible to enter the values needed for the selection of power units, and an interface that allows its connection with other simulation software tools.

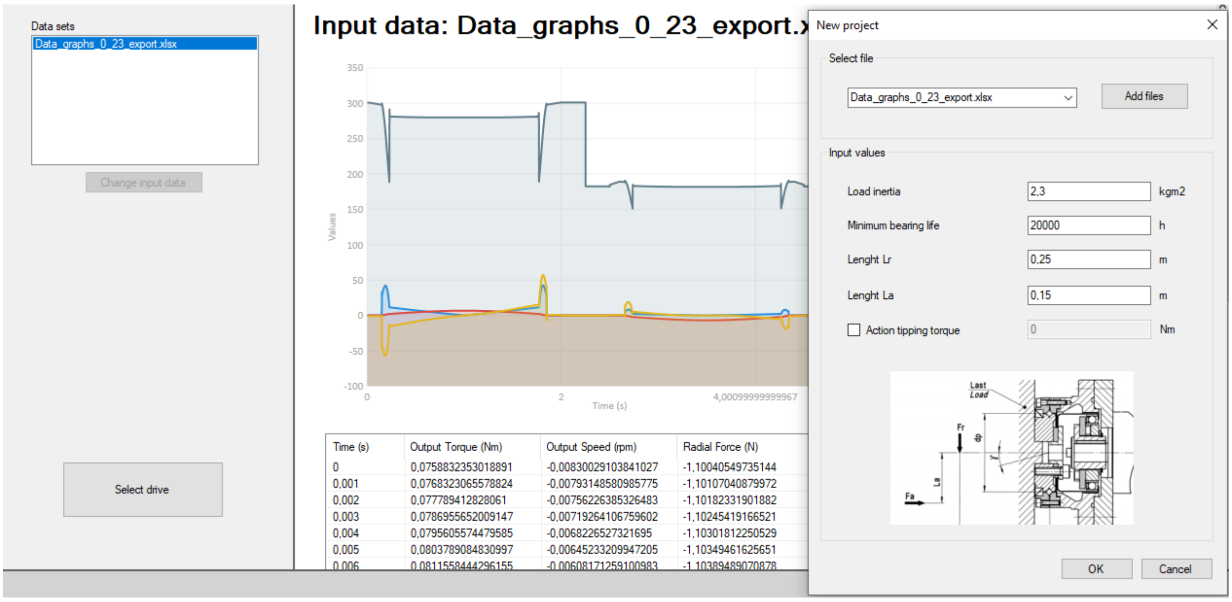

Fig. Drive Picker software tool

The software tool RobotArmDesign was developed for the design of the arms of industrial robots and manipulators. This tool has a database of available solid and thin-walled cross-sections. Based on the input parameters and the relations based on the Castiglián theorem, the dimensions of the profiles that meet these parameters are selected. It is also possible to limit the selection in terms of minimum dimensions, weight or aspect ratios for selected types of cross-sections. It is also possible to use the connection with the SolidWorks CAD system and its module for strength analysis during the design.

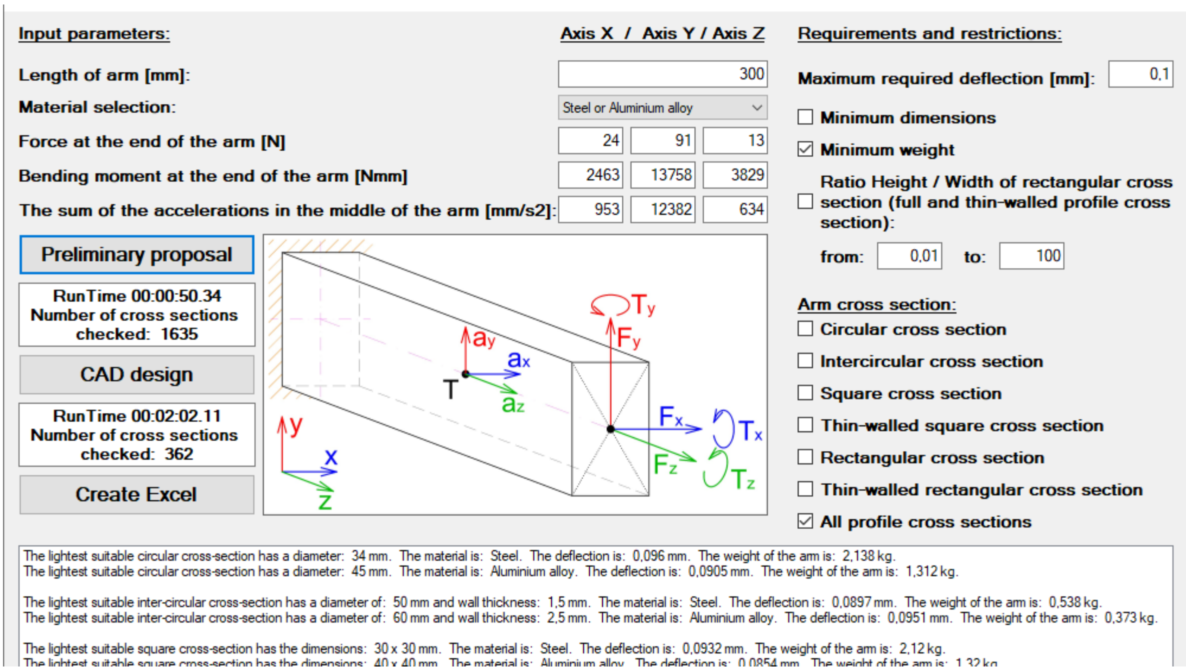

Fig. RobotArmDesign software tool

6.2.15. Synthesis of kinematic structure of robotic manipulator in general form

By synthesizing the kinematic structure of a manipulator is meant finding a structure that is able to perform the desired task. The advantages of a manipulator created "tailor-made" for the task are the reduction of energy consumption, minimization of mail and thus prices, or avoidance of collisions in a densely built-up area, where today ordinary universal manipulators could not even be used.

To achieve the goal are the use of numerical methods, as the analytical approach is a very complex, as yet unsolved problem. One of the methods we use to determine the kinematic structure is nonlinear programming, which falls under a very wide group of optimization algorithms. The aim is to find the local minimum of the target function, while the input is the coordination coordinates of the position and rotation of individual positions, which the manipulator must meet. The result is a table of Denavit-Hartenberg parameters, which is one of the most common notations for describing the kinematic structure of a manipulator.

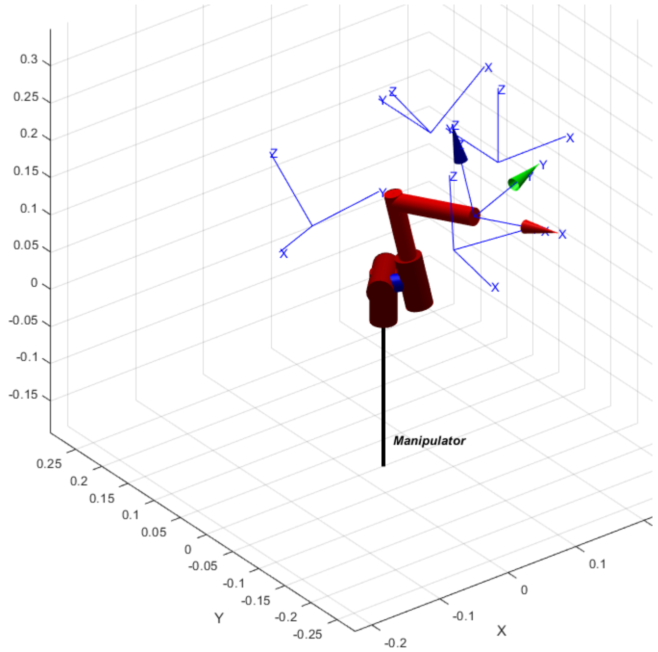

Fig.. Example of the result of the synthesis of the kinematic structure of the manipulator

The figure above graphically depicts one of the possible results of the synthesis of the kinematic structure of the manipulator. The five coordination systems (blue) served as input values for the algorithm. The method found a possible solution for 3 degrees of freedom (3 axes - robot motors), which are represented by a dark red thick cylinder. The thin cylinder shows the offset of the robot's end effector, its coordinate system is in the same position as one input coordination system.

6.3. Finished projects

The following text briefly presents some interesting projects solved in recent years at the Department of Robotics.

6.3.1. Safety Ambient Monitor - SAM

The two–years project SAM – Safety Ambient Monitor have been solved during 2014 – 2016 and co-financed from the European Regional Development Fund and the state budget of the Czech Republic. Project title: Pre-seed activities VŠB-TUO II – Safety. Reg. no.: CZ.1.05/3.1.00/14.0316.

SAM is a pocket system used to monitor and evaluate temperatures and other risk factors affecting firemen or other rescue team members.

The device increases the health safety of rescuers during fires and explosions and in other dangerous situations. During an event, a person using this device is constantly monitored via sensors. Data from the sensors are continuously monitored by a high-performance processor that, if necessary, sends out an alarm and notifies the user to take relevant steps to reduce the risk of bodily harm. Measured data can be wirelessly transmitted to the commander.

http://robot2.vsb.cz/sam (in English)

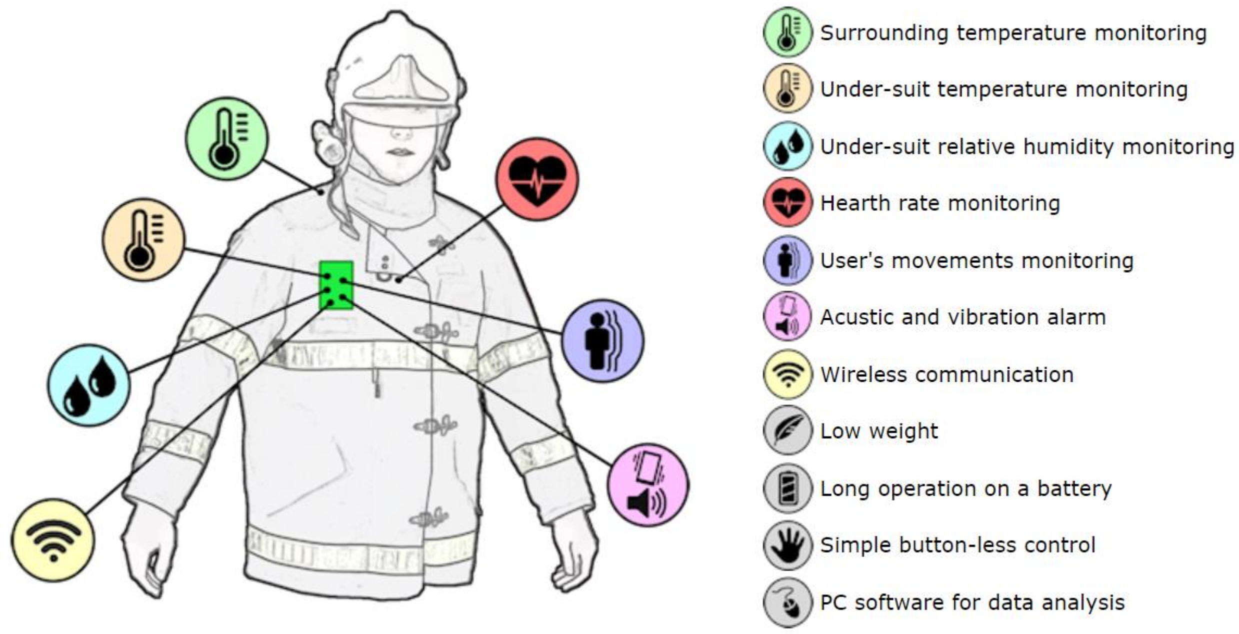

Fig. SAM functionality

Fig. SAM – unit and Commander´s tablet

6.3.2. TeleRescuer

The focus of the project "System of the mobile robot TeleRescuer for inspecting coal mine areas affected by catastrophic events" (supported by European Commission research fund Coal and Steel No. RFCR-CT-2014-00002 was the development and realization of a system for virtual teleportation (virtual immersion) of rescuers to the underground areas of a coal mine that have been closed due to a catastrophic event within them. It was an international project managed by a consortium composed of the Silesian University of Technology (Gliwice, Poland), the VSB -

Technical University of Ostrava (Ostrava, Czech Republic), the Universidad Carlos III de Madrid (Madrid, Spain), COPEX (Katowice, Poland), Simmersion GmbH (Groß-Siegharts, Austria), and Skytech Research (Gliwice, Poland) during 2014–2017 years. The one of the most important task there was safety requirements related to working at a coal mine with the hazard of an explosive atmosphere. There are some limitations related to the ATEX standards (EN 60079-0, Explosive atmospheres – Part 0: Equipment – General requirements).

The TeleRescuer robot (see figure below) consists of the main chassis with four independent tracked arms (eight motors, gears, motor controllers, batteries, and the main control system are placed in a flameproof housing), a sensory arm with a sensory head, a 3D laser scanner unit, and a mote deploying subsystem (motes are small Wi-Fi repeater modules). Every subsystem has its own independent power supply. The budget of this project was about 2,5 M Euro.

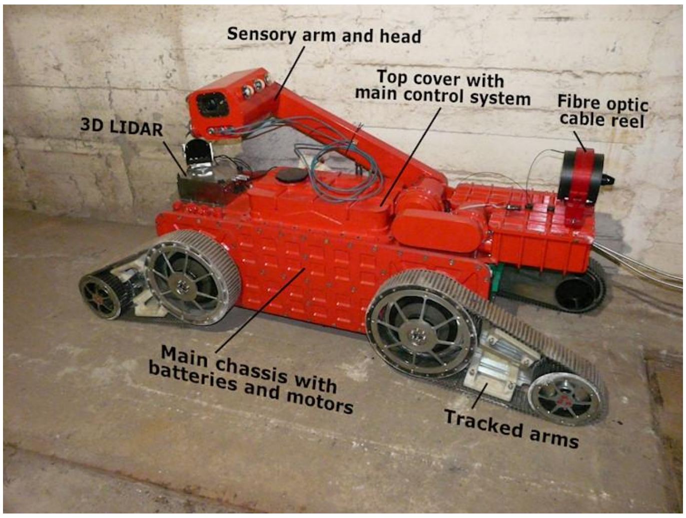

Fig. TeleRescuer—main subsystems and 3D map of Coal mine corridor

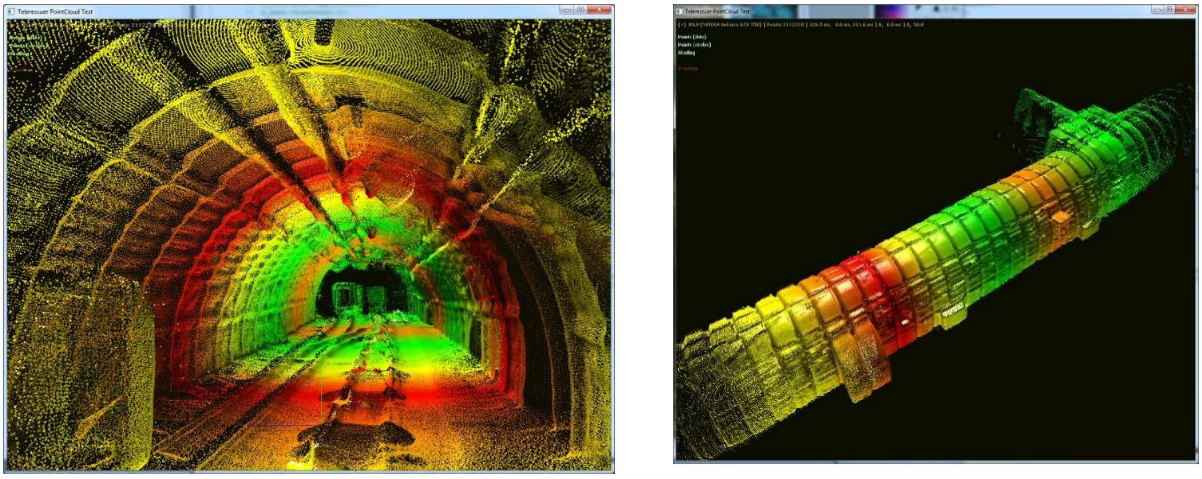

Fig. Visualization of coil mine corridor 3D map – points of clouds

http://robot2.vsb.cz/telerescuer (in English)

http://www.telerescuer.polsl.pl/ - official web

6.3.3. Hardy

Hardy is a remotely-controlled multipurpose service, emergency and rescue mobile robot designed for manipulations with objects of up to 300 kilograms of weight and also for other fire brigade and reconnaissance tasks. It is meant for use it emergency situations where a direct intervention of human rescuers or firemen is not safe. The robot is able to extinguish fire with a stream of water, with remotely adjustable shape of the stream. The mobile robot consists of three main parts: a robust chassis providing perfect stability and maneuverability, a manipulation arm with high load capacity, and a multipurpose effector with three adjustable gripping fingers and integrated water jet.

The robot was designed and developed in cooperation of: Strojírny Třinec a.s., Fite a.s. and VŠB – Technical University of Ostrava, Department of Robotics as part of project FT-TA5/071, supported by the Research and Development Program of the Ministry of Industry and Trade. Dimensions 3100 x 2060 x 2910 mm, Weight: 4500 kg.

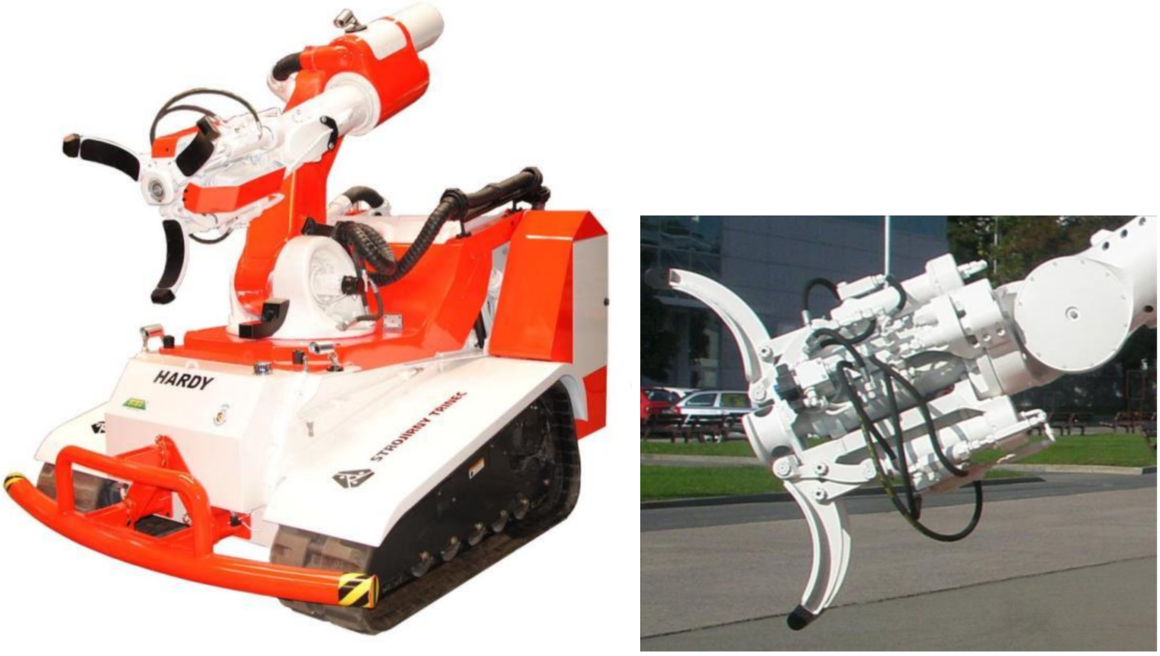

Fig. Robot Hardy (left), Robot gripper without shields with the integrated water nozzle (right)

6.3.4. TAROS

The Tactical Robotic System – TAROS is a military mobile robot developed in VOP CZ company with the cooperation of the CAFR consortium (*Centre for Advanced Field Robotics*), where Department of Robotics is the co-founding member. The Department of Robotics solved the design of a special robotic arm and gripper (7DOF) with control of grasping force and advanced control system with utilizing virtual reality. The part of the system is the real-time anti-collision system of the robotic arm and the robot body.

https://www.youtube.com/watch?v=nRejyA3d8bM&t=10s

Fig. Mobile robot TAROS

6.3.5. Detector

The DETECTOR (systems of 3D cameras and SW) is able to detect cardboard boxes within a shipping container. Boxes can have different shades of brown colour, labels and they can be in various conditions. The detector returns positions and orientations of the boxes and selects the best box for robotic unloading.

Fig. HW and SW system for recognition of boxes in a container. Digits indicate the proposed order of collection.

6.4. Newly submitted projects

Name	Period	Budget (Euro)
Safety of collaborative robots *(with Faculty of Safety Engineering)*	2020-2022	300k
Digital twins of robotic systems and their verification II	2021	40k
Low cost technology	2020 - 2021	100k

6.5. New laboratories, equipment

Panoramic photos of selected laboratories and workplaces are available on the website of the Faculty of Mechanical Engineering. Our Robotics Center can also be viewed here –

Fig. https://tourmkr.com/F1HkXNQESO/16644803p&190.36h&89.84t

6.5.1. Demonstration workplace with a collaborative robot I

As part of the solved bachelor thesis and its further extension implemented within the SGS project, a demonstration and teaching workplace with a UR3 robot was designed and implemented, adapted for easy transport.

Furthermore, a new electrical connection was made to the workplace with the IRB 360 robot and its peripherals in accordance with applicable legislation. The machine vision system and the outer conveyor belt were modified. It is intended for the elaboration of new demonstration and teaching tasks.

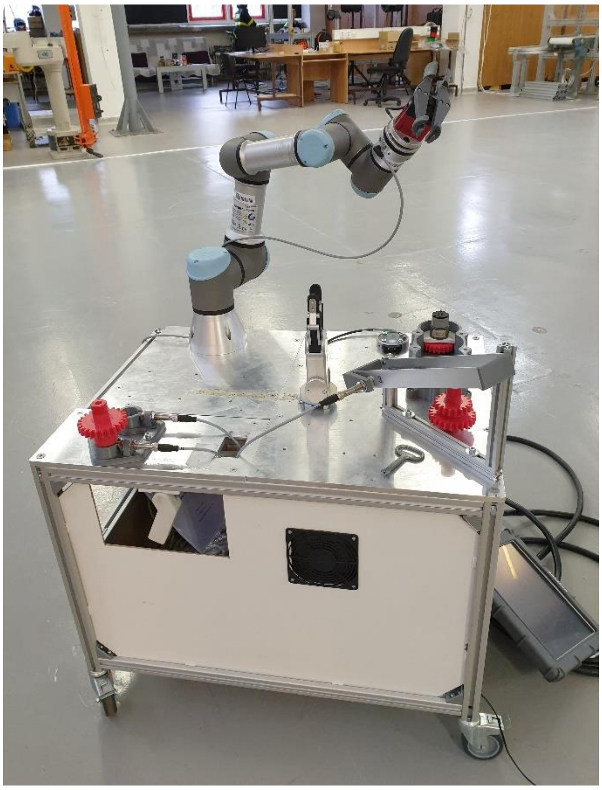

Fig. Mobile demonstration workplace with UR3 robot

Fig. Robotized workplace with ABB IRB360 robot, conveyors and machine vision system

6.5.2. 3D scanning unit

In connection with the project Platform for research focused on Industry 4.0 and robotics in the Ostrava agglomeration, a system for creating 3D scans of physical objects was acquired to automate the identification of an unknown mechanical component - a point scanner creates a point cloud and then compares it with models in the database. based on a specially designed algorithm.

The system was supplied by Photoneo and consists of a pair of PhoXi 3D Scanner M scanners, which can be placed in the required positions above a motorized rotary table using adjustable tripods. The functionality of the unit is provided by the PhoXi 3D Meshing software, which controls the scanners and the rotary table and also performs the connection and filtering of individual clouds into the resulting 3D model. The number of steps of the rotary table can be freely set, the exact positions and rotation of the scanners relative to the table are detected by a calibration process. Any number of scanners can be used - the pair was chosen as a compromise allowing sufficient coverage of the surface of the scanned object (each scanner is located at a different height) while maintaining an acceptable purchase price and scan length.

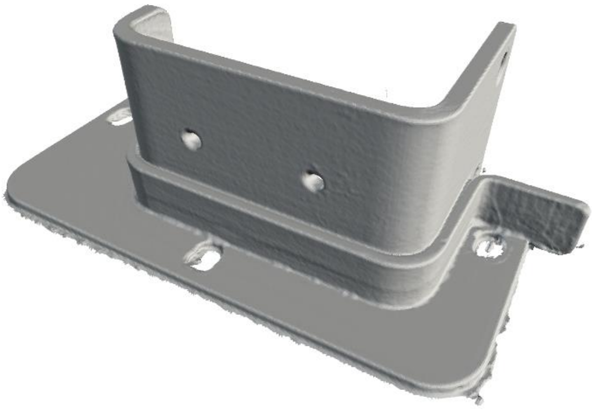

Fig. Scanning system when creating a 3D scan

Fig. Example of the resulting 3D part model

6.5.3. Modular workplace with Cobots II and III

The modular workstation with two robots from Universal Robots is designed for science and research, as well as for teaching with cooperating robots. By connecting the two workstations, a system is created where the larger of the UR10 robots can interfere with the working environment of the smaller UR3 robot and thus simulate an obstacle. The robust aluminium frame can be fitted with profiles for anchoring accessories such as cameras and other measuring devices. The robots are attached to aluminium plates, which serve as work surfaces, both workplaces have a work surface at a height, which is designed for cooperation with the operator. There is a set of threaded holes on the plates for attaching peripheral devices.

Depending on the task performed, the end flange of the robot is equipped with an electric effector RG2 / RG6 from the company OnRobot or another measuring / gripping / passive element. The cabling to the end effector can be routed through a flexible cable duct.

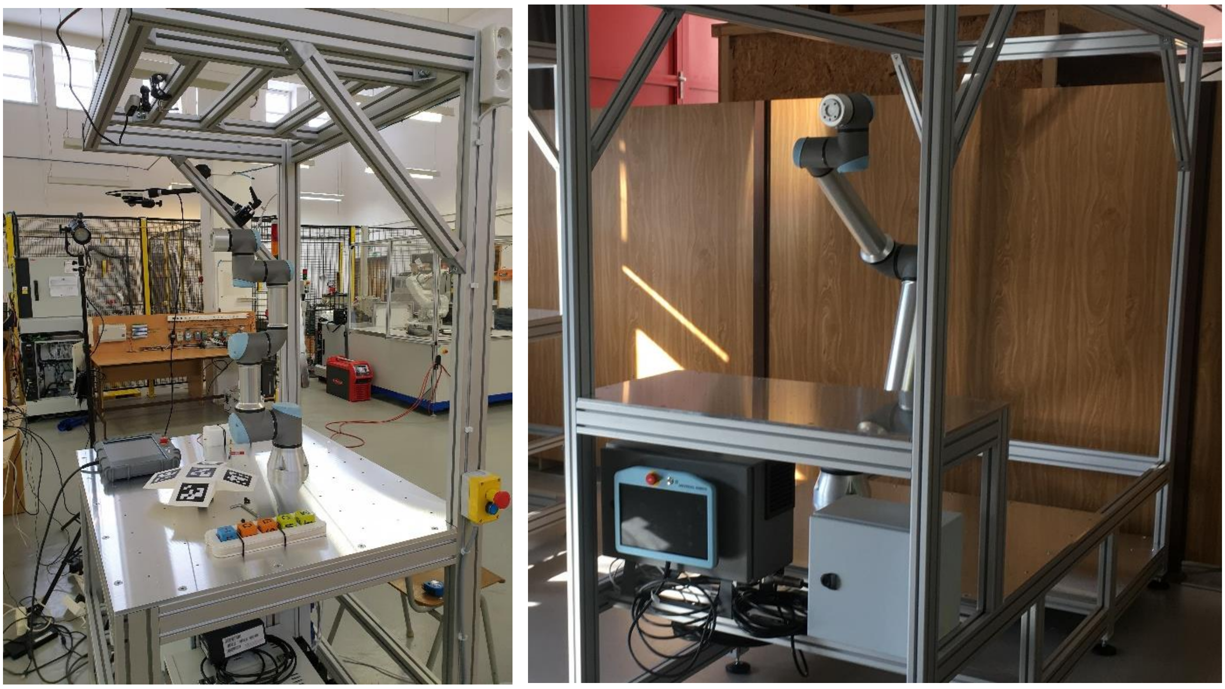

Fig. Modular workplace with collaborative robots UR3 and UR10

Workplaces are further expanded with safety elements that allow the operation of workplaces even outside the limits of requirements for direct cooperation with the robot. Other infrastructure of workplaces increasing the possibilities and comfort of work are gradually being supplemented. In the case of human-operated tests, the manikin may be used first.

6.5.4. Workplace identification

For more accurate positioning of cameras and objects in the workspace, we have created a new library for 3D gridboard detection, with Aruco tags - see the picture. This library combines simple detection of 2D Aruco tags, with newly created 3D distributed tags. Since the position of the individual tags is known, each tag is transformed into the coordinate system of the 3D gridboard and these transformed systems are subsequently filtered. This allows for more robust filtration, which leads to orders of magnitude more accurate results.

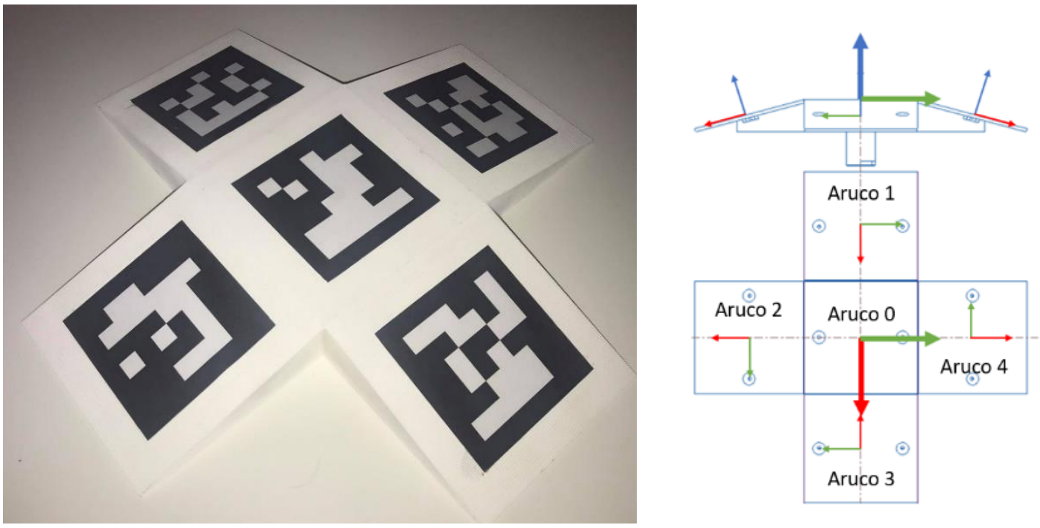

Fig. 3D Gridboard

With this technology, it was possible to determine the location of the workplace and measure the accuracy of the system, see the picture. Here, the position of the manipulator, the dimensions of the end effector, and the position of the cameras relative to the basic coordinate system were determined.

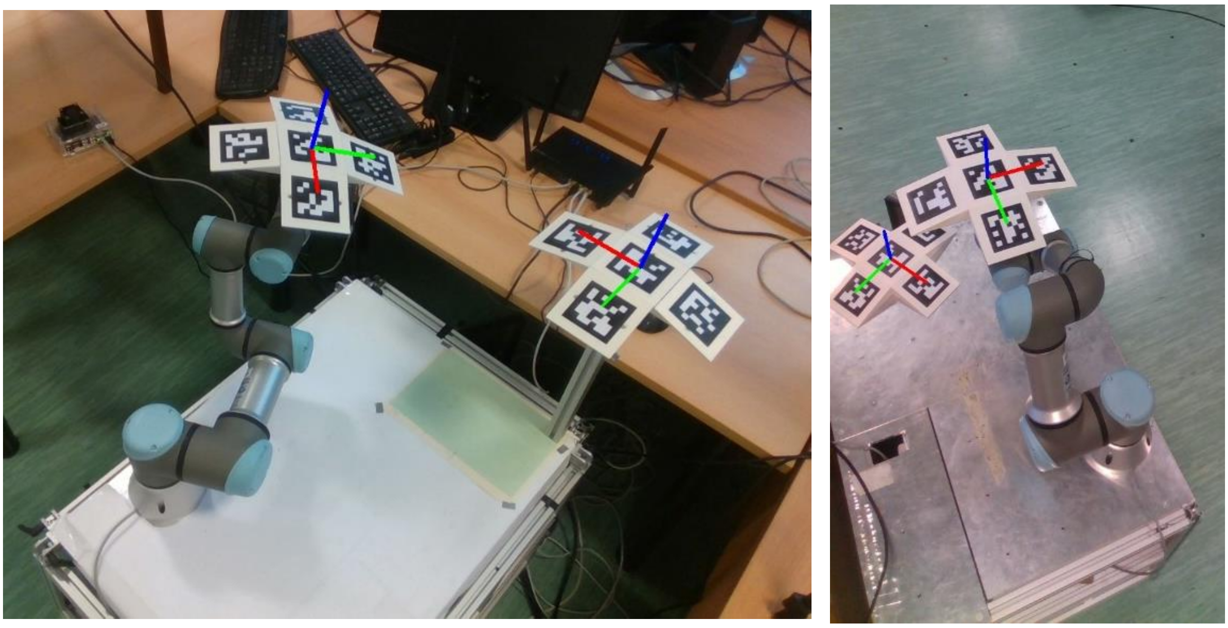

Fig. Measurement of workplace layout

This method is a fast and inexpensive solution for determining the layout of the workplace and for checking whether the workplace has all the peripherals needed for a given part of the process to be performed at the workplace. The accuracy of the system depends on the size of the marks used and the accuracy of the camera calibration. In general, this method allows identification on accuracy with an error up to 2 mm.

6.5.5. Confocal measuring system

For the needs of very accurate sensing of the positioning of the end point of the industrial robot, a contactless measuring system CL-3000 from the company Keyence was purchased. The confocal principle of optical distance measurement makes it possible to perform very accurate non-contact measurements of small distances, depths and irregularities in the range up to several tens of mm with absolute accuracy in the order of micrometers and with a resolution of tens of nanometers.

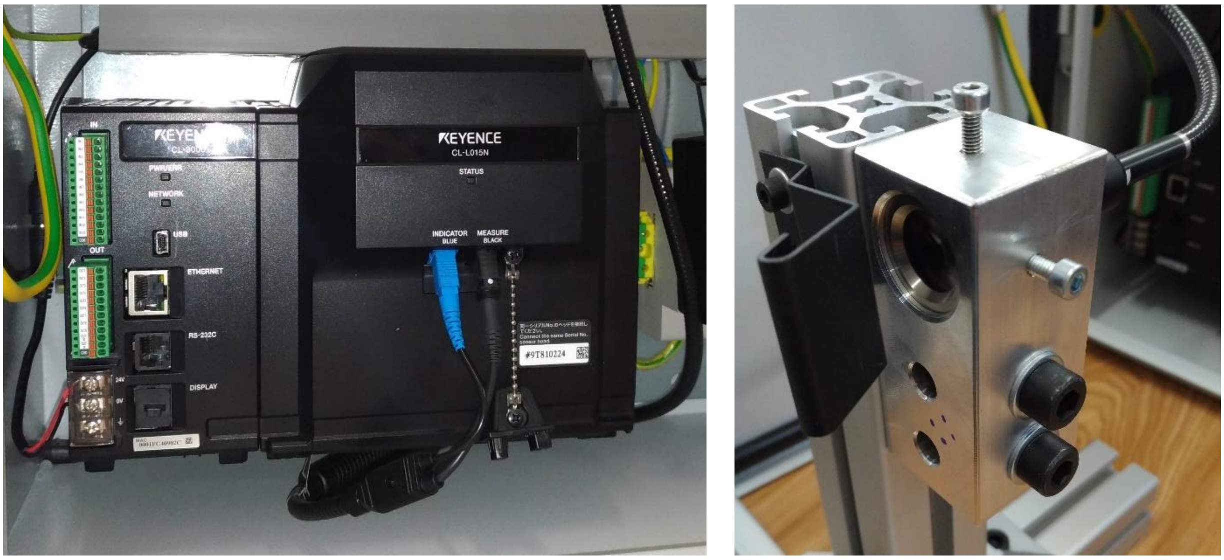

Fig. Confocal measuring system - evaluation unit and sensor in a mounting bracket

7. COOPERATION IN SCIENCE AND RESEARCH

7.1. Cooperation with entities in the Czech Republic

Within the framework of research and development in the field of service robotics, the Department of Robotics cooperates with leading robotic research workplaces in the Czech Republic:

- The Czech Technical University in Prague,
- CIIRC – Czech Institute of Informatics, Robotics and Cybernetics,
- Brno University of Technology,
- University of Defence, Czech R.
- VOP CZ (Military repair company), Czech R.
- Energy In, s.r.o.
- Vitesco Technologies (Continental),
- Brose,
- Hella
- Škoda Auto,
- Brano,
- Varroc,
- Robotsystem,
- Elvac,
- ABB robotics,
- and others…

7.2. Cooperation with entities abroad

- UC3M, (Madrid, University), Spain – Robotics
- SkyTech Research, Poland – Robotics, Mechatronics
- Shenyang Aerospace University, China – Robotics, Laboratory
- Silesian University of Technology Gliwice, Institute of Fundamentals of Machinery Design – Robotics, Mechatronics, research and educational stays
- IT University of Copenhagen, Robotics, Evolution, and Art Lab, Denmark – robotics, stays
- Universitat Innsbruck, Joanneum research – Robotics – stays
- Technical University of Košice, Slovakia, Mechatronics, stays

8. PUBLISHING ACTIVITIES

International journals

Vysocký, A., Grushko, S., Oščádal, P., Kot, T., Babjak, J., Jánoš, R., Sukop, M., Bobovský, Z. Analysis of Precision and Stability of Hand Tracking with Leap Motion Sensor. *Sensors 2020*. 2020, 20, 4088. Scopus, WoS, Impact factor 3.275, pořadí 15/64 (**Q1**)

Grushko, S., Spurný, T., Černý, M. Control Methods for Transradial Prostheses Based on Remnant Muscle Activity and Its Relationship with Proprioceptive Feedback. *Sensors*. 2020, vol. 20, issue 17. e-ISSN 1424-4822. Scopus, WoS, Impact factor 3.275, pořadí 15/64 (**Q1**)

Oščádal, P., Heczko, D., Vysocký, A., Mlotek, J., Novák, P., Virgala, I., Sukop, M., Bobovský, Z. Improved Pose Estimation of Aruco Tags Using a Novel 3D Placement Strategy. *Sensors 2020*. 2020. 20(17). Scopus, WoS, Impact factor 3.275, pořadí 15/64 (**Q1**)

Virgala, I., Kelemen, M., Božek, P., Bobovský, Z., Hagara, M., Prada, E., Oščádal, P., Varga, M. Investigation of Snake Robot Locomotion Possibilities in a Pipe. *Symmetry*. 2020, vol. 12, issue 6. e-ISSN 2073-3899. Scopus, WoS, Impact factor 2.645, pořadí 29/71 (**Q2**)

Kelemenová, T., Dovica, M., Božek, P., Koláriková, I., Benedik, O., Virgala, I., Prada, E., Miková, L., Kot, T., Kelemen, M. Specific Problems in Measurement of Coefficient of Friction Using Variable Incidence Tribometer. *Symmetry*. 2020, 12(8). Scopus, WoS, Impact factor 2.645, pořadí 30/69 (**Q2**)

Huczala, D., Oščádal, P., Spurný, T., Vysocký, A., Vocetka, M., Bobovský, Z. Camera-Based Method for Identification of the Layout of a Robotic Workcell. *Applied sciences*. 2020, 10(21). Scopus, WoS, Impact factor 2.474, pořadí 32/91 (**Q2**)

Vocetka, M., Huňady, R., Hagara, M., Bobovský, Z., Kot, T., Krys, V. Influence of the Approach Direction on the Repeatability of an Industrial Robot. *Applied sciences*. 2020. 10(23), 8714. Scopus, Impact factor 2.474, pořadí 32/91 (**Q2**)

Vysocký, A., Papřok, R., Šafařík, J., Kot, T., Bobovský, Z., Novák, P., Snášel, V. Reduction in Robotic Arm Energy Consumption by Particle Swarm Optimization. *Applied sciences*. 2020, 10(22), 8241. Scopus, WoS, Impact factor 2.474, pořadí 32/91 (**Q2**)

Oščádal, P., Huczala, D., Bém, J., Krys, V., Bobovský, Z. Smart Building Surveillance System as Shared Sensory System for Localization of AGVs. *Applied sciences*. 2020. 10(23). Scopus, Impact factor 2.474, pořadí 32/91 (**Q2**)

Home (Czech) journals

Jha, V., Grushko, S., Mlotek, J., Kot, T., Krys, V., Oščádal, P., Bobovský, Z. A Depth Image Quality Benchmark of Three Popular Low-Cost Depth Cameras. *MM Science Journal*. 2020, issue December, pp. 4194-4200.

Mostýn, V., Huczala, D., Moczulski, W., Timofiejczuk, A. Dimensional optimization of the robotic arm to reduce energy consumption. *MM Science Journal*. 2020, issue March, pp. 3745-3753. ISSN 1803-3126. e-ISSN 1805-5047. Scopus, WoS

Paška, Z., Rojíček, J., Ferfecki, P., Fusek, M., Heczko, D., Krys, V. Methodology of Arm Design for Mobile Robot Manipulator Using Topological Optimization. *MM Science Journal*. 2020, vol. 2020, issue June, pp. 3918-3925. ISSN 1803-3126. Scopus, WoS

Suder, J., Bobovský, Z., Zeman, Z., Mlotek, J., Vocetka, M. The Influence of Annealing Temperature on Tensile Strength of Polylactic Acid. *MM Science Journal*. 2020, issue November, pp. 4132-4137. Scopus, WoS

Vocetka, M., Suder, J., Huczala, D. The Use of the Two-Handed Collaborative Robot in Non-Collaborative Application. *Acta Polytechnica*. 2020, vol. 60, issue 2, pp. 151-157. ISSN 1210-2709. Scopus, WoS

Grushko, S., Vysocký, A., Jha, V., Pastor, R., Bobovský, Z., Prada, E., Miková, L. Tuning Perception and Motion Planning Parameters for Moveit! Framework. *MM Science Journal*. 2020, issue November, pp. 4154-4163. Scopus, WoS

Conference papers

Suder, J., Machalla, V., Safář, M., Heczko, D., Zeman, Z. Influence of Annealing Time on Tensile Strength and Change of Dimensions of PLA Samples Produced by Fused Filament Fabrication. In *EAN 2020 58th conference on experimental stress analysis*. Ostrava : VSB-TU Ostrava, 2020. pp. 476-482. ISBN 978-80-248-4451-0.

Machalla, V., Suder, J., Fojtík, F., Zeman, Z. Testing of Glued Joints on 3D Printed Flexible Materials Made by FFF Technology. In *EAN 2020 58th conference on experimental stress analysis*. Ostrava : VSB-TU Ostrava, 2020. pp. 302-307. ISBN 978-80-248-4451-0.

Pastor, R., Huczala, D., Vysocký, A., Oščádal, P., Mlotek, J., Heczko, D., Zeman, Z., Široký, P. Modular Rover Design for Exploration and Analytical Tasks. In *Lecture Notes in Computer Science*. 2020. pp. 203-215. ISBN 9783030438890. ISSN 0302-2974. Scopus

The current overview of publishing activities and other outputs of the Department of Robotics is given at:

http://robot2.vsb.cz/publications/