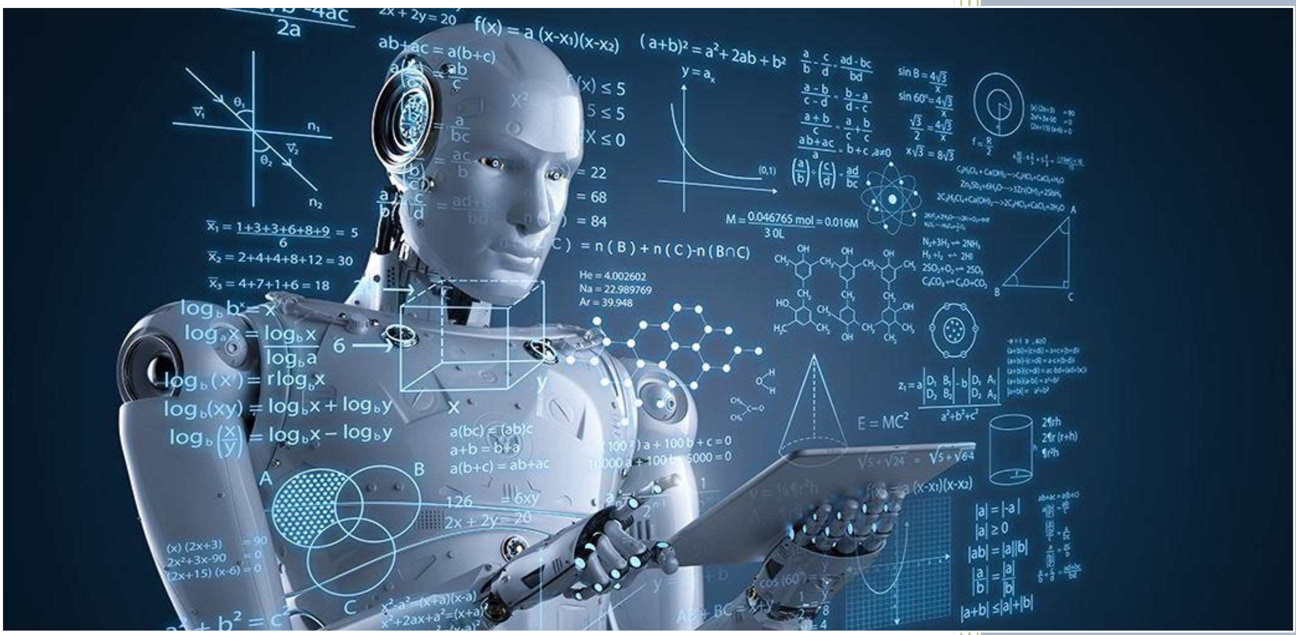
2021

Annual Report of Department of Robotics



Faculty of Mechanical Engineering

VŠB – Technical University of Ostrava

Czech Republic

17th January 2022

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

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Annual Report

2021

Department of Robotics

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

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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:	doc. Ing. Zdenko Bobovský, Ph.D.
Secretary:	Ing. Václav Krys, Ph.D.
Assistant:	Ing. Petra Pišťáčková
Professors:	prof. Dr. Ing. Vladimír Mostýn
	prof. Dr. Ing. Petr Novák
Associate professors:	doc. Ing. Zdenko Bobovský, Ph.D.
	doc. Ing Tomáš Kot, Ph.D.
	doc. Ing. Milan Mihola, Ph.D.
Assistant professor:	Ing. Ladislav Kárník, Ph.D.
	Ing. Václav Krys, Ph.D.
	Ing. Aleš Vysocký, Ph.D.
	Ing. Stefan Grushko, Ph.D.
	Ing. Robert Pastor, Ph.D.
	Ing. Jiří Suder, Ph.D.
	Ing. Michal Vocetka
Researchers:	Ing. Ján Babjak, Ph.D.
	Ing. Dominik Heczko
	Ing. Jakub Mlotek
	Ing. Petr Oščádal
	Ing. Zdeněk Zeman
	Ing. Tomáš Spurný
	Ing. Rostislav Wierbica
	Ing. Jakub Krejčí
	Ing. Adam Boleslavský
Technicians:	Karel Ranocha (till 8.2021)

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.

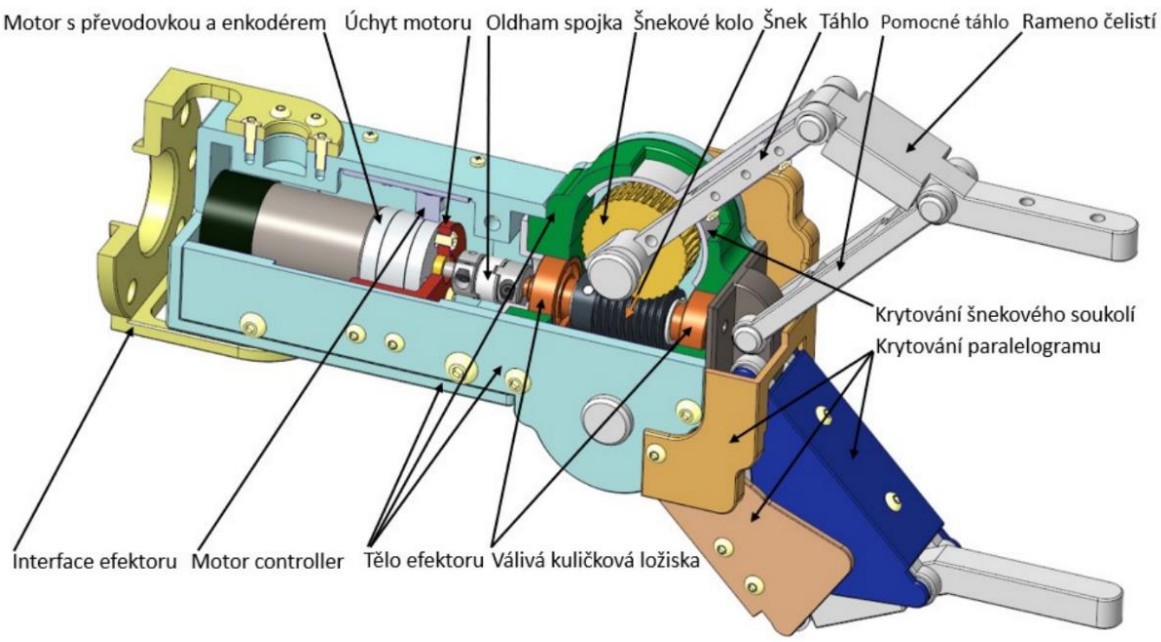


Fig. 4.1: (Bc.) Daniel Kovářik, Design of a safe gripping effector for a workplace with a cooperating robot, bachelor's thesis, supervisor: Ing. Ales Vysocky, Ph.D.

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.

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.

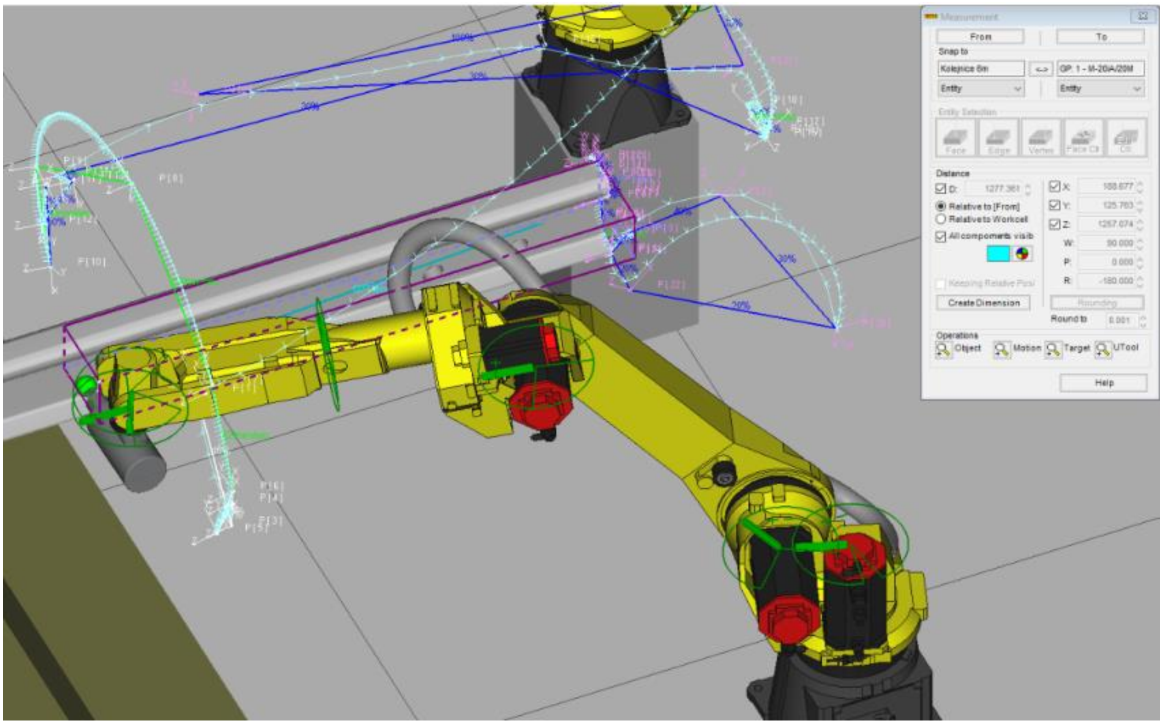


Fig. 4.2: (Bc.) Robert Sliwka Robotic chamfering of rail profiles using PLC, bachelor's thesis, supervisor: doc. Ing. Miroslav Mahdal, Ph.D. – Department of Control Systems and Instrumentation.

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.

4.1.2. 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.

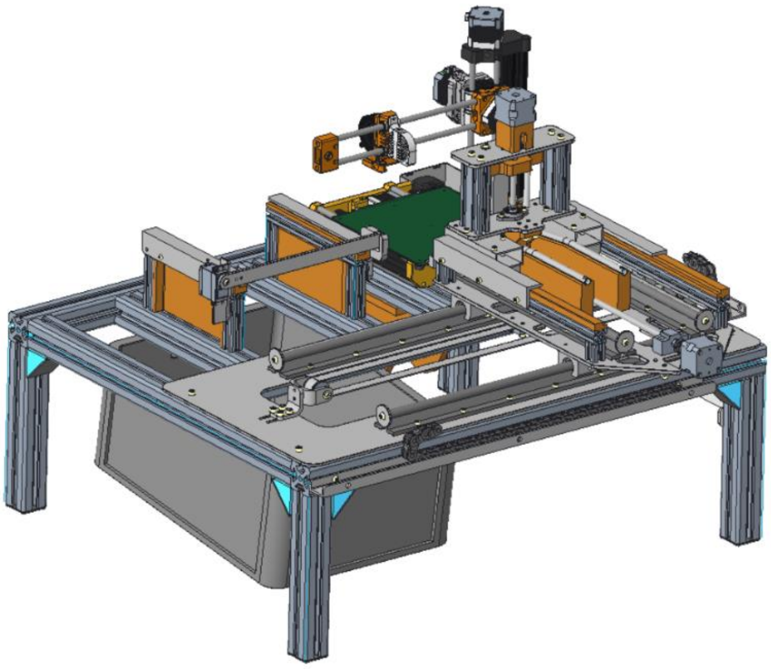


Fig. 4.3: (Ing.) Bc. Adam Stehlík, System of automatic taking of prints from a 3D printer, head Ing. Jiří Suder, Ph.D.

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.

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).

Title: **Robotics** (from 2022)

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.

4.1.3. Doctoral Fields of Study

Title: **Robotics** (till 2021)

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.

Title: **Robotics** (from 2021)

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.

4.2. List of Defended Theses

4.2.1. Bachelor Theses

	Student	Supervisor	Topic
1.	Vojtěch Bartl	Ing. Zdeněk Zeman	Roller Conveyor for Conveying of Longer Rods of Circular Cross Section
2.	Jakub Častulík	Ing. Václav Krys, Ph.D.	Current State of Service Robotics for Logistics
3.	Daniel Kovářík	Ing. Aleš Vysocký, Ph.D	Design of Safe Gripper for the Human - Robot Cooperation Workplace
4.	Sebastian Matůš	doc. Ing. Milan Mihola, Ph.D.	Analysis of The Current State of Mobile Service Robots Based on The Arduino Platform
5.	Jan Pavčo	Ing. Jakub Mlotek	Design of a Two-axis Camera Positioner
6.	Ing. Kateřina Pekařová	Ing. Daniel Huczala	Application of Brain Signal Processing in Robotics
7.	Čeněk Slezák	Ing. Jiří Suder, Ph.D.	Proposal of Equipment for Laser Engraving
8.	Jakub Stonawski	Ing. Václav Krys, Ph.D.	Library of Pneumatic Components 3D Models for Simulation Models and Design of a Suction Cup Effector
9.	Pavel Škoda	Ing. Aleš Vysocký, Ph.D.	Demonstration Task with the UR3 Robot

4.2.2. Diploma Theses

	Student	Supervisor	Topic
1.	Bc. Jan Bém	Ing. Aleš Vysocký, Ph.D.	Design of Rover Chassis for the URC Competition
2.	Bc. Adam Boleslavský	doc. Ing. Milan Mihola, Ph.D.	Automated Reconfiguration of a 3D Model of a Robotic Workplace
3.	Bc. Tereza Kanisová	doc. Ing. Zdenko Bobovský, PhD.	Virtual Twin of a Service Robotic System
4.	Bc. Tomasz Kowalczyk	doc. Ing. Milan Mihola, Ph.D.	Design of a Robotic Workplace for Welding of Shipping Storage Containers
5.	Bc. Jakub Krejčí	Ing. Václav Krys, Ph.D.	Demonstration Tasks of Cooperation of Two IRB 1200 Robots
6.	Bc. Marek Mihálik	Ing. Michal Vocetka	Demonstration workplace with the robot IRB 1660
7.	Bc. Marek Ročňák	Ing. Jiří Suder	Design of Automatic Filament Feeder
8.	Bc. Josef Rozsypal	Ing. Václav Krys, Ph.D.	Design of Automated Feeding of Semi-finished Products to the Workplace

9.	Bc. Tomáš Spurný	Ing. Robert Pastor, Ph.D.	Control and Navigation Subsystem of a Mobile Robot
10.	Bc. Adam Stehlík	Ing. Jiří Suder	System for Automatic Removal of Prints from a 3D Printer
11.	Bc. Luboš Varecha	doc. Ing. Zdenko Bobovský, PhD.	Robotic System for Unloading Shipping Containers
12.	Bc. Jan Vicherek	Ing. Václav Krys, Ph.D.	Mechanical Design of End Effectors of Industrial Robots
13.	Bc. Rostislav Wierbica	Ing. Michal Vocetka	Proposal and Implementation of a Demonstration Task of a Robot Machining

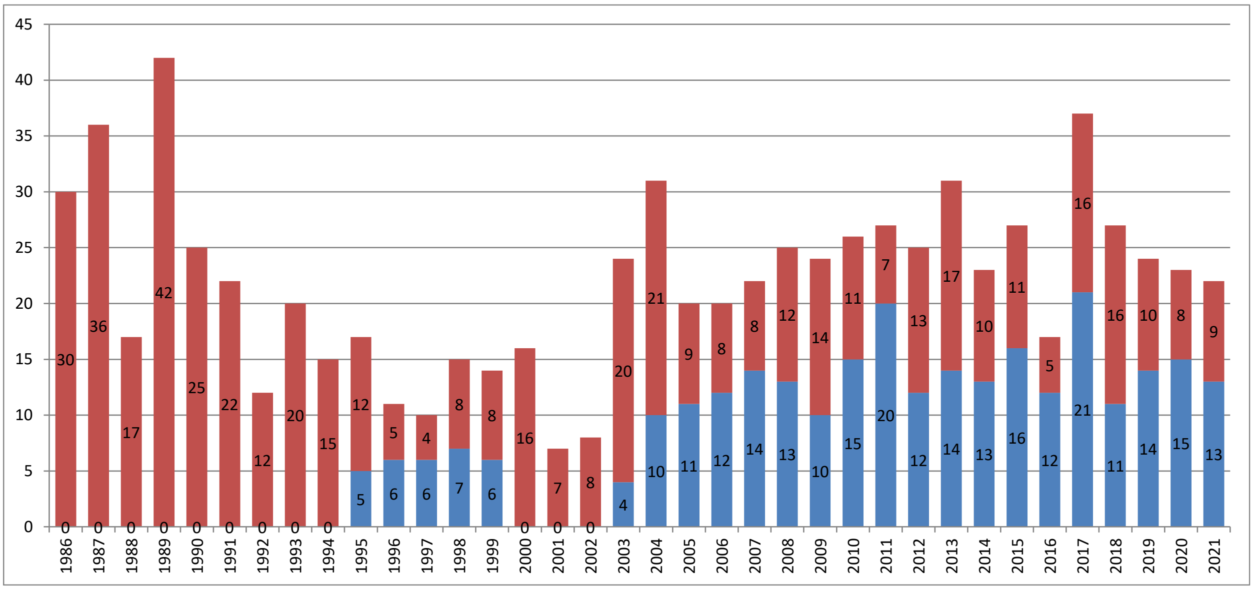


Fig. 4.4: Overview of numbers of graduates (former Manufacturing Systems with Industrial Robots and Manipulators and now Robotics) Departments of Robotics: Bc. – Blue, Msc. – Red

4.3. List of PhD Students

	Student	Dissertation	Year	Form	Tutor
1.	Ing. Stefan Grushko, Ph.D.	Motion planning for manipulator in dynamic environment using RGB-D sensor	4 *	P	doc. Ing. Zdenko Bobovský, PhD.
2.	Ing. Robert Pastor,Ph.D.	Machine learning applications in robot kinematics design	4 *	P	prof. Dr. Ing. Petr Novák
3.	Ing. Jiří Suder,Ph.D.	The use of 3D printing in the design of robots	4 *	P	doc. Ing. Zdenko Bobovský, PhD.
4.	Ing. Dominik Heczko	Increasing the accuracy of position and orientation of the objects placed by the manipulator	4	P	doc. Ing. Zdenko Bobovský, PhD.
5.	Ing. Daniel Huczala	The Synthesis of Kinematic Structure of Robotic Manipulators	4	P	doc. Ing. Tomáš Kot, Ph.D.
6.	Ing. Michal Vocetka	Manipulator accuracy improvement	4	P	doc. Ing. Zdenko Bobovský, PhD.
7.	Ing. Jakub Mlotek	Shape Adjustable Links of Robotic Systems	3	P	doc. Ing. Zdenko Bobovský, PhD.
8.	Ing. Petr Oščádal	Robot Arm Trajectory Optimization under Dynamically Changing Work Space	3	P	doc. Ing. Zdenko Bobovský, PhD.
9.	Ing. Zdeněk Zeman	Topological Design of Robotics' Arms	3	P	prof. Dr. Ing. Petr Novák
10.	Ing. Jan Bém	Modularity as a Key Aspect in Robotics	1	P	Doc.Ing.Milan Mihola, Ph.D.
11.	Ing. Adam Boleslavský	Automation of the Design Process of Mechatronic Devices	1	P	doc.Ing.Marek Babiuch,Ph.D.
12.	Ing. Jakub Krejčí	The concept of IoRT (Internet of Robotic Things) and its use	1	P	doc.Ing.Tomáš Kot, Ph.D.
13.	Ing. Tien Hiep Nguyen	Optimization of m Methodological Procedures used in the Design of Mechatronic Devices	1	P	doc. Ing. Zdenko Bobovský, PhD.
14.	Ing. Tomáš Spurný	Motion Planning of a Robot Arm under Dynamically Changing Work Space	1	P	doc.Ing.Milan Mihola, Ph.D.
15.	Ing. Rostislav Wierbica	Optimization of kinematic structure of a robotic manipulator for a given task	1	P	doc.Ing.Milan Mihola, Ph.D.

*) Successfully completed doctoral studies in 2021

P - full-time form of study

4.4. Defended Dissertations

Ing. Stefan Grushko, Ph.D.

Motion planning for manipulator in dynamic environment using RGB-D sensor

The research in this work focuses on the topic of motion planning and communication of the robot motion plan to a human worker during cooperation in a shared workspace. The requirement is not only a theoretical exploration of possibilities but also a practical implementation in the form of an experimental workplace to verify the proposed principles. The introductory part of the thesis analyses the current state of the art in the field of path planning, motion planning frameworks, environment perception, approaches to improving mutual awareness during human-robot cooperation and implementation of haptic feedback devices. The main contribution of the research is the concept of a novel collaborative system, which combines rapid robot path planning with the system for notifying the user about the currently planned path of the robot and its status. The principles of the system are implemented and tested on an experimental workspace. The robot's path planning system is based on a motion planning framework optimized for better performance in a set of tasks simulated in a virtual environment. It is hypothesized that the use of the proposed notification system during human-robot collaboration will improve the overall performance, awareness about the planned robot trajectory and encourage a positive experience to the human user. In order to test this hypothesis, a user study is performed, and its data are statistically analysed. The results indicate the potential of the developed haptic notification-based approach in improving mutual understanding during human-robot interaction. The topic of the work is relevant for the deployment of collaborative robots in industrial tasks and aims at improving the effectiveness of human-robot cooperation.

Ing. Jiří Suder, Ph.D.

The use of 3D printing in the design of robots

The dissertation deals with the use of 3D printing in the design of robots, focusing on the method of Fused Filament Fabrication. It deals with some selected topics associated with the design and implementation of materials that can be further used for the construction of robots. The work deals with testing of glued joints, the influence of annealing of printed samples on their final tensile strength and temperature resistance, water tightness tests and pressure tests. The tested materials are most often PLA and relatively new flexible TPU materials. Part of the work is also the solution of basic problems when printing from flexible materials, namely the design of the own extruder on a printer of the own design and implementation of the purchased special extruder Flexion for printing from flexible materials on the purchased printer Original Prusa I3 MK3S. The work contains a methodology for setting the printing parameters to achieve a waterproof printed sample. Furthermore, the work deals with the use of 3D printing from flexible materials in the design of robots. In this section, two applications are presented, namely the use of printed elastic inserts of the jaws of a collaborative robot to increase the friction force of the jaw and printed adaptive fingers based on the Fin Ray effect for use in soft robotics. Part of the Fin Ray finger testing is the design of a new and simple method for optimizing these fingers in terms of their wrapping around the embossed object. A procedure for simulating these fingers and comparing simulations with real tests on printed fingers is presented.

Ing. Robert Pastor, Ph.D.

Machine learning applications in robot kinematics design

Evolutionary robotics aims to create robots and their controllers using methods inspired by the evolution of natural organisms, such as optimization by genetic algorithms and controlling the robots with neural network. Machine learning deals with algorithms and techniques that work with a mathematical model, which through a learning process can solve problems that are often difficult to define. Evolutionary robotics has been experimenting with methods for the automatic design of robots since the 1980s, but the research usually does not leave laboratories and is hardly used in practice. This may be due to the computational complexity of the methods used, where the optimization of the robot's kinematics takes too long and with uncertain results for practical use. The focus of the thesis is on a synthesis of a robot manipulator, optimized for a specific task. The tasks are defined as trajectories composed of target points. The main part of the thesis defines a method for a task-based synthesis of robot manipulators using a genetic algorithm in the MATLAB environment. Emphasis is placed on the correct definition of the optimized vector i.e., genotype and on the definition of the objective function, according to which the manipulator is evaluated. The results of the method are presented on several example tasks. A proposal to verify the results on a real modular manipulator is described next. Lastly, a method that uses neural networks for rapid robot kinematics design is presented.

4.5. 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.

4.5.1. Student Grant Competition 2021

The project of the student grant competition "Digital twins of robotic systems and processes" was divided into four main activities so that it was possible to involve as many doctoral and master's degree students as possible in their solution. 24 doctoral and master's degree students took part in the project. 9 articles were published as outputs of the project. 7 of them were published in journals with impact factor (4x Q1 and 3x Q2). 1 functional sample and 1 SW were registered as outputs of the project.

Main project activities:

- Simulation models of robotic workplaces and their subsystems
- Simulation models of mobile robots and their subsystems
- Internet of Things applications in robotic systems
- Design, implementation and testing of flexible materials and their applications in robotics

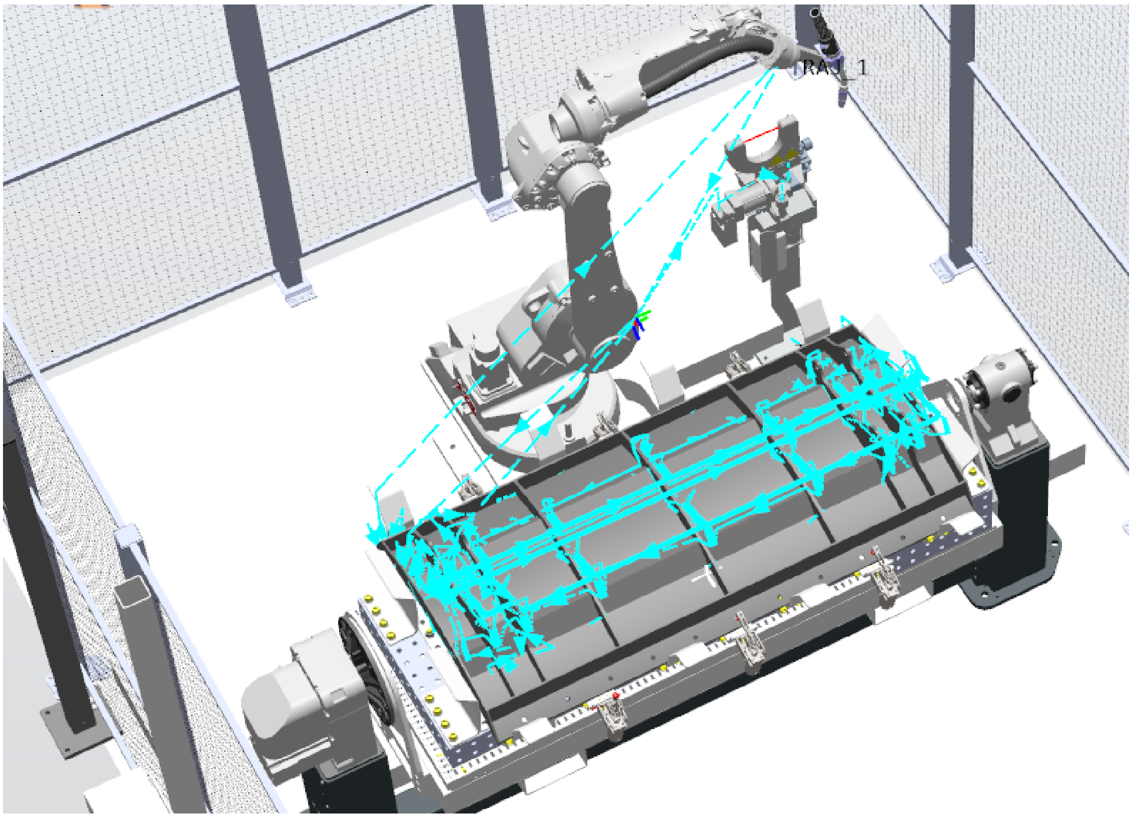


Fig. 4.5: Simulation model of welding workplace with IRB 1660 with marked trajectory of robot endpoint created in RobotStudio

In 2021, a total of 9 theses (3 dissertations and 6 diploma theses) supported or related to the SGS project were defended:

1) Ing. Stefan Grushko, Ph.D. – Motion planning for manipulator in dynamic environment using RGB-D sensor
2) Ing. Robert Pastor, Ph.D. – Machine learning applications in robot kinematics design
3) Ing. Jiří Suder, Ph.D. – The use of 3D printing in the design of robots
4) Ing. Tereza Kanisová – Virtual twin of a service robotic system
5) Ing. Jakub Krejčí – Demonstration Tasks of Cooperation of Two IRB 1200 Robots
6) Ing. Marek Mihálik – Demonstration workplace with the robot IRB 1660
7) Ing. Tomáš Spurný – Control and Navigation Subsystem of a mobile robot
8) Ing. Luboš Varecha – Robotic System for Unloading Shipping Containers
9) Ing. Rostislav Wierbica – Proposal and Implementation of a Demonstration Task of a Robot Machining

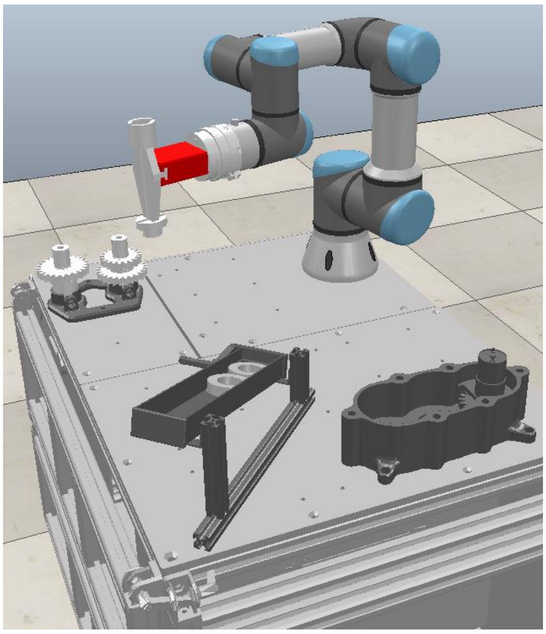


Fig. 4.6: Simulation model of an educational workplace with a collaborative robot UR3 in the CoppeliaSim SW system

4.5.2. European Rover Challenge

Our student team RoverOva has attended the European Rover Challenge this September. Our competition rover required several upgrades for this year. The students have worked on these upgrades during the summer months. Six undergraduate and graduate students from out department have attended the competition in Poland. The team was competing in five challenging tasks and managed to reach sixth place from 20 qualified teams.

The competition robot K3P4is equipped with a four wheel undercarriage with an independent wheel turning mechanism, a manipulator with five degrees of freedom kinematics, various end effectors for manipulation and soil scooping, a specialised module for manipulating with scientific caches, a deep sample drill, soil containers and camera modules for intuitive control and autonomous navigation in terrain. Two diploma theses were created this year in connection with the work on the competition rover K3P4.

Fig. 4.7: Our competing team on ERC 2021 in Poland

Fig 4.8: Competitive mobile robot K3P4 at ERC 2021 in Poland

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 - For the sixth year in a row, weekly student internships (5th year) have been taking place during the winter semester at ABB Hrabová - ABB's global industrial robot refurbishment center, where they perform a complete “disassembly” of industrial robots plus the necessary output measurements. Students take a test and get a certificate.
- SoliCAD s.r.o. 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.

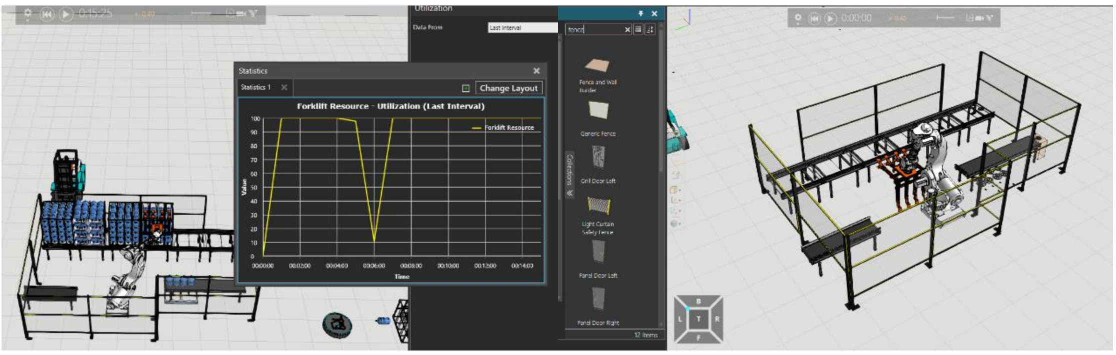


Fig. 5.1: Simulation models of robotic workplace in SW Visual Components

- AV ENGINEERING a.s. - 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.

6. SCIENCE - RESEARCH ACTIVITIES

6.1. Currently Solved Projects

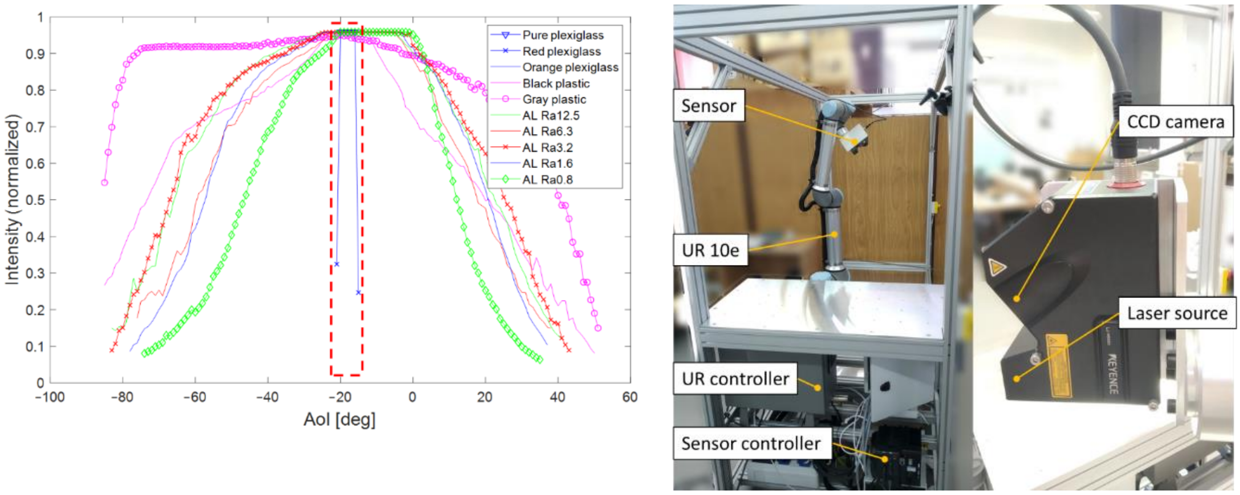
Name	Period	Budget (Euro)
Robot for participation in competitions	2021	0,2M
Research Centre of Advanced Mechatronic Systems	2018 - 2022	2,6M (from 9,6M)
Research Platform focused on Industry 4.0 and Robotics in Ostrava Agglomeration	2018 - 2022	0,64M (from 3,2M)
Digital twins of robotic systems processes	2021	34k
National Competence Centre of Mechatronics and Smart Technologies for Mechanical Engineering	2021-2022	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 Reliability of Data Collection of 2D Laser Line Triangulation Sensor

In industry, 2D laser line triangulation (LLT) sensors are often used to measure and inspect the functional surfaces of manufactured parts. LLT sensors are highly accurate and very fast and can measure several thousand points within milliseconds. However, optical sensors are sensitive to the geometry and optical properties of the scanned surfaces. Therefore, in this part of the research, we investigated the effect of the angle of incidence of the laser beam on the intensity of the reflected laser beam. For triangulation laser sensors, it is important that at least part of the light is reflected from the surface into the receiver (CCD chip) of the sensor. This is particularly problematic when scanning shiny, very smooth, and transparent surfaces, where the beam may reflect off the surface outside the sensor's CCD chip and the sensor does not detect the laser line. Therefore, the characteristics of the incidence angle of a laser ray on the reflected laser intensity were measured for materials commonly used in the automotive industry. These characteristics, which can be seen in figure bellow a, were measured at the experimental workplace with the UR10e robot (see figure bellow b). The measured dependencies help in positioning the sensors relative to the scanned part to increase the reliability of data collection. The research is described in detail in the paper HECZKO, Dominik, Petr OŠČÁDAL, Tomáš KOT, Daniel HUCZALA, Ján SEMJON a Zdenko BOBOVSKÝ. Increasing the Reliability of Data Collection of Laser Line Triangulation Sensor by Proper Placement of the Sensor. *Sensors*. 2021, **21**(8). ISSN 1424-8220. Available at: doi:10.3390/s21082890.



(a) (b)

Fig. 6.1: The measured characteristics of the incidence angle of a laser ray on the reflected laser intensity

6.2.2. Adaptive Robotic Precision Inspection of 3D Printed and Welded Parts

Precision inspection of objects produced by 3D printing and welding is performed using the LJ-X8080 laser linear triangulation sensor (LLT sensor) with the LJ-X8000 control unit. The LLT sensor control unit has integrated software for measuring basic parameters in a 2D profile, such as the coordinates of the highest point, the angle of the selected plane to the reference plane, the radius of the selected part in the profile, and more. Objects made by 3D printing has a complex 3D shape, so an algorithm was developed to track and measure the selected part of this complex feature on the part. Figure below shows the measurement process. First, the sensor is positioned only in the Y-axis. Once the TCP of the robot is in the region of interest, the algorithm starts searching for the position of the measured feature. The TCP of the robot (identical to the sensor coordinate system) will copy the "adaptive trajectory" – indicated by the cyan line in figure bellow.

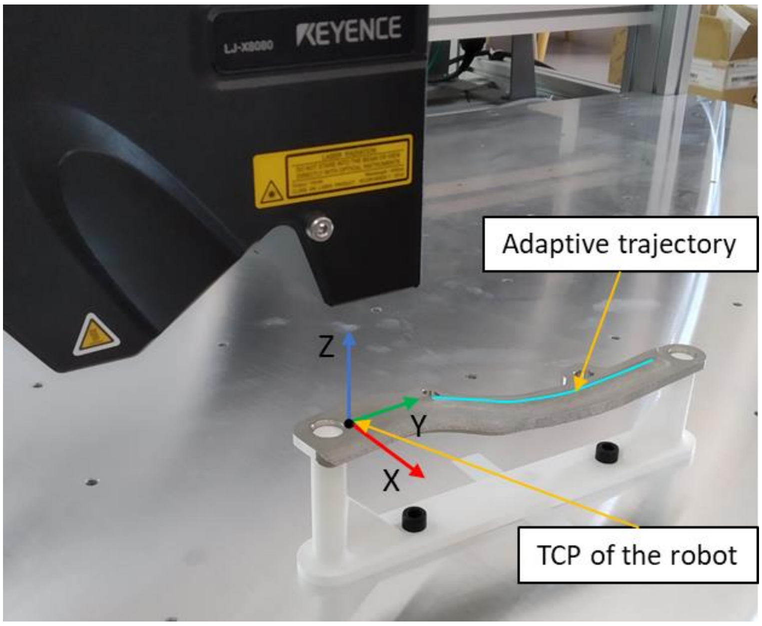


Fig. 6.2: Measurement of the radius by adaptive measurement.

6.2.3. Increasing the Accuracy of the Manipulator

Following previous research, which is summarized in the publication *Influence of the Approach Direction on the 2 Repeatability of an Industrial Robot* (*https://doi.org/10.3390/app10238714*) the effect of temperature on an industrial robot´s repeatable accuracy, which is generally known as drift, was investigated. According to the previously determined temperature characteristics, it was possible to perform drift and temperature measurements on a pair of ABB IRB 1200 robots, which are equipped with temperature sensor circuits. Based on this information, a set of compensation equations was compiled. These equations determine the value of drift in the X, Y and Z axes at a specific temperature of individual parts of the industrial robot.

With the detailed information of the effect of drift on the industrial robot structure, this effect can be significantly reduced.

Fig. 6.3: Measuring nest. A robot with the payload tool approaches to confocal sensor that measures the TCP Z-axis distance. TCP X and Y are measured by a pair of laser profilers above the payload tool.

The confocal sensor Keyence CL3000 and a pair of line profilers of the same manufacturer, the LJ-X8080 series, were used for the measurement. These sensors have been used to measure precision in five axes, but measurements have shown that rotation errors are so small that they can be neglected, so the research only focused on the displacement in the TCP X, TCP Y and TCP Z axes.

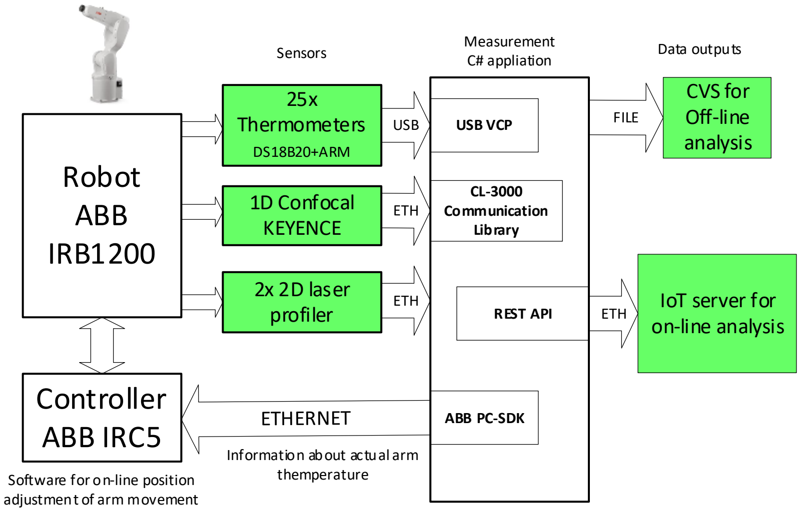


Fig. 6.4: Block diagram of a measuring set with a robot

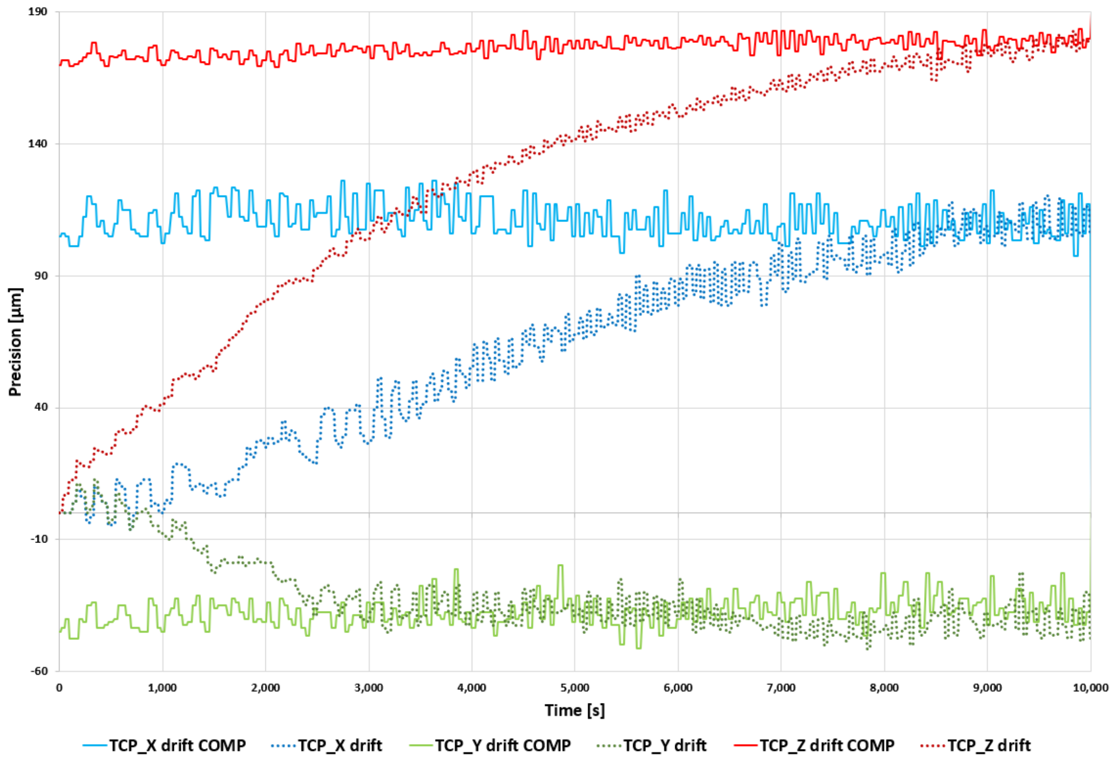


Fig. 6.5: DOF repeatability comparison. Blue dots—TCP X not compensated, blue line-TCP X compensated, green dots -TCP Y not compensated, green line - TCP Y compensated, red dots - TCP Z not compensated, red line - TCP Z compensated.

During the testing, a reduction of up to 90% was achieved. The procedure and the achieved results are described in detail in the article: *Influence of Drift on Robot Repeatability and Its Compensation (*https://doi.org/10.3390/app112210813*)*. This new methodology will be further developed and verified on other types of robots.

6.2.4. Gesture-based Human-robot Interaction

In this project, we focused on intuitive human-machine interaction methods for safe and effective cooperation with robots, specifically gesture-based robot guiding. The prototype of the system was tested in an assembly workspace with a collaborative robot. In our research we used custom-built and trained neural network for image segmentation and hand tracking. This network is trained on synthetic dataset generated from a virtual simulation and then used in a real workplace.

The synthetic dataset was additionally augmented with camera-specific noise and random background objects whose task is to bring the generated images closer to the real ones. Since a large and diversified dataset is the topmost priority when training a neural network, the generated synthetic data significantly simplified the process and allowed to prepare a fully labelled dataset containing over 200k images in a short time. The resulting trained neural network is able to successfully track the human hand with data from a real camera even though it was never trained on such data. Currently we are working on improving stability of the image segmentation and hand gesture recognition.

For gesture-based robot guiding, we designed a testing application which uses third-party neural network-based hand tracker and hand gesture recognizer. Distributed computation graph utilizes multiple nodes to efficiently process data from multiple RGB-D cameras which provide complete coverage of the workspace and allows to reliably localize the operator's hands in the environment. The developed system allows to define a path for the robot containing an arbitrary number of waypoints and control the movement of the robot along the defined path using only hand gestures (without need of interacting with input devices).

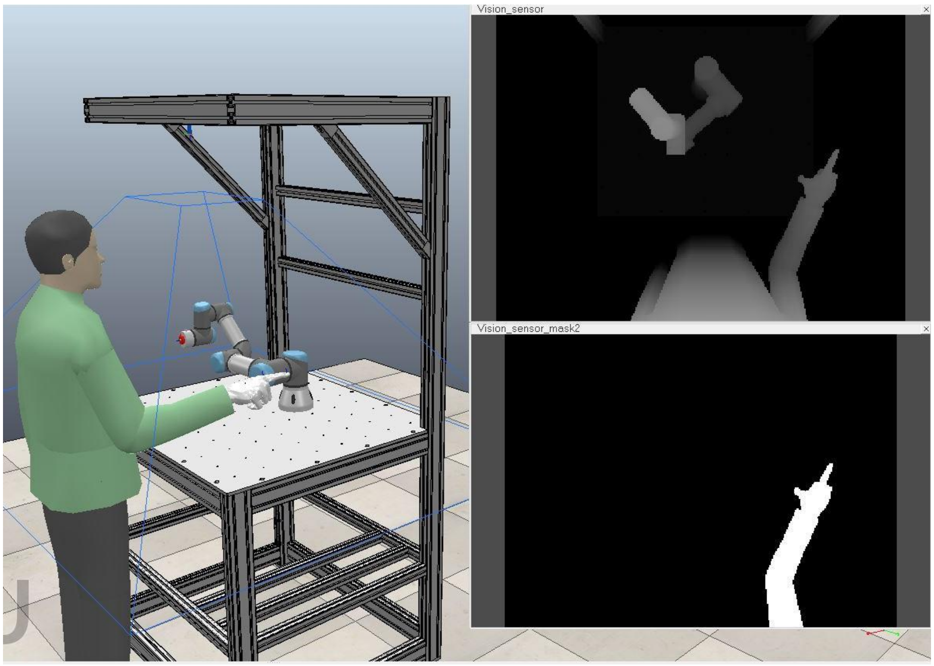


Fig. 6.6: Dataset generation in virtual simulation model of the workspace

Fig. 6.7: Image segmentation and hand tracking using custom neural network-based system: (left) scene with the hand; (right) input and corresponding output in the image segmentation neural network

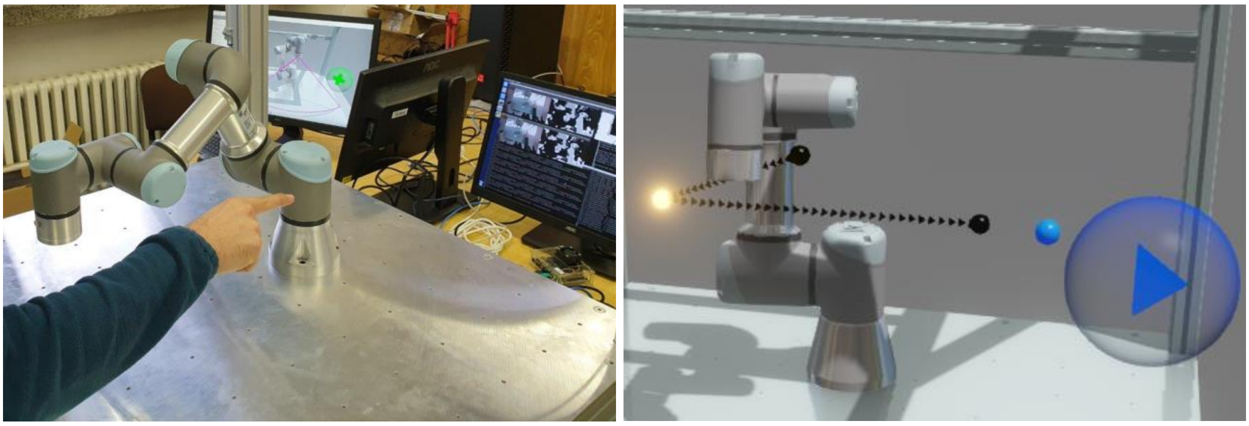


Fig. 6.8: Gesture-based robot guiding: (left) robot workplace with cameras; (right) user-defined trajectory created using hand gestures

6.2.5. Improved Mutual Awareness During Human-robot Collaboration

In a collaborative scenario, the communication between humans and robots is a fundamental aspect to achieve good efficiency and ergonomics in the task execution. A lot of research has been made related to enabling a robot system to understand and predict human behaviour, allowing the robot to adapt its motion to avoid collisions with human workers. Assuming the production task has a high degree of variability, the robot's movements can be difficult to predict, leading to a feeling of anxiety in the worker when the robot changes its trajectory and approaches since the worker has no information about the planned movement of the robot. Additionally, without information about the robot's movement, the human worker cannot effectively plan own activity without forcing the robot to constantly replan its movement. We proposed a novel approach to communicating the robot's intentions to a human worker.

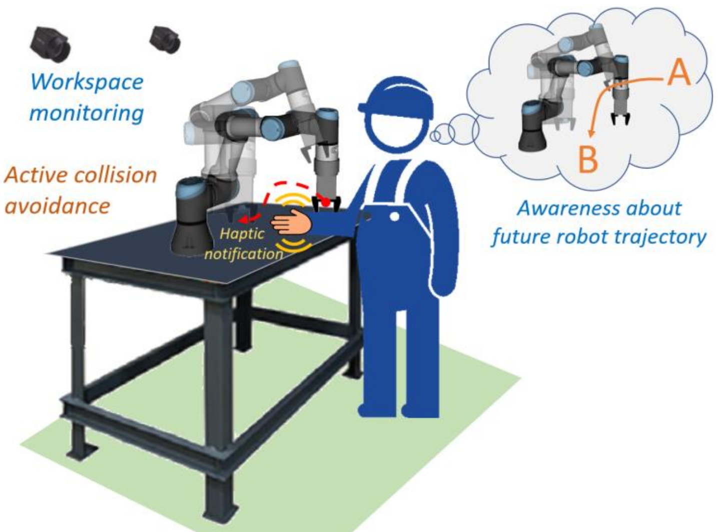


Fig. 6.9: Concept of improved HRC combines principles of active collision avoidance with an increased awareness provided by the wearable haptic feedback device

The improvement to the collaboration is presented by introducing haptic feedback devices, whose task is to notify the human worker about the currently planned robot's trajectory and changes in its status. The human worker is equipped with haptic feedback device fastened at each hand.

Fig. 6.10: Prototype of the notification devices. Each glove is equipped with six vibration motors, which provide haptic feedback

These feedback devices provide continuous vibration alert to the user about the proximity to the currently planned trajectory of the robot. The closer the worker's hand approaches the future segment of the trajectory, the stronger is the vibration provided by the device. When a person, despite a warning, interferes with the currently planned trajectory, the robot attempts to find a new feasible path to the goal position and continue the activity. Every time a new trajectory is planned as a result of environment change, both feedback devices use strong vibration notification to draw the attention of the human worker and to indicate that the robot has detected an environment change and has replanned its movement. If no feasible path to the target has been found, both feedback devices also provide a different type of a strong vibration alert which lasts until the robot is able to continue its activity.

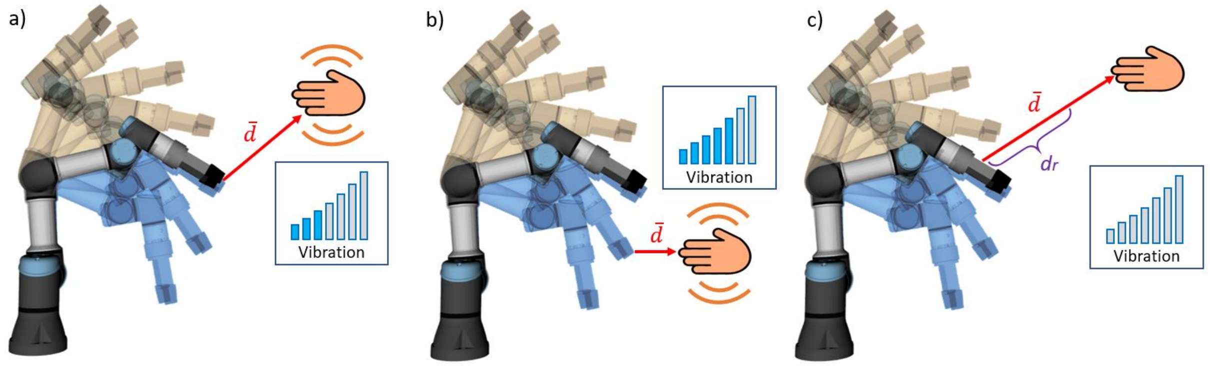


Fig 6.11:. Illustrating distance notification principle: (a-b) vibration intensity is proportional to the distance to the closes point of the robot body in any timestep of the future trajectory; (c) distance notification is not active when the hand is further than the safe distance

We further improved the developed system by introducing spatial tactile feedback, which provides the human worker with more intuitive information about the currently planned robot's trajectory, given its spatial configuration.

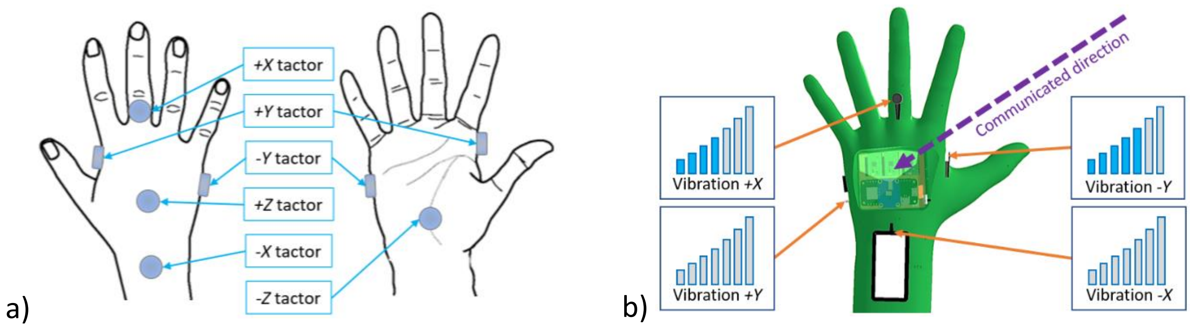


Fig. 6.12: Tactors placement around the hand: (a) function of each tactor (positive and negative directions of X, Y, Z axes); (b) spatial organization of the tactors may represents an arbitrary direction of a possible collision through a difference in activation of tactors located around the hand

In order to verify the effectiveness of the developed human-machine interface in the conditions of a shared collaborative workspace, a user study was designed and conducted among 17 participants, whose objective was to accurately recognise the goal position of the robot during its movement. Statistically significant results of the experiment indicated that all the participants could improve their task completion time by over 45% and generally were more subjectively satisfied when completing the task with equipped haptic feedback devices. The results suggested the usefulness of the developed notification system since it improved users' awareness about the motion plan of the robot. The system may also be able to reduce the time required for unskilled operators to get used to the manufacturing process and the movement of the robot in the near vicinity.

6.2.6. Structural Optimization Method of a FinRay Finger for the Best Wrapping of Object

The main goal of this research was to determine a new method for finger optimization based on the Fin Ray effect. A new and simple method was introduced to mathematically evaluate the wrapping of the finger around the object, in which the values of two points after loading were determined at the place of maximum elongation and at the fingertip. Using these two values, the proposed deflection coefficient was calculated, which serves to compare the proposed structures of Fin Ray fingers. A total of 46 different jaw variants were designed for mutual comparison according to the deflection coefficient determined from the simulations. The fingers were designed from TPU 30D material. The selected fingers were then printed and tested on a real device for comparison with the simulation results. During the real testing, the cyclic hysteresis of the printed fingers was also measured, which was manifested on the one hand by a different course of force on the deformation while pressing the object into the finger and during its extension and at the same time by a total shift of this course according to the number of loaded cycles.

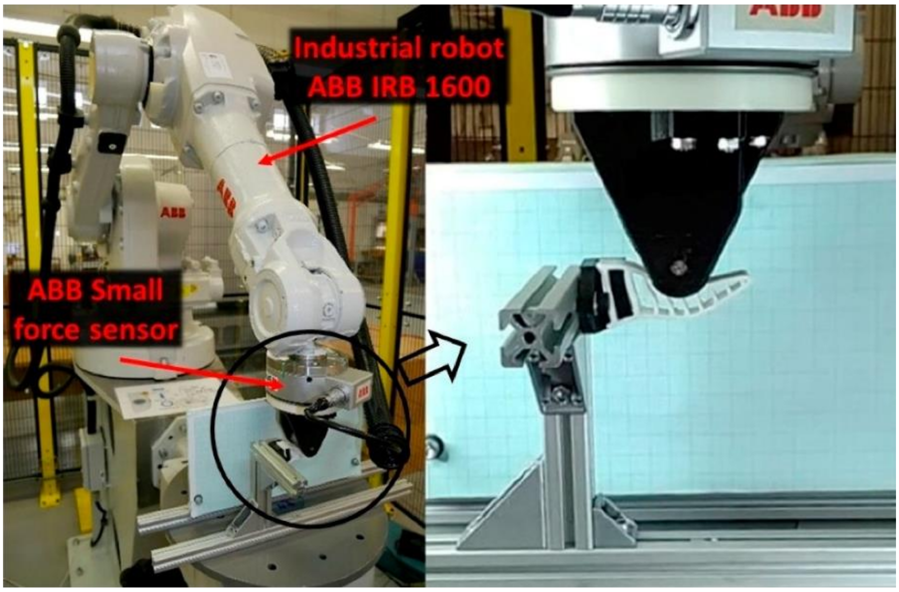


Fig. 6.13: Testing device. Left: entire device, right: detail under load.

The internal structures of the fingers, which were evaluated as most suitable based on the methods used in wrapping around the gripped object, were tested when handling various objects, as shown in the following figure.

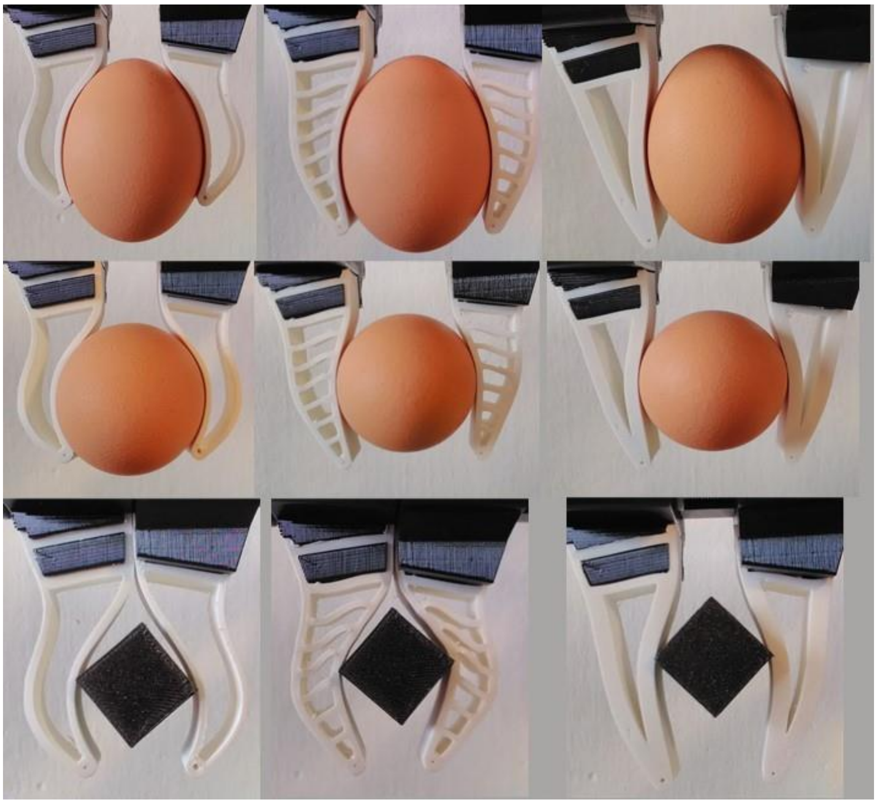


Fig. 6.14: Demonstration of grasping various objects.

The results of this work show the most suitable structure of the tested fingers from the point of view of wrapping the finger around the object. The results can help the designers to use the new optimization method to compare their designed finger variants.

The research is described in detail in the article Suder, Jiří, Zdenko Bobovský, Jakub Mlotek, Michal Vocetka, Petr Oščádal and Zdeněk Zeman. Structural Optimization Method of a FinRay Finger for the Best Wrapping of Object. 11. Applied Sciences, 2021. ISSN 2076-3417. Available from: doi:10.3390/app11093858.

6.2.7. Analysis of Increasing the Friction Force of the Robot Jaws by Adding 3D Printed Flexible Inserts

The work is devoted to analysing the increase of the friction force of the robot jaws by adding 3D printed flexible inserts. The work describes a technical problem from practice when the manipulated object made of steel material slipped in the printed PLA jaws of the robot during the work cycle. Two surface shapes of printed inserts produced and two types of flexible materials TPU 30D and TPE 88 are tested. The increase in frictional force is measured on a measuring device with an industrial robot and a force measuring sensor. The most suitable type of printed inserts and material is then tested on a collaborative robot in its required work cycle.

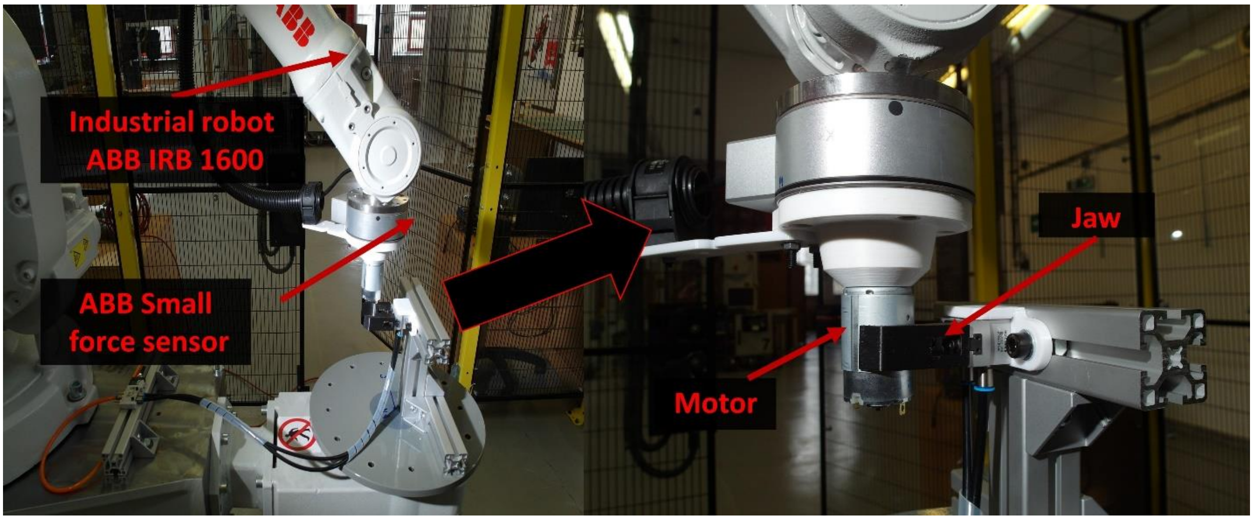


Fig. 6.15: Testing device. Left: entire device, right: detailed view of the jaw.

The results of this work are intended to help designers as a source of information or inspiration in designing similar applications.

The research is described in detail in the article Suder, Jiří, Tomáš Kot, Alan Panec And Michal Vocetka. Analysis Of Increasing The Friction Force Of The Robot Jaws By Adding 3d Printed Flexible Inserts. MM Science Journal. 2021, 2021(6), 5322-5326. ISSN 18031269. Available from: doi:10.17973/MMSJ.2021_12_2021127.

6.2.8. System of Automation for Design of Industrial Robots and Manipulators

As part of the research of advanced mechatronic systems, a system for automating the design of industrial robots and manipulators was further developed. Based on the proposed kinematic structure using, for example, genetic algorithms, the individual parts of the robotic arm are gradually designed, starting with the end effector and ending with the base. With the help of iterative processes, dimensional optimizations of structural parts take place, in order to achieve the required parameters of these elements, while minimizing their weight. Kinematic, dynamic and strength analyzes are performed within the design. Possible collisions are also sought and resolved not only within the proposed equipment, but within the entire proposed robotic workplace. The result of the design is a robotic arm, optimized for the application.

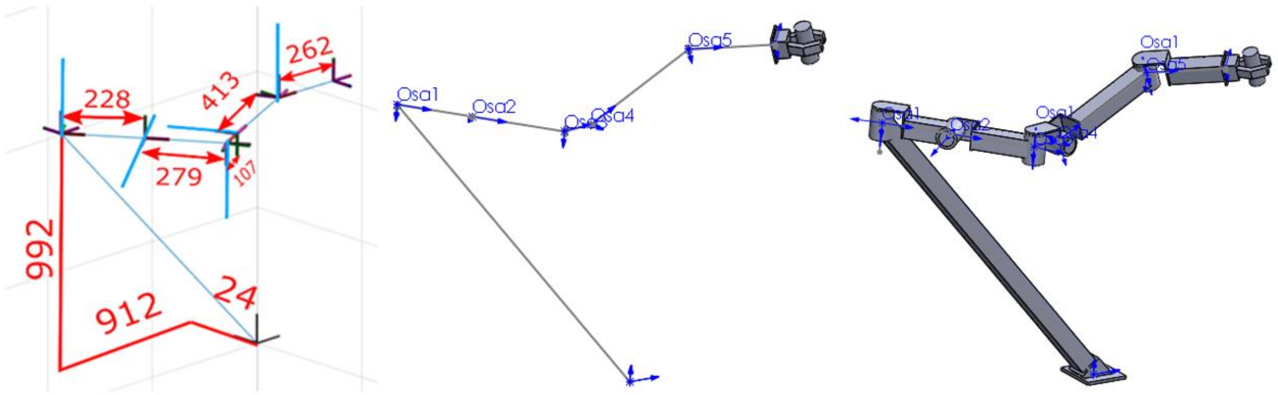


Fig. 6.16: Phases of the robotic arm design process, from the kinematic structure, through the skeleton, to the 3D model

Proprietary software tools (such as DrivePicker or RobotArmDesign) are used in the design in combination with the SolidWorks CAD system, which enables the automation of 3D modeling and analysis using an application programming interface (API). Thanks to this, it is possible not only to significantly reduce the design time of industrial robots and manipulators, but also to obtain better overall design results.

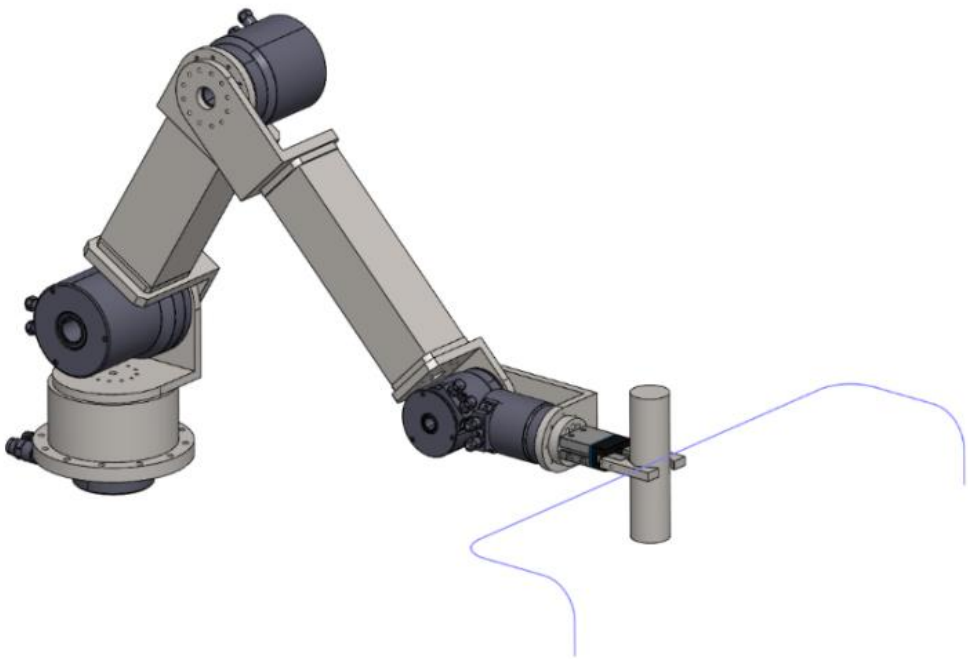


Fig. 6.17: 3D model of the automatically designed robotic arm

6.2.9. The Synthesis of Kinematic Structures

This research focuses on finding the kinematic structure (i.e., motor axis placement) of a serial manipulator that can perform a desired task or trajectory. The advantages of such a tailor-made manipulator are the reduction of energy consumption, minimization of axes and therefore cost, or avoiding collisions in densely built-up areas where conventional universal manipulators could not even be deployed today.

This is a complex problem, where not only the factors that are obvious at first sight, i.e., the specified trajectory and collision environment, but also the mathematical description of the manipulator itself play a role. In the figure below it is possible to see the deployment of the coordinate systems (motor axes) of one and the same manipulator, once using Denavit-Hartenberg parameters and the second time using the so-called Screw vectors. Both representations have identical axes of rotation of each joint, i.e., identical kinematic structure - they represent the same robot. However, their mathematical expression is very different if investigated closer.

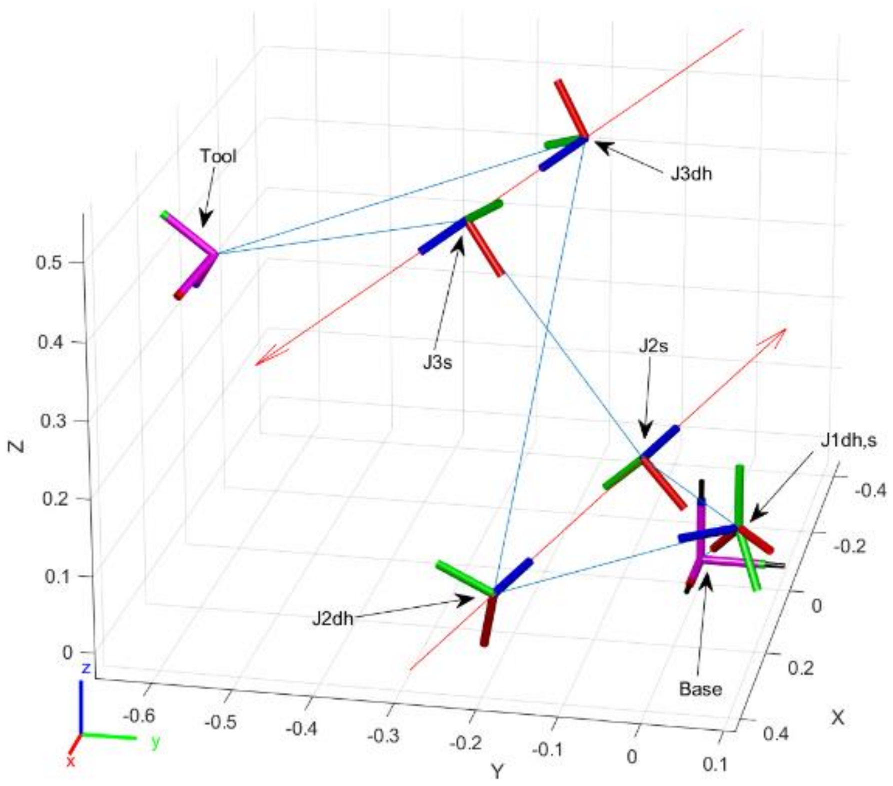


Fig. 6.18: Visualization of one robot using two different kinematic structure notations - DH parameters and Screw vectors

One of the directions of our research is to determine which mathematical description (including other than the two mentioned in the figure) of the manipulator is the most advantageous for the synthesis of kinematic structures when applying given numerical methods. An important observation is that by using analytical geometry and related algorithms that we have either applied or fully developed, it is possible to "switch" between the different mathematical representations at any time, even after the synthesis process. Thus, the choice of representation has no influence on the subsequent calculations concerning the dynamics and control of the manipulators.

6.2.10. Control System of a Collaborative Robot for Obstacle Avoidance

Although collaborative robots are designed to work directly with humans in a workplace and therefore will not cause injury in the event of a collision, any collision between a collaborative robot and a human operator represents a delay in the production cycle because the robot is in emergency shutdown mode after the collision. Therefore, for cases where the worker directly shares the workspace with the robot and frequently places his or her hands in the robot's path, it is more advantageous if the robot control system can detect the presence of dynamic obstacles and adjust its path. The department is in the process of designing a complex system including both the sensor part (detecting the presence of a dynamic obstacle) and the robot control system reacting to obstacles in real time.

One of the proposed and implemented obstacle avoidance algorithms is suitable for a robot moving along a defined arbitrarily complex trajectory (curve, see purple line in the figure) and is based on the principle of springs (potential field). The representation of a dynamic obstacle (e.g., a hand) is provided from the sensor system in the form of a list of voxels. The algorithm generates repulsive springs between the voxels and the surface of the 3D model of the robot arm (see yellow arrows in the figure). At the same time, the robot endpoint is attracted by another spring to a point expressing the current ideal position on the trajectory. By calculating the balance of the imaginary forces generated by all springs, the motion of the robot is ensured along an alternative dynamically changing trajectory (see dotted purple line).

For the cases when the robot moves from one working point to another and the trajectory is not fixed (pick&place operation), a different algorithm was designed, using an imaginary simulated elastic band stretched between the pair of key points. Any voxels representing a dynamic obstacle exert forces on this rubber, deflecting it away from the obstacle. The resulting trajectory ensures that the key points always connect smoothly and continuously.

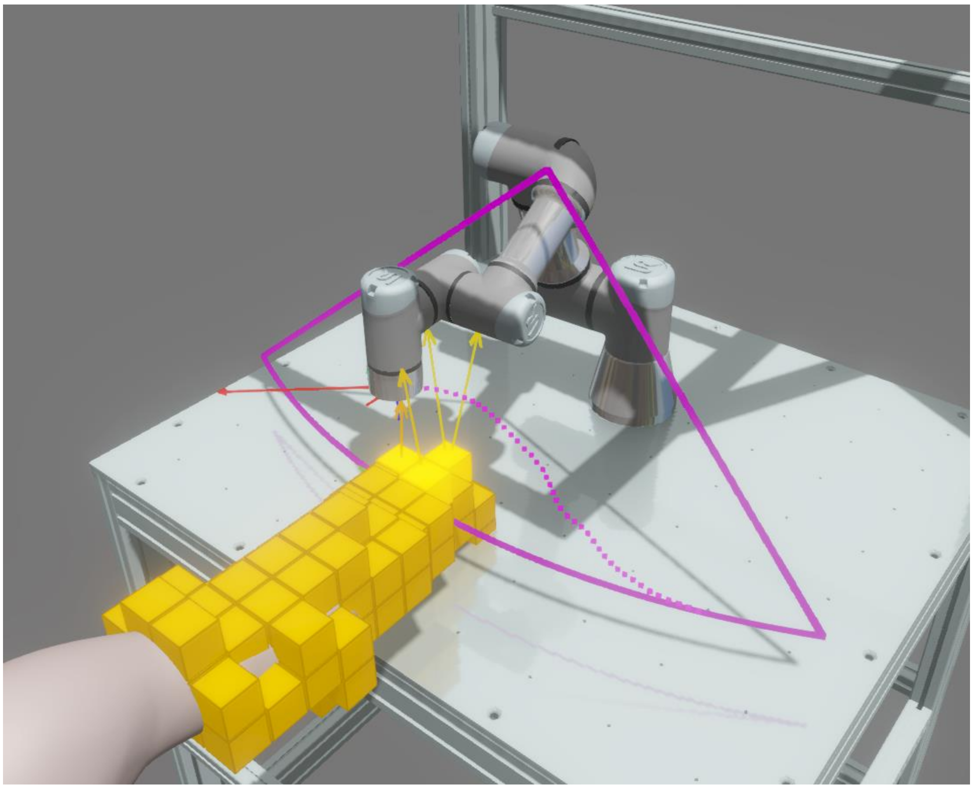


Fig. 6.19: Visualisation of the obstacle avoidance algorithm using springs

Fig. 6.20: Practical testing of the obstacle avoidance algorithm using an imaginary elastic band, in the foreground the real workplace, in the background the control system with 3D real-time visualization

6.2.11. Synthesis of an Optimized Kinematic Structure of a Robot

Synthesis of a kinematic structure of a robot tailored for a given task is one of the topics addressed at the Department of Robotics. One of the proposed algorithms uses the PSO (Particle Swarm Optimization) optimization algorithm to find the optimal combination of all Denavig-Hartenberg parameters describing the kinematic structure of the robot, thus obtaining a completely untypical structure, which, however, may have better parameters compared to the classical structure of commercially available manipulator arms. The optimization criteria may be, for example, minimization of the total length of the links, minimization of the joint velocities over the entire trajectory, minimization of force effects, etc..

For even greater variability in the proposed solutions, especially in a confined workspace, it is possible to replace the two main robot arms with a curve of several different curvature types and complexities. The optimization algorithm then varies the corresponding values of the control curves in addition to the Denavit-Hartenberg parameters.

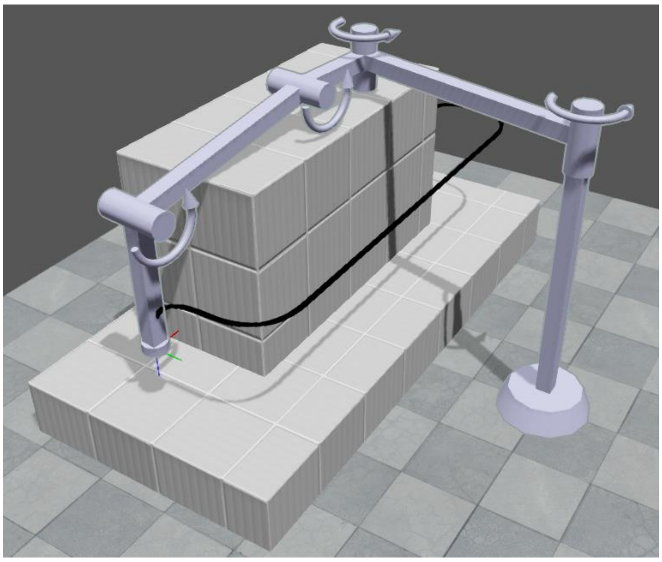


Fig. 6.21: Example of a proposed general optimal kinematic structure with straight arms

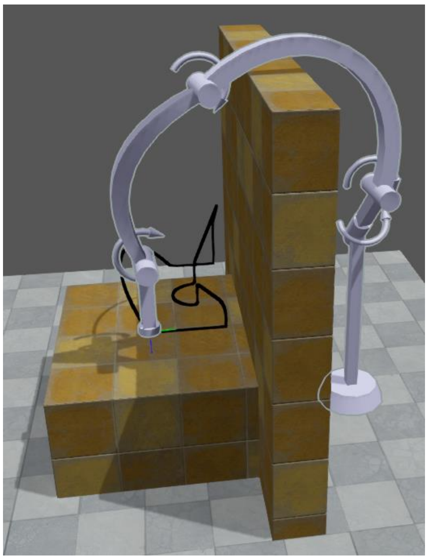


Fig. 6.22: Example of a proposed general optimal kinematic structure with curved arms

6.2.12. Creating 3D Scans of Real Mechanical Components

In the framework of research on automatic recognition of mechanical components based on 3D scanning, an algorithm for designing the optimal placement of scanners around a rotary scanning table was proposed. The goal is to maximize the surface coverage of any component (from a statistical point of view) using the smallest number of steps of the rotary table and the smallest number of scanners used. The algorithm uses the principle of simulated scanning of a large number of 3D models of mechanical components of different shapes and sizes. The output is the recommended values of the scanner angles from the horizontal plane and the number of rotation steps.

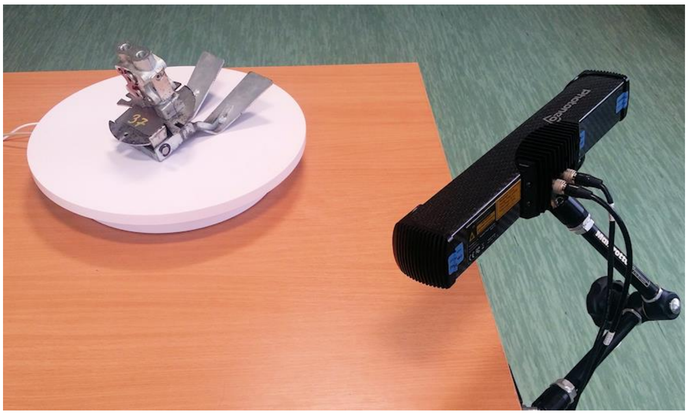


Fig. 6.23: Scanning rotary table with one Photoneo scanner positioned at a selected angle

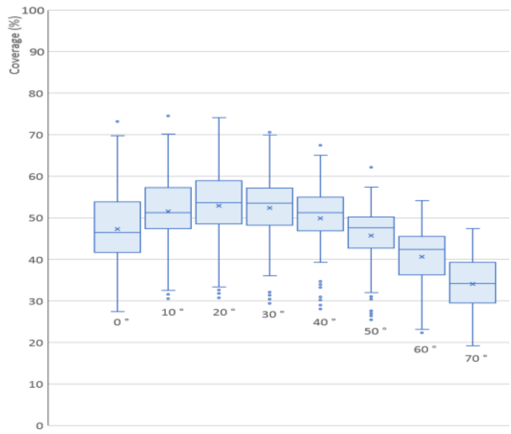


Fig. 6.24: Graph showing the statistical distribution of surface coverage values of a scanned object using a single scanner as a function of scanner angle

6.2.13. Optimizing a Manipulator Kinematics Using a Genetic Algorithm

This method is used to find the appropriate kinematic structure of a manipulator and the location of the manipulator base for a defined task. The whole method is implemented in the Matlab environment and uses the Robotics System Toolbox and the Global Optimization Toolbox.

The task for the manipulator in this method is defined by the trajectory and the working space. The trajectory is defined as a set of target points (6DOF position + orientation). The workspace is defined as the set of collision volumes and the volume in which the robot base can be located. The manipulators are built from joints and links during optimization. The joints exist in several variants, differing in the mutual transformation of coordinate frames. The figure below shows three variants of the transformations between the joints. The links placed between the joints change their length during optimization.

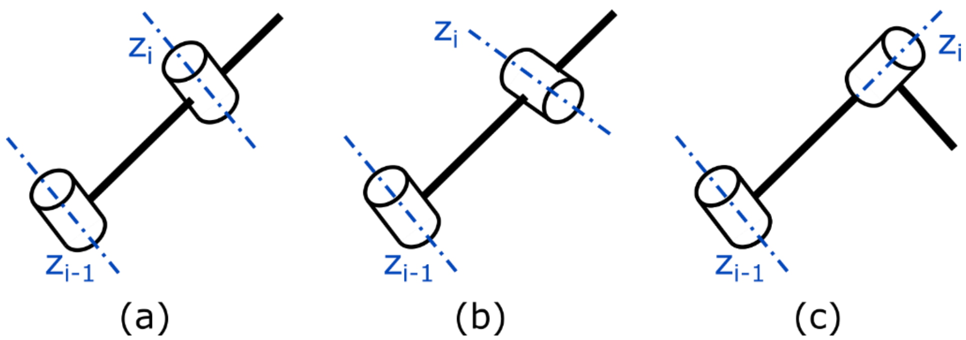


Fig. 6.25: Cases of joint transformations: a) $\alpha = 0$, b) $\alpha = 1$, c) $\alpha = 2$

Manipulators are defined in the genetic algorithm as a vector that starts with three values describing the position of the manipulator base, then the vector contains pairs of values describing the manipulator [joint type, article length]. The length of the optimized vector therefore corresponds to the number of joints in the manipulator * 2 + 3. The genetic algorithm modifies and verifies these vectors (manipulators) during the optimization using an objective function. Several objective functions have been defined, minimizing the length of the manipulator, minimizing the torques during movement, maintaining the prescribed distance from obstacles and the price of the modules. It is possible to use these objective functions or their combinations for evaluation during optimization.

This method has been tested on several sample simulation tasks. The figures below show the manipulators with optimized kinematics.

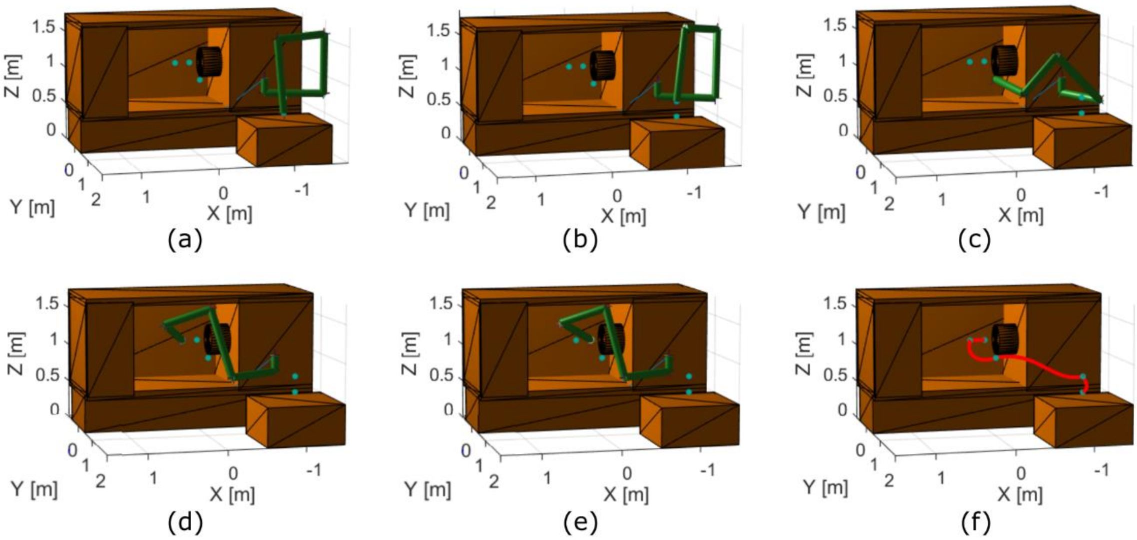


Fig. 6.26: Optimization result in the task: Lathe operation a) target 1, b) target 2, c) target 3, d) target 4, e) target 5, f) end-effector trajectory

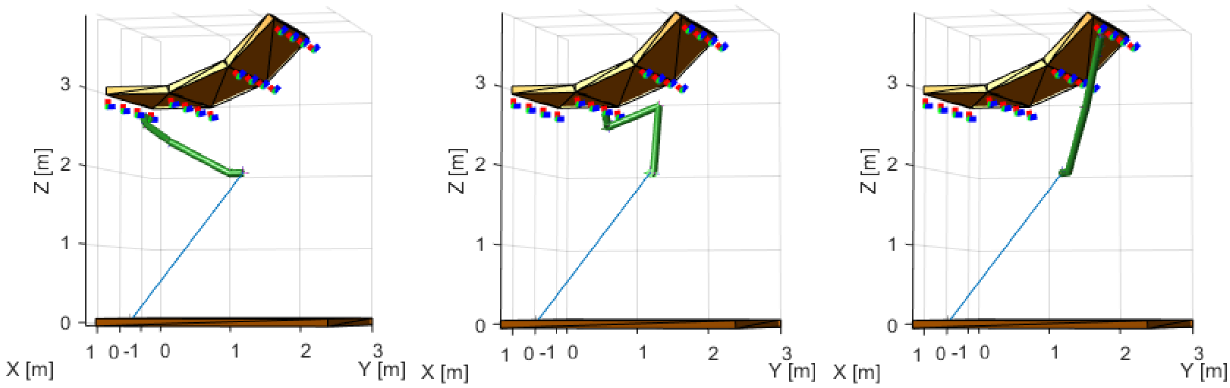


Fig. 6.27: Optimization result in a servicing task

6.2.14. Using Neural Network for Manipulator Kinematics Synthesis

An alternative to the automatic generation of manipulator kinematics using optimization algorithms is to use a neural network. The method is based on a simple end-to-end principle, providing a task definition for the manipulator on the input layer of the neural network and reading the definition of the manipulator from the output layer. However, creating a dataset for teaching this neural network is a complex task. At the same time, it is unclear what is the best way to encode the task definition for the manipulator so that it is in a suitable form for the neural network input data or which neural network architecture to choose.

This method was tested on a simplified manipulation task in 2D. The kinematics of the manipulators were optimized in randomly generated tasks. The result was a dataset of 5,000 manipulation tasks and their associated optimized manipulators. This dataset was used to teach the neural network. The input data was defined as a grid of size 100x100, where the target points of the trajectory and obstacles are marked. The output data defines the position of the manipulator in the X and Y axes and the lengths of the individual manipulator elements. The selected neural network uses fully interconnected layers, shown in the figure below.

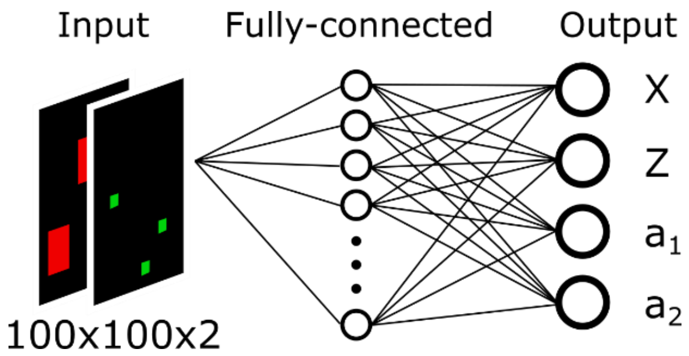


Fig. 6.28: Schematic diagram of the used neural network

The following figure shows a test 2D work environment and manipulators generated using a neural network.

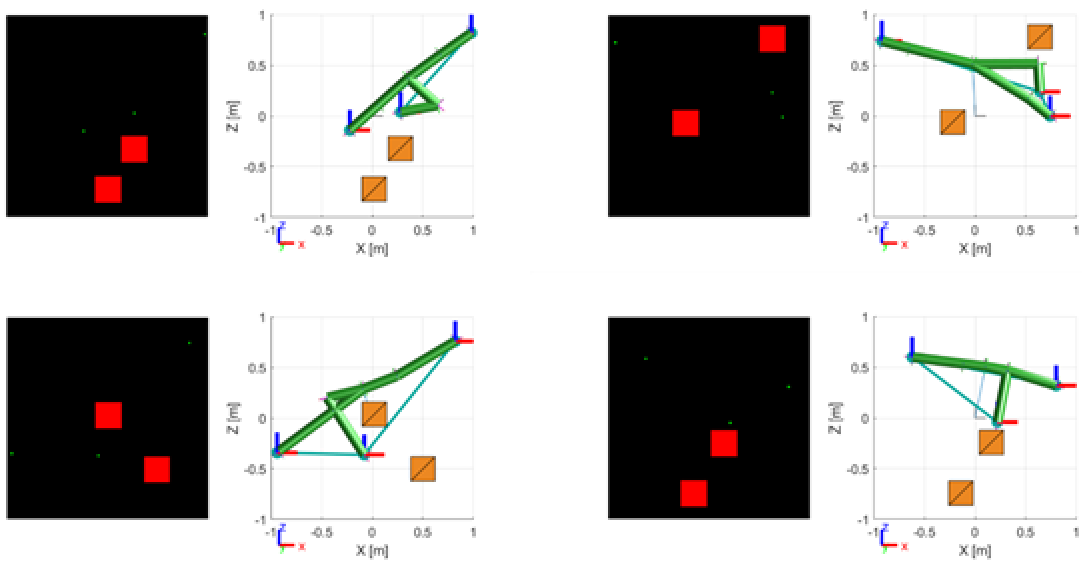


Fig. 6.29: Newly generated tasks and manipulators generated by NN

6.2.15. Automated Assembly of Pipe Clamps

In cooperation with the FEI (beneficiary), the solution of the project "Research of possibilities of robotization of technology of assembly of metal products with rubber" - TAČR EPSILON TH04010428 applied research of the system by which it would be possible to fully automate the assembly of pipe clamps was continued. Contracting authority is the company Optimont 2000 s.r.o. The project was completed on the 31st of December 2021.

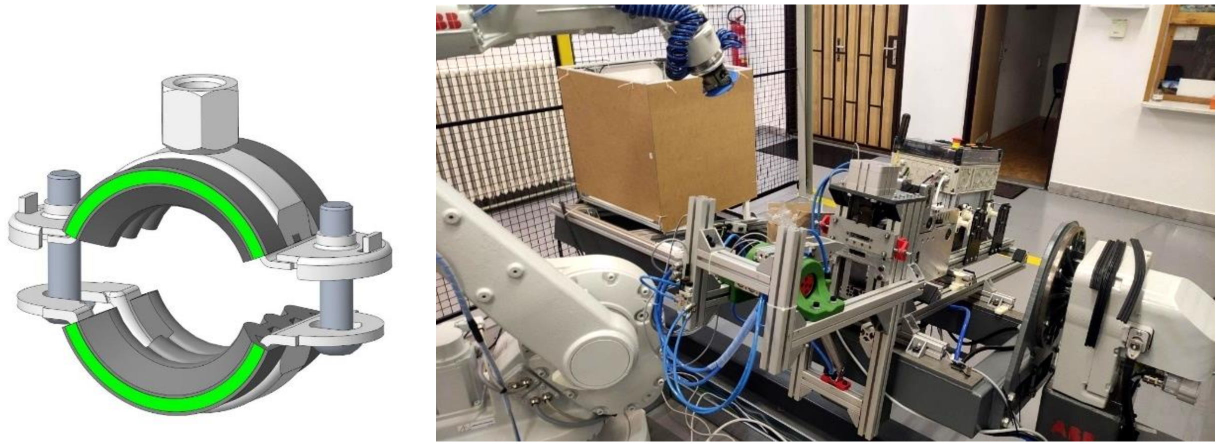


Fig. 6.30: 3D model of the clamp and a photo of the test workplace of the feeder prototype

The output of the project is a prototype of a rubber profile feeder, which is able to move, cut and prepare the rubber profile for its automatic application on the stamping of the clamp part. Based on the user experience from testing the prototype of the feeder, the concept of a robotic assembly workplace for the assembly of clamps was designed and simulated. The workplace work cycle simulation was created in the RobotStudio software tool. The achieved cycle time of the workplace is 15 s per assembled clamp.

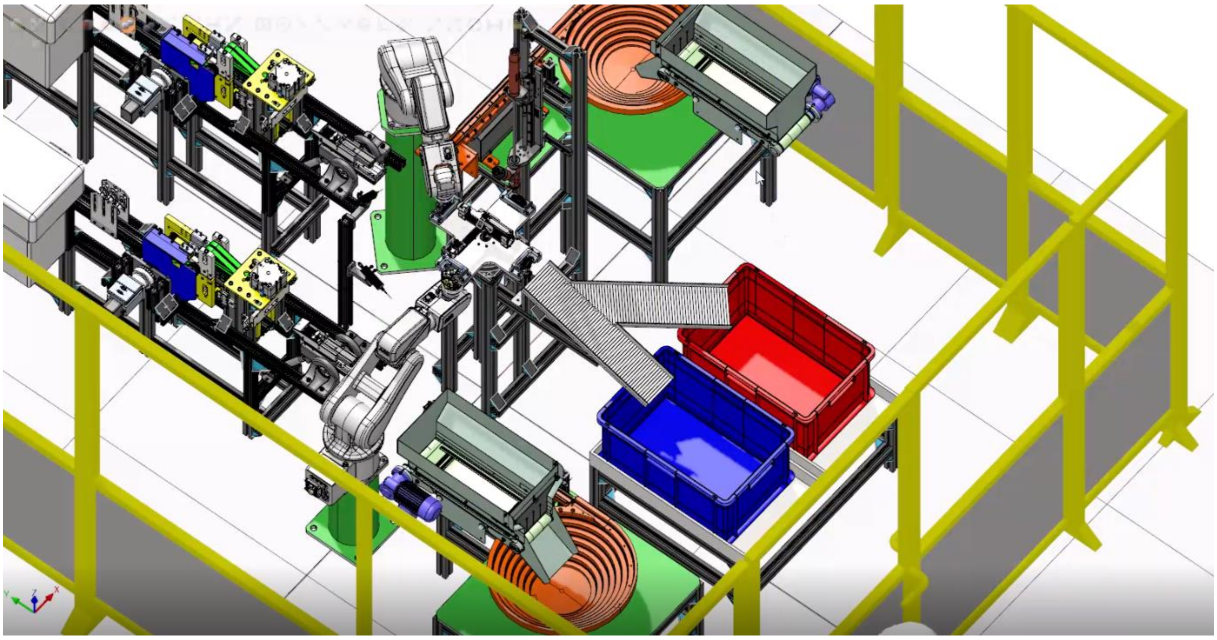


Fig. 6.31: Assembly workplace concept simulation

6.2.16. Low-cost Automation in the Concept of Industry 4.0

Within the project Low-cost automation for the Moravian-Silesian automotive cluster, the workplaces are gradually being solved as simplified technical-economic studies, which are to specify the possibilities of automation and robotization solutions for selected production nodes and their payback period for the members of the automotive cluster. This is an assignment for the integrator company IFTSolutions, where the robotization of the workplace for threading rubber rings on ultrasonic sensors is solved and it is a delivery for the company Valeo.

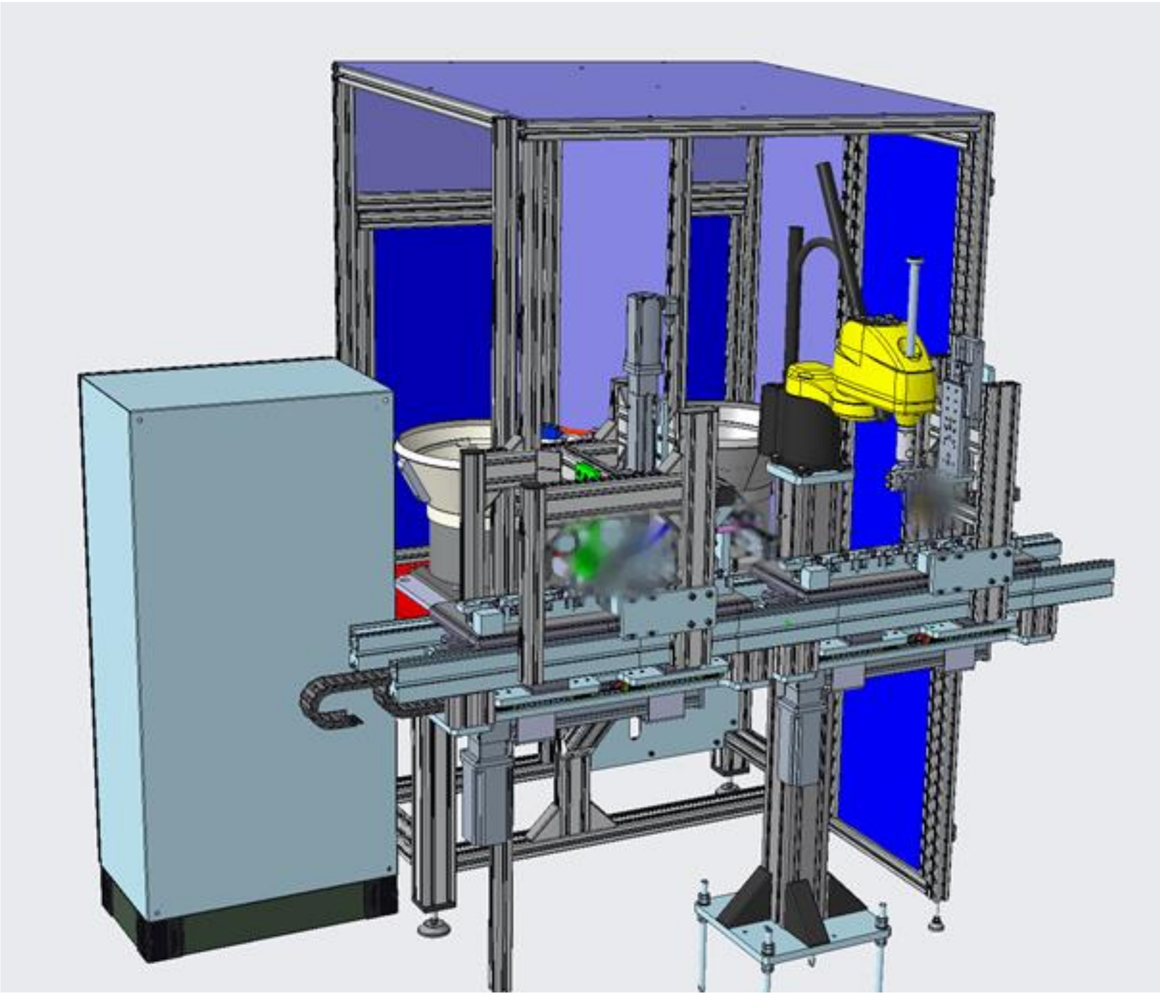


Fig. 6.32: Robotic workplace project for putting rings on sensors (IFTSolutions)

The next assignment is a workplace for the company KSR (production of pedals, sheet metal parts, etc.). This is a workplace for the production of connectors, where the existing scara robot puts the contacts into the mould, the contacts are sprayed with plastic in the press and after inspection the same robot puts them on the conveyor with a suction cup. At the output, there is an operator who folds the connectors into a KLT container and interleaves it with paper interleaves. The objective of the study is to replace the operator with a suitable robot and replace the conveyor with an automatic KLT container change facility with a stock of 3 KLTs. The original robot will remain, the new robot will remove the connectors from 4 fixed positions in the equipment, stack them one by one in the container and when the layer is full, it will remove the interleaving from the stack and place it on the layer and continue until the container is full.

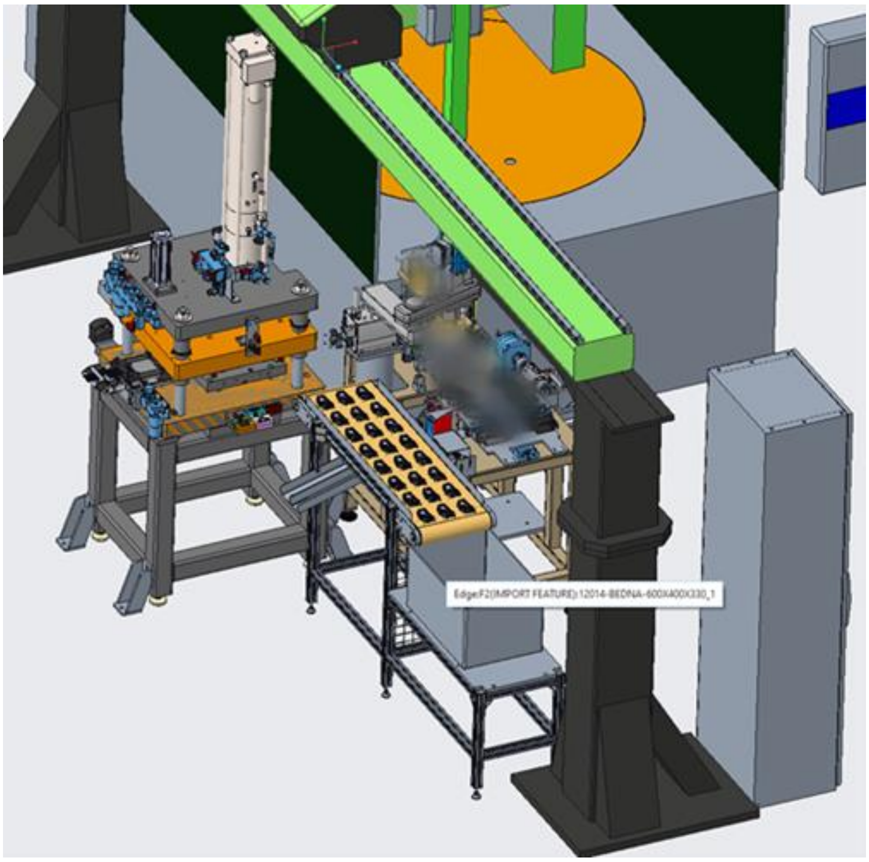


Fig. 6.33: Existing production node in KSR

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)

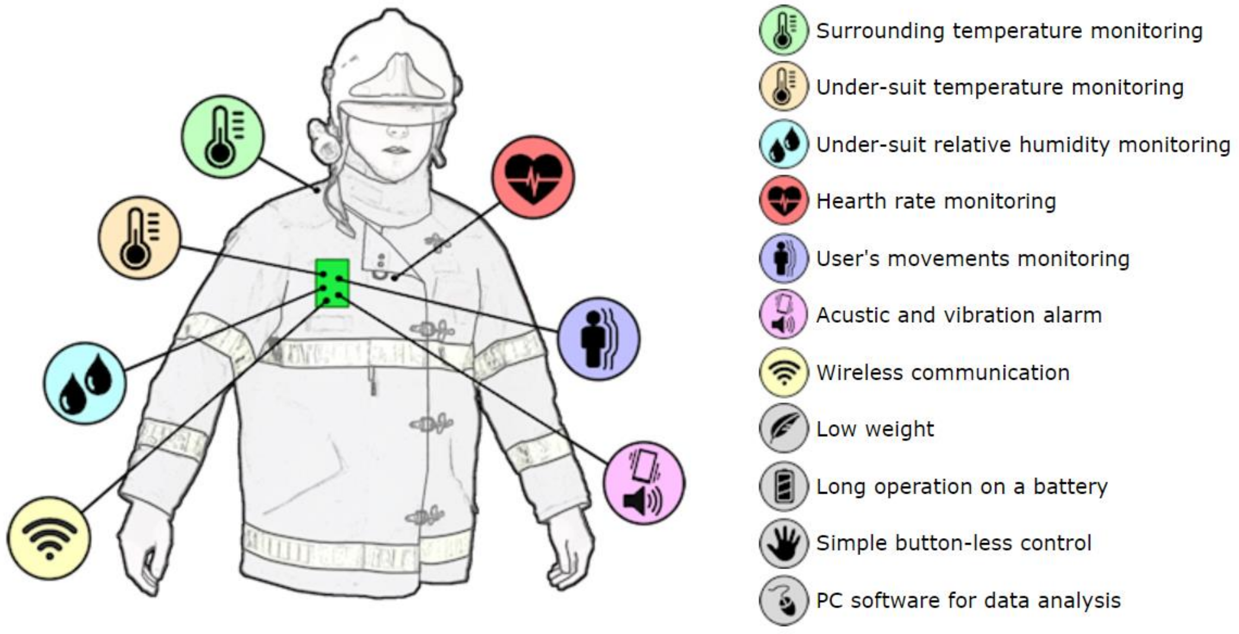


Fig. 6.34: SAM functionality

Fig. 6.35: 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.

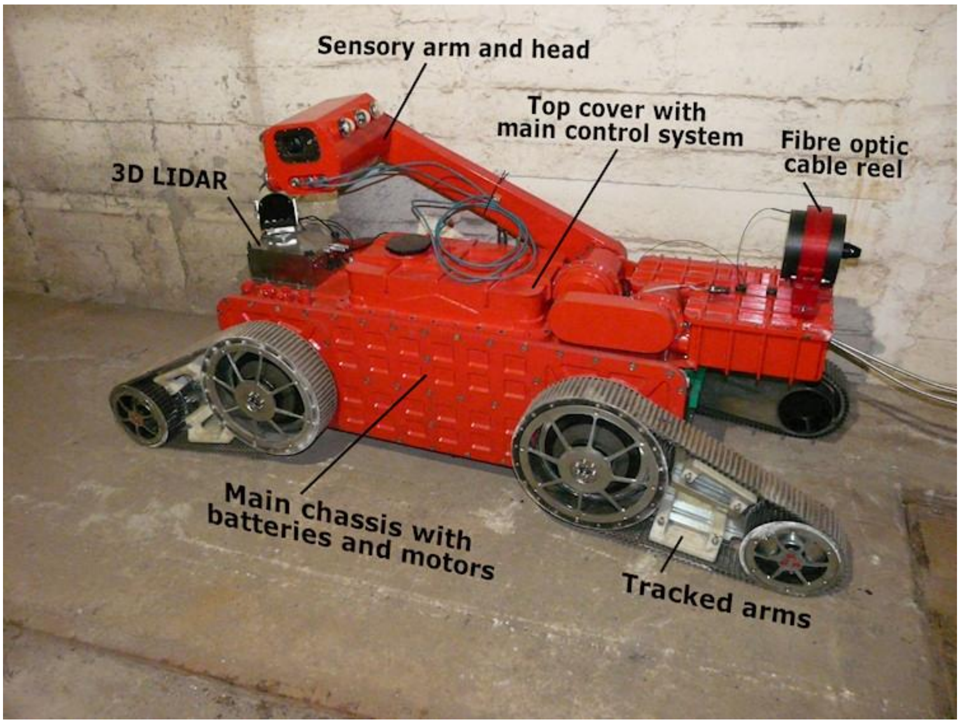


Fig. 6.36: TeleRescuer—main subsystems and 3D map of Coal mine corridor

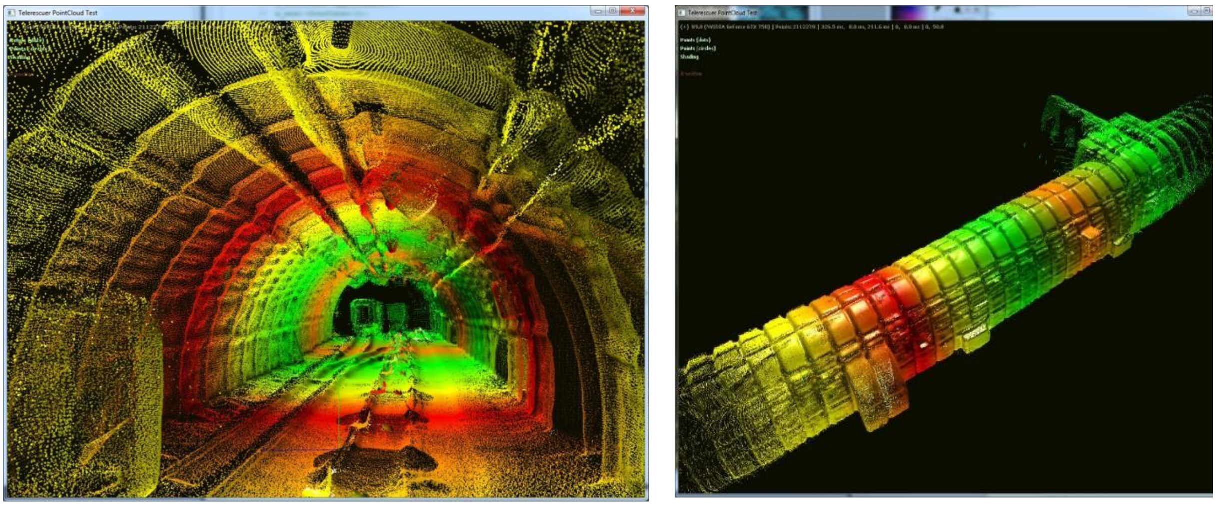


Fig. 6.37: Visualization of coil mine corridor 3D map (point clouds)

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.

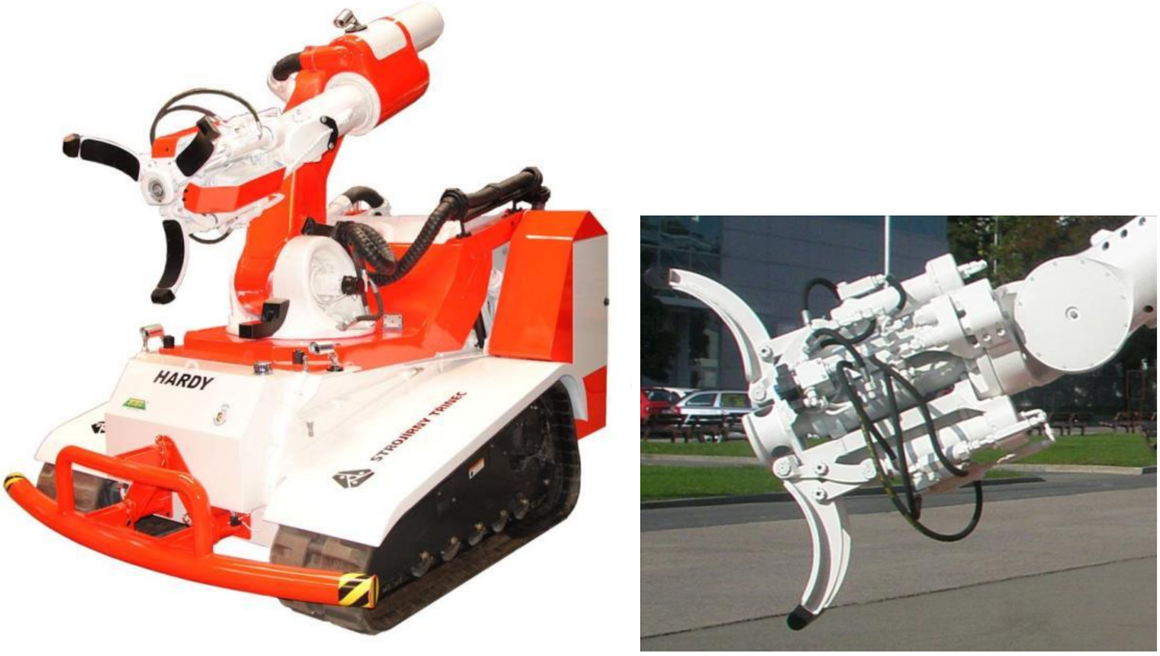


Fig. 6.38: Robot Hardy (left), Robot gripper without shields with the integrated water nozzle (right)

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. 6.39: 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. 6.40: 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)
Use of digitization of robotic systems in their design	2022	40k
RoMoLab – Robotic Mobile Laboratory for Genetic Tests, especially in the direction of SARS-CoV-2 HORIZON-CL3-2021-DRS-01-05 Proposal number: SEP-210797428	2022-2025	400k (4M)

6.5. New Laboratories and Equipment

Panoramic photos of selected laboratories and workplaces are available on the website of the Faculty of Mechanical Engineering. Our Robotics Centre can also be viewed there:

https://www.fs.vsb.cz/cs/katedry-a-pracoviste/laboratore/

6.5.1. Test Workplace of Experimental Robots

The workplace was acquired for the needs of solving a research project. It will be used for functional testing of robot manipulator prototypes designed by created design algorithms. The main components of the workplace are 2 distribution cabinets for the servo controllers of the drive units of the designed experimental robots. A public contract was announced for the supply of workplace equipment, in which the company ELVAC, a.s. succeeded.

Fig. 6.41: Photo of the created experimental workplace for experimental robots

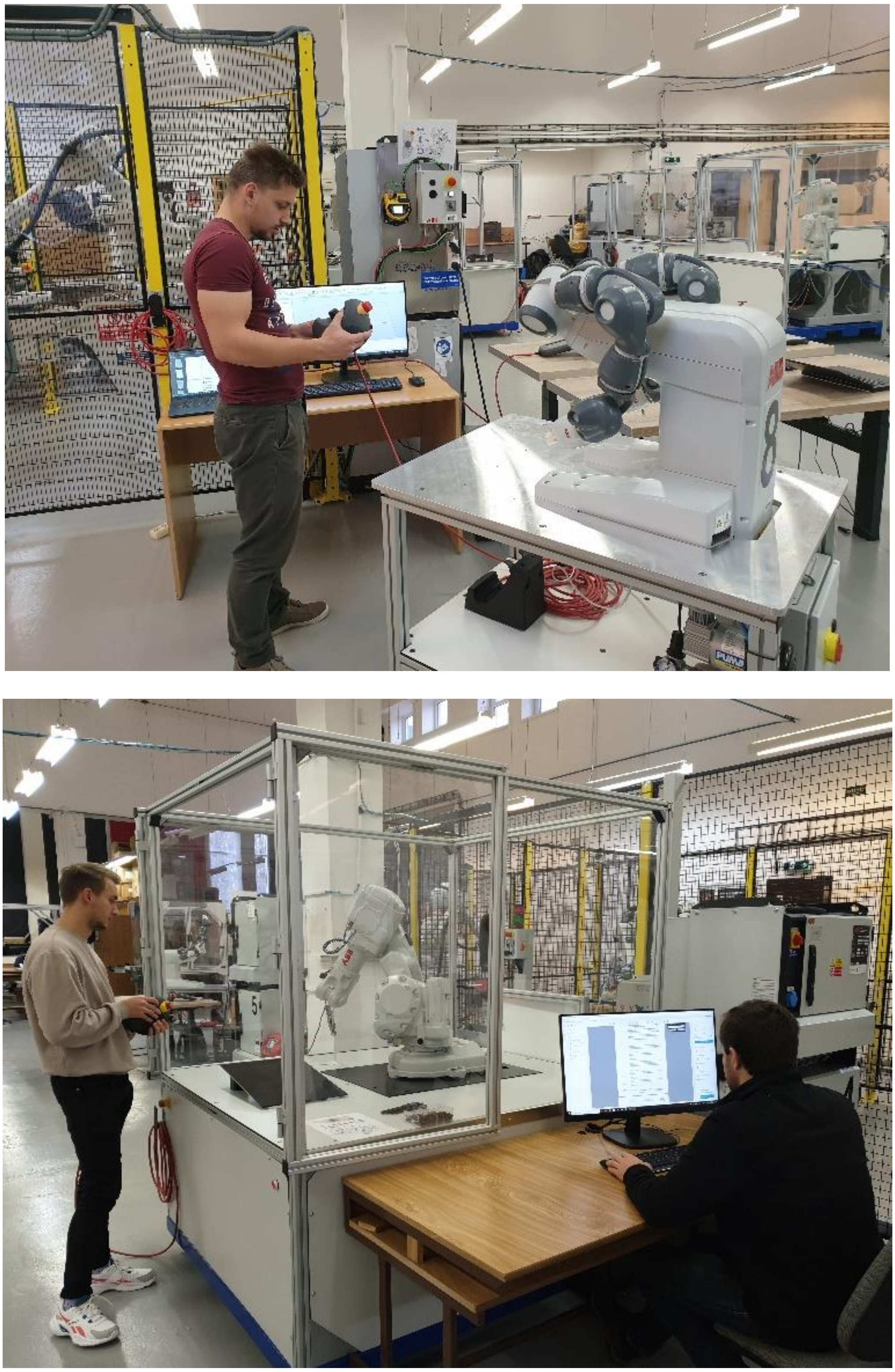


Fig. 6.42: Students learning collaborative and industrial robot programming

7. COOPERATION IN SCIENCE AND RESEARCH

7.1. Cooperation with Subjects 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,g.
- Robotsystem,
- Elvac,
- ABB robotics,
- IFTSolutions,

7.2. Cooperation with Subjects 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 internships
- IT University of Copenhagen, Robotics, Evolution, and Art Lab, Denmark – robotics, internships
- Universitat Innsbruck, Joanneum research – Robotics – internships
- Technical University of Košice, Slovakia, Mechatronics, internships

8. PUBLISHING ACTIVITIES

8.1. Articles in International Journals

Virgala, I., Kelemen, M., Prada, E., Sukop, M., Kot, T., Bobovský, Z., Varga, M., Ferenčík, P. A Snake Robot for Locomotion in a Pipe Using Trapezium-like Travelling Wave. *Mechanism and Machine Theory*. 2021, Volume 158, April 2021, Article number 104221. Scopus, WoS, Impact factor 3.312, order 30/130 (**Q1**)

Grushko, S., Vysocký, A., Oščádal, P., Vocetka, M., Novák, P., Bobovský, Z. Improved Mutual Understanding for Human-Robot Collaboration: Combining Human-Aware Motion Planning with Haptic Feedback Devices for Communicating Planned Trajectory. *Sensors*. 2021, vol. 21, issue 11, 3673. Scopus, WoS, Impact factor 3.275, order 15/64 (**Q1**)

Heczko, D., Oščádal, P., Kot, T., Huczala, D., Semjon, J., Bobovský, Z. Increasing the Reliability of Data Collection of Laser Line Triangulation Sensor by Proper Placement of the Sensor. *Sensors*. 2021. 21(8), 2890. Scopus, WoS, Impact factor 3.275, order 15/64 (**Q1**)

Grushko, S., Vysocký, A., Heczko, D., Bobovský, Z. Intuitive Spatial Tactile Feedback for Better Awareness about Robot Trajectory during Human-Robot Collaboration. *Sensors*. 2021, 21(17), 5748. Scopus, WoS, Impact factor 3.567, order 14/64 (**Q1**)

Kot, T., Bobovský, Z., Heczko, D., Vysocký, A., Virgala, I., Prada, E. Using Virtual Scanning to Find Optimal Configuration of a 3D Scanner Turntable for Scanning of Mechanical Parts. *Sensors*. 2021, 21(16), 5343. Scopus, WoS, Impact factor 3.576, order 14/64 (**Q1**)

Sinčák, P., Virgala, I., Kelemen, M., Prada, E., Bobovský, Z., Kot, T. Chimney sweeping robot based on a pneumatic actuator. *Applied sciences*. 2021, 11(11), 4872. Scopus, WoS, Impact factor 2.474, order 32/91 (**Q2**)

Kot, T., Bobovský, Z., Brandstötter, M., Krys, V., Virgala, I., Novák, P. Finding Optimal Manipulator Arm Shapes to Avoid Collisions in a Static Environment. *Applied sciences*. 2021, 11(1), 64. Scopus, WoS, Impact factor 2.474, order 32/91 (**Q2**)

Pastor, R., Bobovský, Z., Huczala, D., Grushko, S. Genetic Optimization of a Manipulator: Comparison between Straight, Rounded, and Curved Mechanism Links. *Applied sciences*. 2021. 11(6), 2471. Scopus, WoS, Impact factor 2.474, order 32/91 (**Q2**)

Huczala, D., Kot, T., Pfurner, M., Heczko, D., Oščádal, P., Mostýn, V. Initial Estimation of Kinematic Structure of a Robotic Manipulator as an Input for Its Synthesis. *Applied sciences*. 2021. 11(8), 3548. Scopus, WoS, Impact factor 2.474, order 32/91 (**Q2**)

Ondočko, Š., Svetlík, J., Šašala, M., Bobovský, Z., Stejskal, T., Dobránsky, J., Demeč, P., Hrivniak, L. Inverse Kinematics Data Adaptation to Non-Standard Modular Robotic Arm Consisting of Unique Rotational Modules. *Applied sciences*. 2021. 11(3), 1203. Scopus, WoS, Impact factor 2.474, order 32/91 (**Q2**)

Straková, E., Lukáš, D., Bobovský, Z., Kot, T., Mihola, M., Novák, P. Matching Point Clouds with STL Models by Using the Principle Component Analysis and a Decomposition into Geometric Primitives. *Applied sciences*. 2021. 11(5), 2268. Scopus, WoS, Impact factor 2.474, order 32/91 (**Q2**)

Kot, T., Bobovský, Z., Vysocký, A., Krys, V., Šafařík, J., Ružarovský, R. Method for Robot Manipulator Joint Wear Reduction by Finding the Optimal Robot Placement in a Robotic Cell. *Applied sciences*. 2021, 11(12), 5398. Scopus, WoS, Impact factor 2.747, order 32/91 (**Q2**)

Rojíček, J., Paška, Z., Fusek, M., Bobovský, Z., Sapietová, A., Mostýn, V., Ličová, D. Optimization of a Truss Structure Used to Design of the Manipulator Arm from a Set of Components. *Applied sciences*. 2021, vol. 11, issue 21. e-ISSN 2076-6341. Scopus, WoS, Impact factor 2.747, order 32/91 (**Q2**)

Huňady, R., Lengvarský, P., Pavelka, P., Kaľavský, A., Mlotek, J. Stiffness Estimation and Equivalence of Boundary Conditions in FEM Models. *Applied sciences*. 2021. 11(4), 1482. Scopus, WoS, Impact factor 2.474, order 32/91 (**Q2**)

Suder, J., Bobovský, Z., Mlotek, J., Vocetka, M., Oščádal, P., Zeman, Z. Structural Optimization Method of a FinRay Finger for the Best Wrapping of Object. *Applied sciences*. 2021. 11(9), 3858. Scopus, WoS, Impact factor 2.474, order 32/91 (**Q2**)

Vocetka, M., Bobovský, Z., Babjak, J., Suder, J., Grushko, S., Mlotek, J., Krys, V., Hagara, M. The influence of the Drift on the Robot Repeatability and its Compensation. *Applied sciences*. 2021. Scopus, WoS, Impact factor 2.747, order 32/91 (**Q2**)

8.2. Articles in Czech Journals

Suder, J., Kot, T., Panec, A., Vocetka, M. Analysis of Increasing the Friction Force of the Robot Jaws by Adding 3D Printed Flexible Inserts. *MM Science Journal*. 2021, issue December, pp. 5322-5326. ISSN 1803-3126. WoS

Mihola, M., Zeman, Z., Fojtík, D. Automation of the Design of the Cross-Section of the Manipulator Arms Profile. *MM Science Journal*. 2021, issue October, pp. 4863-4871. ISSN 1803-3126. Scopus, WoS

Zeman, Z., Mihola, M., Suder, J. Design of Algorithms for Automatic Selection of Drive Units for Mechatronic Devices. *MM Science Journal*. 2021, issue June, pp. 4362-4370. ISSN 1803-3126. Scopus, WoS

Suder, J., Bobovský, Z., Mlotek, J., Vocetka, M., Zeman, Z., Šafář, M. Experimental Analysis of Temperature Resistance of 3D Printed PLA Components. *MM Science Journal*. 2021, issue March, pp. 4322-4327. ISSN 1803-3126. Scopus, WoS

Grushko, S., Vysocký, A., Suder, J., Glogar, L., Bobovský, Z. Improving Human Awareness During Collaboration With Robot: Review. *MM Science Journal*. 2021, issue December, pp. 5475-5480. ISSN 1803-3126.

Paška, Z., Rojíček, J., Fojtík, F., Krys, V., Fusek, M., Ličková, D. Load Capacity of Helicoil Inserts in ABS-M30 Material Used for Additive Manufacturing. *MM Science Journal*. 2021, issue December, pp. 5414-5420. ISSN 1803-3126. WoS

Pastor, R., Bobovský, Z., Oščádal, P., Měsíček, J., Pagáč, M., Prada, E., Miková, L., Babjak, J. Optimizing a Quadruped Robot: A Comparison of Two Methods. *MM Science Journal*. 2021, vol. 2021, issue June, pp. 4348-4355. ISSN 1803-3126. Scopus, WoS

Mihola, M., Zeman, Z., Fojtík, D. Research and Development of a Knowledge-Based Design System for Designing Selected Elements of Mechatronic Devices. *MM Science Journal*. 2021, issue December, pp. 5381-5390. ISSN 1803-3126. WoS

An up-to-date overview of publications of the Department of Robotics is available at:

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