2023

Annual Report of the Department of Robotics

Faculty of Mechanical Engineering,

VŠB – Technical University of Ostrava

Czech Republic

19th January 2024

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

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2023

Department of Robotics

Faculty of Mechanical Engineering,

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https://www.instagram.com/katedra_robotiky/
https://www.youtube.com/user/robot354

CONTENT

1 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 several 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.

2 STAFF

Head of department:	prof. Dr. Ing. Petr Novák
Deputy head:	prof. Ing. Zdenko Bobovský, PhD.
Secretary:	Ing. Václav Krys, Ph.D. Ing. Ján Babjak, Ph.D. *(since December 2023)*
Assistant:	Ing. Petra Pišťáčková
Professors:	prof. Ing. Zdenko Bobovský, PhD. prof. Dr. Ing. Vladimír Mostýn prof. Dr. Ing. Petr Novák
Associate professors:	doc. Ing. Tomáš Kot, Ph.D. doc. Ing. Milan Mihola, Ph.D. doc. Ing. Aleš Vysocký, Ph.D.
Assistant professors:	Ing. Stefan Grushko, Ph.D. *(till August 2023)* Ing. Dominik Heczko, Ph.D. Ing. Ladislav Kárník, CSc. *(till June 2023)* Ing. Václav Krys, Ph.D. Ing. Jakub Mlotek, Ph.D. Ing. Petr Oščádal, Ph.D. Ing. Robert Pastor, Ph.D. *(till June2023)* Ing. Jiří Suder, Ph.D. Ing. Michal Vocetka, Ph.D. Ing. Aleš Vysocký, Ph.D. Ing. Zdeněk Zeman, Ph.D.
Researchers:	Ing. Ján Babjak, Ph.D. Ing. Jan Bém Ing. Adam Boleslavský Ing. Daniel Huczala, Ph.D. *(till June2023)* Ing. Jakub Chlebek Bc. Vyomkesh Kumar Jha Ing. Jakub Krejčí Ing. Jan Maslowski Ing. Tomáš Poštulka Ing. Tomáš Spurný Ing. Rostislav Wierbica

3 EDUCATION ACTIVITIES

3.1 Guaranteed Study Field

3.1.1 Bachelor studies

Title: **Robotics**

Field of Study: B0715A270011/S07 (Czech), B0715A270012/S04 (English)

Guarantor: doc. 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.

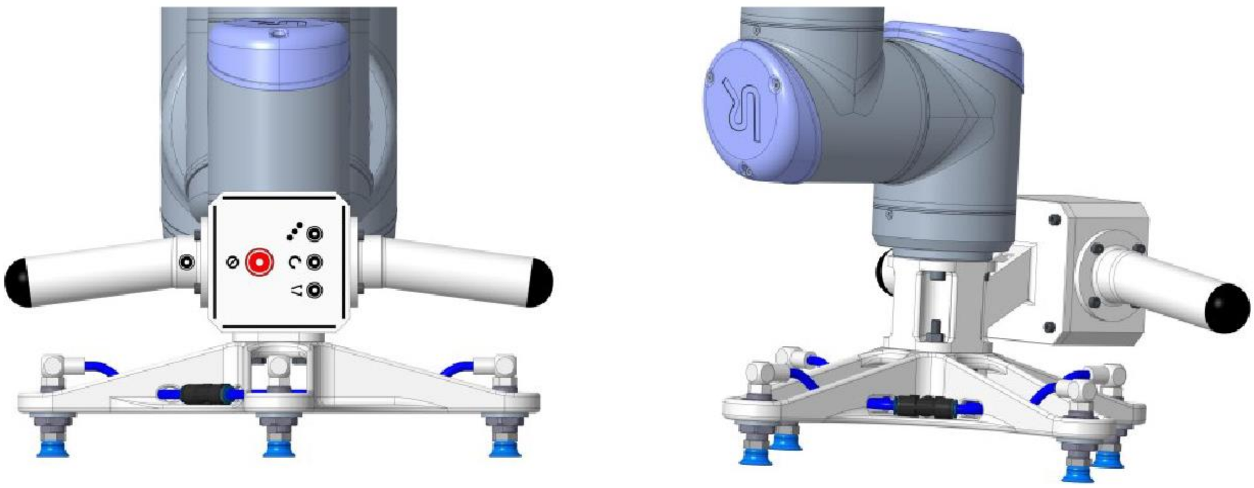


Fig. 3.1: Bc. David Kolář – Device for manual guidance of robots (bachelor's thesis, supervisor: Ing. Rostislav Wierbica)

Title: **Mechatronics**

Field of Study: B0714A270002

Guarantor: prof. Ing. Zdenko Bobovský, PhD.

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.

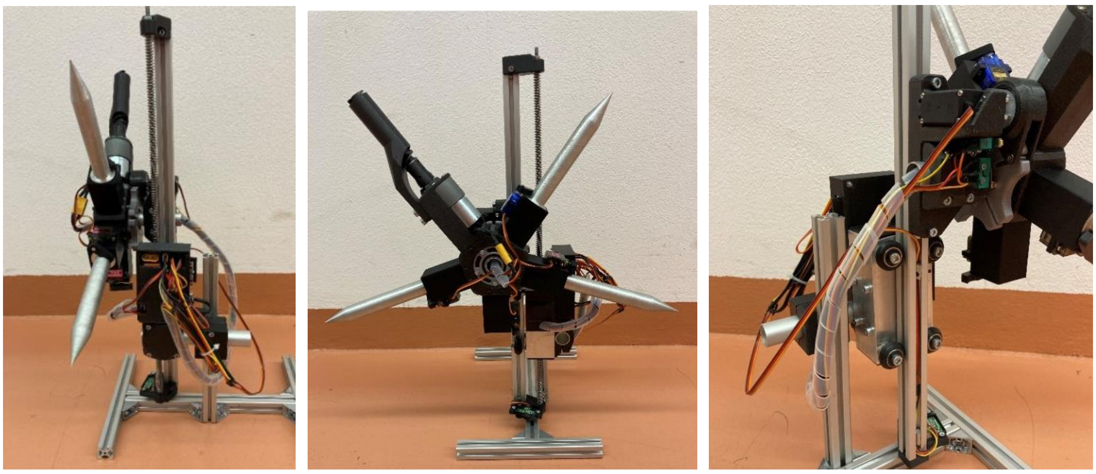


Fig. 3.2: Bc. Tomáš Mokrý – Probe placement module for a mobile robot K3P4
(master's thesis, supervisor: Ing. Tomáš Spurný)

3.1.2 Magister studies

Title: **Robotics**

Field of Study: N0719A270009 (Czech), N0719A270010 (English)

Guarantor: prof. Dr. Ing. Petr Novák

This is a newly accredited master's follow-up study program, replacing the current Robotics study program of the same name. The motivation was primarily to modernize and update the content of the teaching and equip graduates with competencies and knowledge that take into account the current state of this very dynamically developing field. For this reason, this study program now offers 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.

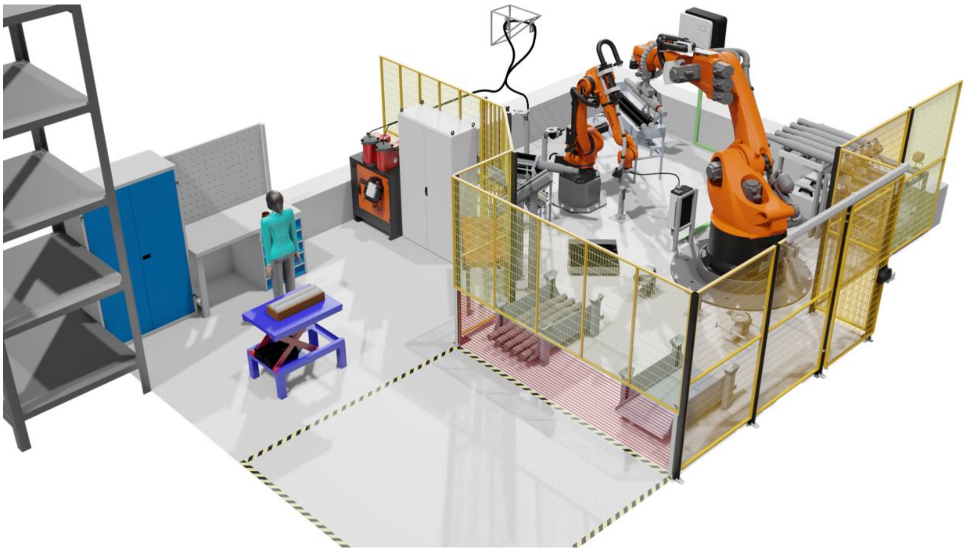


Fig. 3.3: Ing. Matyáš Hodura – Design of the automation of the shaft ring gluing workplace (master's thesis, supervisor: Ing. Václav Krys, Ph.D.)

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.

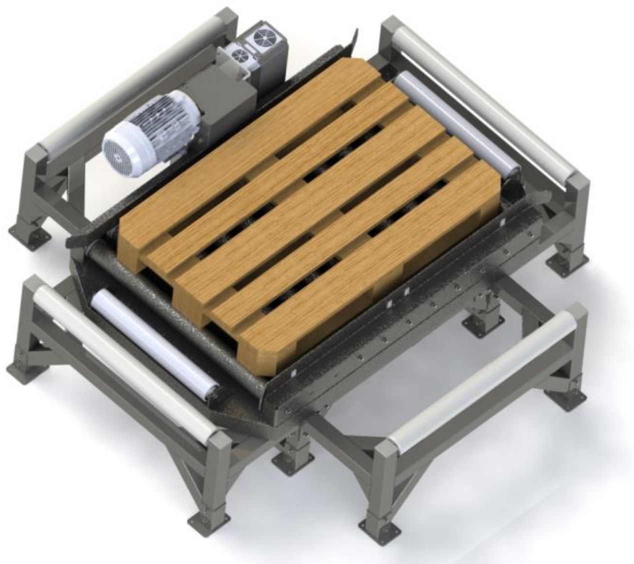


Fig. 3.4: Ing. Jan Filip – Structural Design of The Equipment for Turning Euro Pallets around the Vertical Axis (master’s thesis, supervisor: doc. Ing. Milan Mihola, Ph.D.)

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.

Fig. 3.5: Ing. Sebastian Matůš – Software for teleoperation controller (master's thesis, supervisor: Ing. Robert Pastor, Ph.D.)

3.1.3 Doctoral studies

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.

3.2 List of Defended Theses

3.2.1 Bachelor theses

Student	Supervisor	Topic
Dominik Bobek	Ing. Ondřej Moša	Simulation Model of the Demonstration Task for OpenManipulator
Vojtěch Havlát	Ing. Jan Bém	3D model of the Robotics Centre
David Kolář	Ing. Rostislav Wierbica	Tools for Hand Guidance of Robot
Matyáš Machalla	Ing. Jakub Chlebek	Effector Design for Robot Drawing Task
Martin Musálek	Ing. Jakub Mlotek, Ph.D.	Analysis of the Current State of Available Actuators with Possible Use for Modular Systems
Radomír Nový	Ing. Petr Oščádal, Ph.D.	Simulation of a Mobile Robot in a Maze
Michal Oščádal	Ing. Jakub Mlotek, Ph.D.	Conceptual Design of Automatic Feeder
Otto Pomp	Ing. Dominik Heczko, Ph.D.	Design of a Positioner for Scanning Objects
Adam Říha	Ing. Václav Krys, Ph.D.	Conceptual Design of Brazing Workplace Automation)
Jindřich Třaskoš	Ing. Petr Oščádal, Ph.D.	Simulation of a Mobile Robot Following a Trajectory with Obstacles
Kryštof Začal	Ing. Tomáš Spurný	Robotic Arm Modification for a Service Robot
Eva Čížková (Mechatronics)	doc. Ing. Jaromír Škuta, Ph.D.	Use of Machine Vision in Printed Circuit Boards Inspection
Dominik Lanča (Mechatronics)	Ing. Jan Maslowski	Two-axis orientation system for K3P4 robot

3.2.2 Diploma theses

Student	Supervisor	Topic
Bc. Jakub Častulík	doc. Ing. Milan Mihola, Ph.D.	Structural Design of The Superstructure of a Mobile Robotic Platform for Handling and Transporting Euroboxes
Ing. Michal Jarka	doc. Ing. Milan Mihola, Ph.D.	Mechanical Design of a Superstructure of a Mobile Service Robot for Disinfection in The Common Areas of VŠB-TU Ostrava
Bc. Matyáš Hodura	Ing. Václav Krys, Ph.D.	Automation of the Shaft Ring Gluing Workplace
Bc. Václav Kožušník	doc. Ing. Milan Mihola, Ph.D.	Design of a Subsystem of a Mobile Service Robot for Handling Books in Libraries
Bc. Jan Pavčo	doc. Ing. Milan Mihola, Ph.D.	Structural Design of a Chain Conveyor with The Possibility of Lateral Displacement of Euro Pallets
Bc. Sebastian Matůš	Ing. Robert Pastor, Ph.D.	Teleoperation Controller Software
Bc. Čeněk Slezák	Ing. Michal Vocetka, Ph.D.	Feasibility Study of Automated Bonding of Permanent Magnets to a Rotor Packets

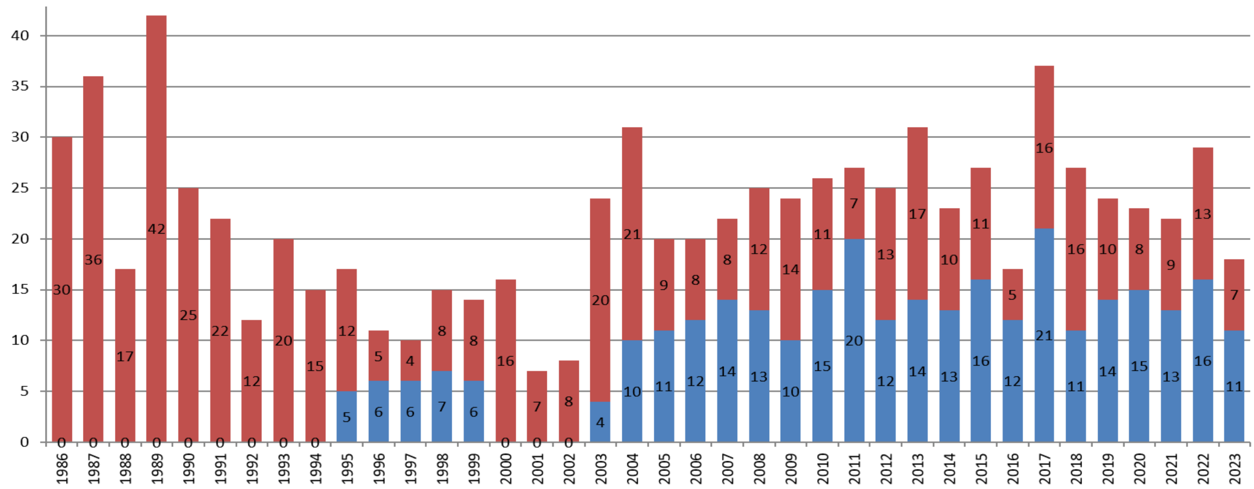


Fig. 3.6: Overview of number of graduates of the Department of Robotics (Bc. – blue, Ing./Msc. – red)

3.3 List of Full-time Doctoral Students

Student	Dissertation topic	Year	Supervisor
Ing. Jakub Mlotek, Ph.D.*	Shape changeable support elements of robotic systems	4	prof. Ing. Zdenko Bobovský, PhD.
Ing. Petr Oščádal, Ph.D.*	Optimizing the trajectory of a robot arm in a dynamically changing workspace	4	prof. Ing. Zdenko Bobovský, PhD.
Ing. Zdeněk Zeman, Ph.D.*	Topological design of robot arms	4	prof. Dr. Ing. Petr Novák
Ing. Jan Bém	The use of flexible materials for passive damping in robotics	3	prof. Ing. Zdenko Bobovský, PhD.
Ing. Adam Boleslavský	Research of structural elements of a robotic arm with a controlled changeable shape	3	doc. Ing. Milan Mihola, Ph.D.
Ing. Jakub Krejčí	The concept of IoRT (Internet of Robotic Things) and its use	3	doc. Ing. Marek Babiuch, Ph.D.
Ing. Tomáš Spurný	Determining the safety space for human-robot cooperation using computer vision and AI	3	prof. Ing. Zdenko Bobovský, PhD.
Ing. Rostislav Wierbica	Finding the optimal kinematic structure of a robotic manipulator for a given task	3	doc. Ing. Tomáš Kot, Ph.D.
Ing. Tomáš Poštulka	Robotic systems with a closed kinematic chain	2	prof. Dr. Ing. Petr Novák
Ing. Jan Maslowski	Calibration of a multi-camera system sensing the workspace	2	prof. Dr. Ing. Petr Novák
Ing. Ondřej Moša	The influence of the shape of the variable support elements of the manipulator on its accuracy	2	prof. Ing. Zdenko Bobovský, PhD.
Ing. Jakub Chlebek	Optimization of the sensor system for detecting obstacles in the surroundings of a collaborative robot	2	doc. Ing. Tomáš Kot, Ph.D.

* Successfully finished doctoral studies in 2023

3.4 Personal Development

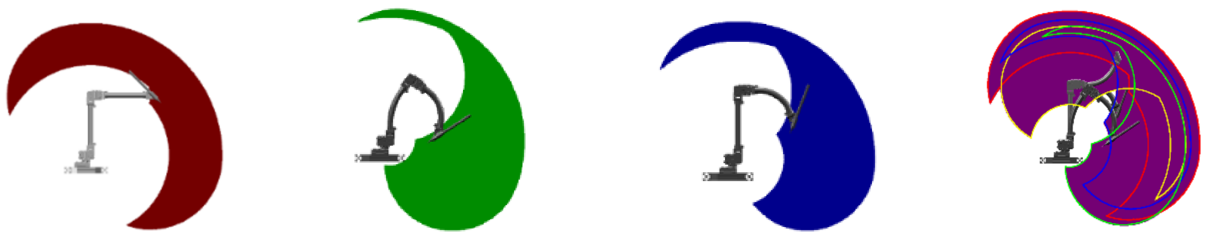
3.4.1 Obtaining the Ph.D. degree

Ing. Jakub Mlotek, Ph.D.

Topic: **Shape-changing segments of load- bearing elements of robotic systems**
Supervisor: prof. Ing. Zdenko Bobovský, Ph.D.

Abstract:

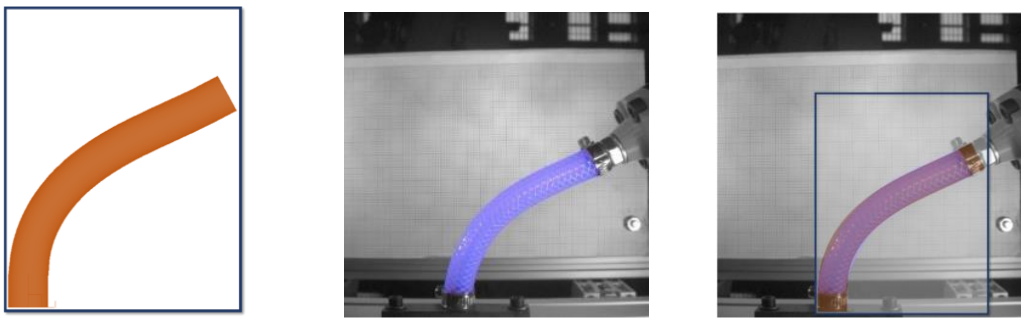
The thesis focuses on the possibilities of increasing the flexibility of robotic manipulators. Robotic manipulator with fixed connecting segments between joints and fixed kinematic structure has good repeatability, load capacity, etc. The disadvantage is that these systems are not flexible and mostly single-purpose. If the work task changes, a situation may arise where the existing kinematics of the system are not sufficient or optimal. One way to solve this problem is to reconfigure the robotic system and thus the manipulator workspace by changing the shape of the connecting segment. The aim of this thesis is to present the possibilities of shape changeable segments based on the principle of stiffness variability. The stiffness-variable segment uses a core made of a low melting temperature material. When this core is heated, the core loses its stiffness and the segment can be deformed. When the segment cools down, the segment increases its stiffness again. This makes it possible to change the kinematics of the manipulator. This achieves a change in the working envelope and reach capability of the manipulator without the need to assemble or disassemble the elements (Fig. 3.7).



(a) (b) (c) (d)

Fig. 3.7: Shape and cross-sectional size of the working envelope of a manipulator with (a) straight segments, (b) deformed segments, (c) combination of straight and deformed segments; (d) merged working envelope

In addition, the structure of the manipulator can be adapted to match the desired work task as closely as possible. The determination of the bending capability of the shape-shifting segment and a method for defining its length are described. The possibilities of robotic systems with curved segments are presented by means of simulation. An experimental segment with variable stiffness based on the use of low melting temperature material is presented in the thesis (Fig. 3.8).



(a) (b) (c)

Fig. 3.8: Comparing the resulting mathematical shape of the segment (a) mathematical shape, (b) real shape, (c) visual comparison

Ing. Petr Oščádal, Ph.D.

Topic: **Monitoring of shared workspace between human-robot**
Supervisor: prof. Ing. Zdenko Bobovský, Ph.D.

Abstract:

The dissertation deals with the monitoring of the workspace of a robotic workstation designed for collaboration between a human and a collaborative robot (cobot). There is a large increase in the deployment of collaborative robots within Industry 4.0. Even though these robots are adapted to collaborate and share workspace with humans, the efficiency of the workplace is not as high as that of standard industrial robots. Since the cobot performs its predefined task without regard to the worker and objects in the workspace, collisions can occur. Due to the characteristics of cobots, then, such a collision is normally safe and will not injure the worker or damage the equipment. However, the consequence of even a minor collision is extended work cycle of the workplace caused by an emergency stop of the cobot. The safety features available today do not allow sensing of the entire dynamically changing environment of robotic workplaces to such an extent that the robot trajectory can be re-planned in real time, and thus avoid collisions between the worker or objects.

The introductory part of this thesis deals with the analysis of the current state of the art in 3D vision, calibration, environmental filtering, and optimization of camera placement in the workplace. Based on the stated objectives of the dissertation, the possibilities of improving the accuracy of estimating the position of cameras in space are then investigated. A newly designed 3D gridboard for camera positioning has been implemented on industrial and service applications. Furthermore, in order to use the camera data efficiently for the manipulator control system, a filtering technology is developed to remove unnecessary data in real time and to transmit only the necessary information to the higher-level control system. By using a distributed structure, real-time sensing and filtering of the monitored area was achieved, regardless of the number of cameras in the system, without slowing down the refresh rate of the scene. Furthermore, a methodology for deploying cameras in a workplace was established to effectively capture the hazardous area where a cobot collision is imminent. Finally, this issue is experimentally verified and implemented in a real control system for dynamic obstacle avoidance.

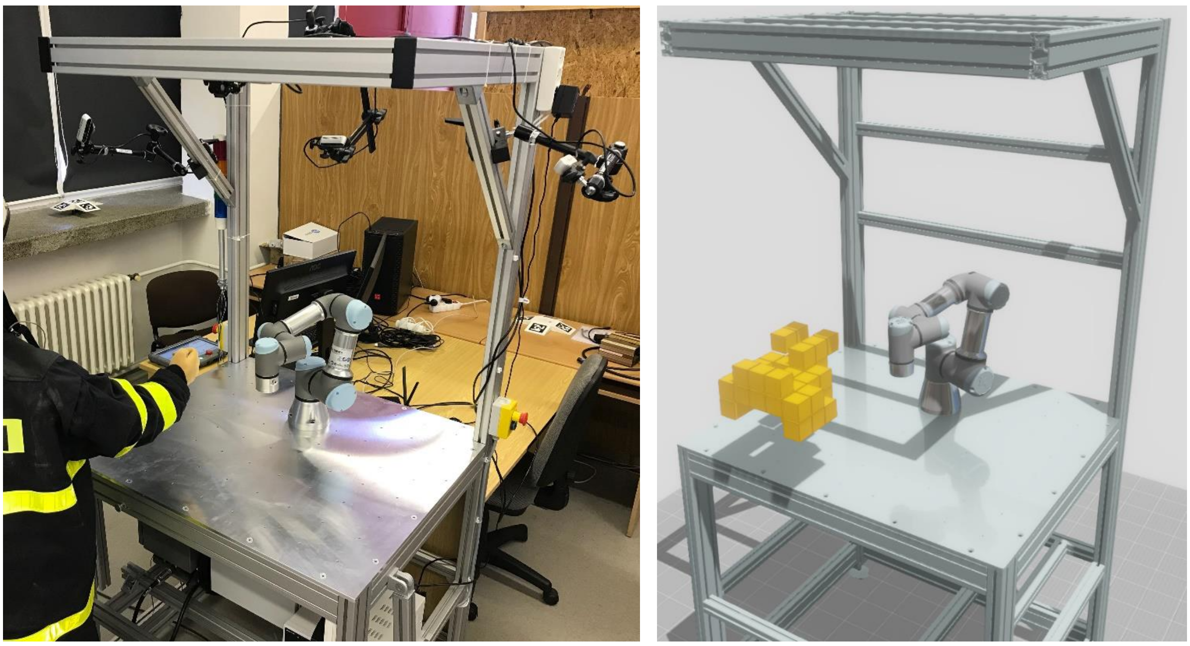


Fig. 3.9: Workplace obstacle detection with a collaborative robot;
(a) real workplace with obstacles; (b) visualization of obstacles (yellow boxes)

Ing. Zdeněk Zeman, Ph.D.

Topic: **Automated design of robotic arms**
Supervisor: doc. Ing. Milan Mihola, Ph.D.

Abstract:

In today's rapidly developing industry, great emphasis is placed on minimizing costs and design time for new equipment. This also applies to the design of single-purpose robotic arms. As part of automating the design process of machine parts and systems, many software tools are currently on the market. However, these tools are limited only to the design of standardized machine parts and the solution of typical technical tasks and problems, such as the design of gear wheels or the calculation of screw joints. In the same way, within the framework of evolutionary robotics, methods of optimizing the kinematic structures of single-purpose robotic arms are investigated, but the results of which are always uncertain for practical use. Automation of the design of robotic arms with the help of modern methods of knowledge engineering, machine learning and generative design would, therefore, not only reduce the cost of designing single-purpose robotic arms but, when connected with the optimization algorithms of kinematic structures, it would provide the necessary feedback to determine the feasibility of the kinematic structures generated by the algorithms. The introductory chapter of the dissertation is devoted to modern methods and approaches to automating the design of mechatronic devices. At the same time, a market survey is conducted with a focus on available software for the automated design of standardized machine components. Furthermore, the work's goals are established based on the analysis of the established methods of designing robotic arms. The actual part of the work is divided into the development of software tools for automating the design of robotic arms, their testing in the context of the genetic optimization algorithms of kinematic structures, and the time optimization of the duration of the design of robotic arms through the designed software using machine learning methods. The conclusion of the thesis contains an evaluation of the achieved results.

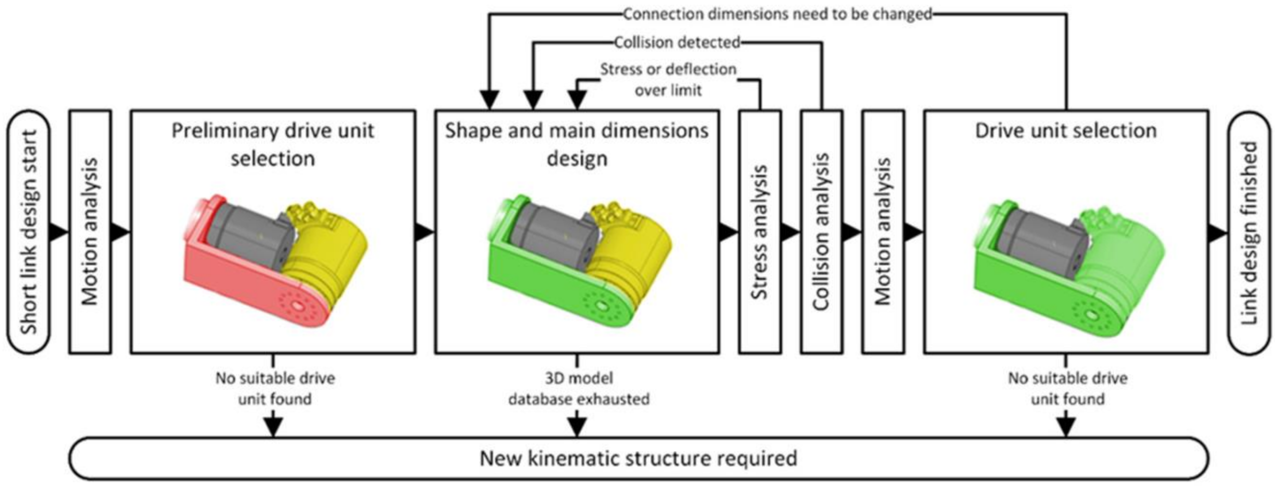


Fig. 3.10: Procedure for automatic design of manipulator parts

3.4.2 Obtaining the docent degree

Doc. Ing. Aleš Vysocký, Ph.D.

Topic: **Intuitive ways of controlling the robot by the operator**

Abstract:

The presented habilitation thesis builds on the author's previous research activities in the field of safety and general usability of collaborative robots in industrial environment. The topic of human-robot collaboration is part of the Industry 4.0 vision, which defines new trends and innovations to address the current requirements for automation and robotics based on the demands of industrial enterprises and the labour market.

Based on an initial analysis of available partial solutions in the field of robot control and interaction, tools have been developed to extend the possibilities of human-robot interaction based on the requirements of the application vision presented in the introduction of the thesis. This vision is based on natural human-machine interaction using gestures. In this area, robust detection and localization of hands in the camera image is crucial. This thesis summarizes the original results achieved in the research and development of the operator hand detection and localization system, which have been published in several impacted journals. These publications address the generation of a synthetic dataset for machine learning models, the learning itself, and the evaluation to create robust segmentation models. The models are compared with the state of the art and evaluated on real situations that may occur in an industrial setting. The comparison shows a substantial improvement of the results in terms of robustness and quality.

For the application validation of the developed tools and principles in the field of intuitive interaction, the paper describes the design and implementation of an experimental workstation. This workstation simulates a working environment for human-robot interaction and the proposed systems can be implemented, tested and further developed on it. The developed tools should enable the creation of practically applicable and cost-effective solutions in the field of human-robot collaboration in an industrial environment with emphasis on compliance with operational safety requirements.

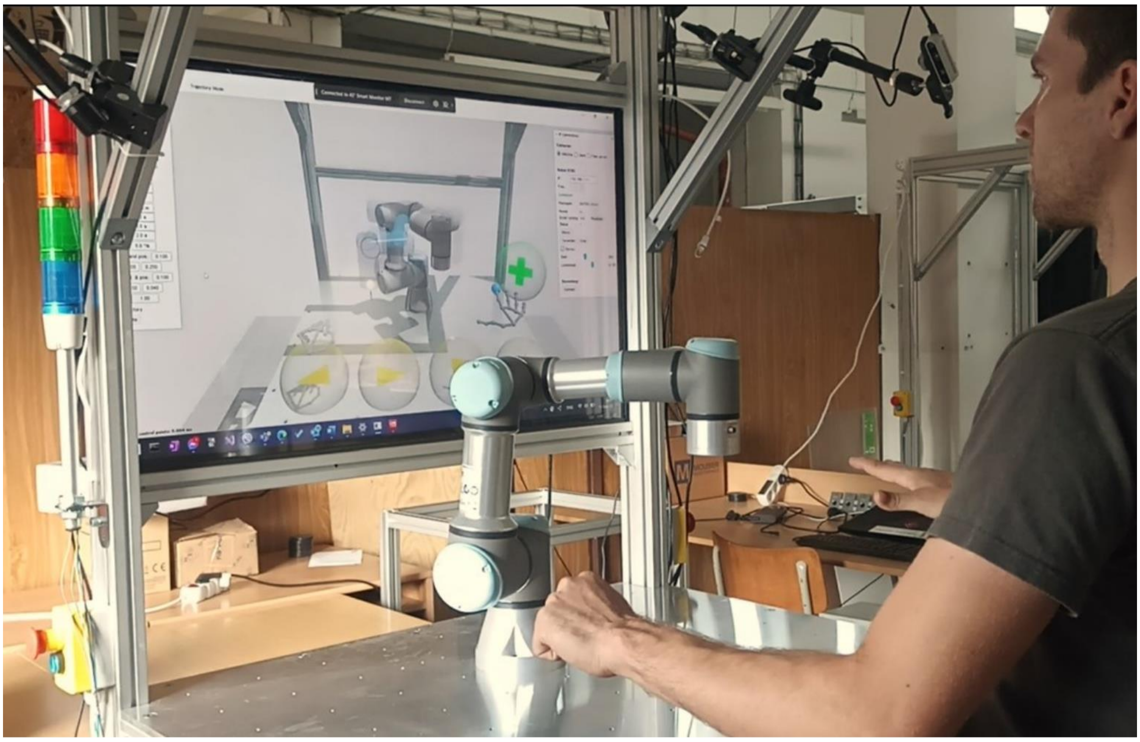


Fig. 3.11: Testing the system of creating a trajectory and controlling the movement of the robot with gestures

3.4.3 Obtaining the professor title

Prof. Ing. Zdenko Bobovský, Ph.D.

Topic of the inaugural lecture: **Increasing the adaptability of robotic systems**

The thesis summarizes the applicant's creative, scientific, and engineering activities. His results in education and training of university students and his ability to conduct research in the given field. The ability to adapt to new conditions is an important characteristic in a dynamically changing environment. Today, more than in the past, for reasons of political and economic developments, there is talk of the need to integrate elements of adaptability into robotic systems to reduce the consumption of material and energy resources. In individual chapters, approaches to increasing the adaptability of robotic systems are presented. For handling tasks that are most often used in industrial robotics. In human-robot cooperation, which have great potential, which is not used due to fear and prejudice. In creating non-standard robots that are designed precisely for a defined task - they are adapted for the activity they are supposed to perform. In the optimization of the activity of existing robots with the aim of improving their parameters and optimization in the design of walking systems to reduce their consumption during movement. Last but not least, the anticipated development of the field is listed. The outputs presented here were financed by the project Center for Research of Advanced Mechatronic Systems, reg. no. CZ.02.1.01/0.0/0.0/16_019/0000867 and the project Platform for Research Oriented to Industry 4.0 and Robotics in the Ostrava Agglomeration, reg. no. CZ .02.1.01/0.0/0.0/17_049/000842.

3.5 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.

3.5.1 Student Grant Competition (SGS) 2023

The project of the student grant competition "Research and development of mobile manipulation tools using digitization tools" was divided into five main activities so that it was possible to involve the largest possible number of doctoral and subsequent master's full-time study students in their solution. Students of the doctoral and follow-up study programs participated in the solution of the project. As part of the project, the preparation of articles in domestic and foreign magazines was supported.

Main project activities:

- Research and development of handling devices applicable in mobile handling and their simulation models.
- Research and development of mobile platforms. Testing of different locomotion principles and development of their simulation models.
- Synthesis and testing of sensor subsystems for applications in mobile handling such as obstacle and person detection in dynamic environments, system localization in indoor and outdoor environments, and state parameter detection of manipulators and chassis.
- Methods and procedures for collecting data and operational parameters of mobile robotic systems for their use in digital twins. Processing and use of the collected data for the improvement of these systems.
- Research and development of human-machine interface devices in the areas of interaction in terms of facilitating the programming and control of robotic systems by gestures and informing the operator of any risk or limit state during cooperation.

In 2023, a total of 6 theses (3 dissertations and 3 master theses) supported or related to the SGS project were defended:

- Ing. Jakub Mlotek, Ph.D. – Shape-changing segments of load- bearing elements of robotic systems.
- Ing. Petr Oščádal, Ph.D. – Monitoring of shared workspace between human-robot.
- Ing. Zdeněk Zeman, Ph.D. – Automated design of robotic arms.
- Ing. Jakub Častulík – Structural design of a mobile platform for handling and transporting Euroboxes.
- Ing. Sebastian Matůš – Teleoperation Controller Software.
- Ing. Pavčo – Structural design of a chain conveyor with the possibility of lateral displacement of euro pallets.

Fig. 3.12: Modification of the K3P4 rover manipulator and its control

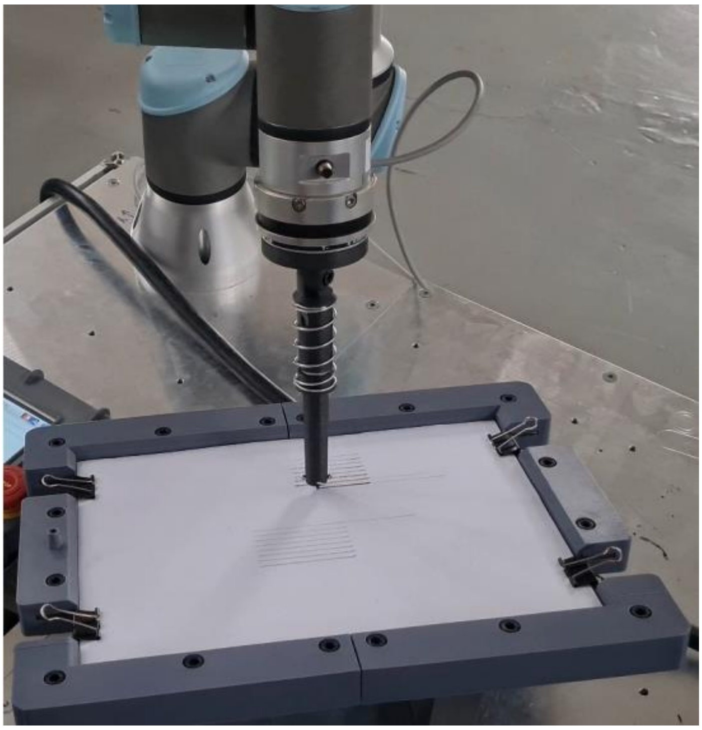


Fig. 3.13: HW and SW system robot drawing – realization of an effector and SW for photo processing and planning of robot movements

3.5.2 University Rover Challenge

At the turn of May and June, our cathedral student team RoverOva participated in the very prestigious international competition University Rover Challenge - URC. For the last three years, our team has been trying to get there, and this year we finally succeeded. Only the best of the best get there. Preparing for this competition required a lot of modifications and development of new modules designed specifically for the purposes of the competition missions and tasks. Six students from doctoral study programs and one supervisor participated in the competition. The team earned points before the competition for documentation and videos and then during the competition in four missions. In the end, the team took 18th place in the world ranking out of 36 qualified teams (130 entries). The competition itself took place in the vicinity of the Mars Desert Research Station (Hanksville, UT 84734, United States, https://mdrs.marssociety.org/)

The K3P4 robot consists of many modules designed as part of bachelor's or diploma theses. It consists of a mobile chassis, currently two robotic arms and several effectors. Specially developed modules are used for competitions, such as a laboratory for evaluating soil samples or camera modules for intuitive control and autonomous navigation in the field. The development of the system was also supported by the Faculty of Mechanical Engineering, Excalibur Army, SGS and the city of Ostrava.

Fig. 3.14: RoverOva Competition Team at URC 2023 in Utah (June 2023)

Fig. 3.15: Robot K3P4 performing one competition task URC 2023 Utah (June 2023)

3.5.3 European Rover Challenge

In September, after a one-year hiatus, the cathedral student team RoverOva took part in the European Rover Challenge - ERC international competition. In this year, a large number of new team members from among students of master's and bachelor's study programs were involved in the team. During this competition, students of doctoral study programs only acted as supervisors. Even though this competition was the second in a row this year, it was necessary to make adjustments to the robot to meet the conditions of the competition in Poland. The team earned points in four competitive disciplines, and finally reached eighteenth place.

Participating in this competition is almost a traditional event and every year the competition is bigger and bigger. There are already other bachelor's and master's theses to prepare modules for the robot for the ERC competition.

Fig. 3.16: Robot K3P4 performing a competition task, ERC 2023 Poland, Kielce (September 2023)

3.6 Pedagogical Cooperation

3.6.1 Bachelor and diploma theses in cooperation with companies

The benefits of contacts with companies are the topics of the student theses, which solve real technical tasks. They are based both on contacts from department staff and from students who have temporary jobs or internships in companies.

Defended bachelor theses:

- Adam Říha – Conceptual Design of Brazing Workplace Automation – in cooperation with Honeywell Aerospace Olomouc, s.r.o. (student's initiative).

Defended diploma theses:

- Čeněk Slezák – Feasibility Study of Automated Bonding of Permanent Magnets to a Rotor Packets – in cooperation with ESPO s.r.o. (the company contacted our department).
- Matyáš Hodura – Automation of the Shaft Ring Gluing Workplace – in cooperation with Siemens, s.r.o. Elektromotory, o.z. Frenštát p. R. (student's initiative).

New topics of theses:

- Eva Dobrovká – Feasibility Study for the Production of a New Product on an Existing Production Line – in cooperation with REHAU Automotive, s.r.o./Linaplast, s.r.o. (student's initiative).
- Jan Palovský – Robotization of Car Body Sealing – in cooperation with Hyundai Motor Manufacturing Czech s.r.o. (student's initiative).
- Daniel Kovářík – Design of the Positioner for the Welding Workplace – in cooperation with Valk Welding CZ, s. r. o. (student's initiative).
- Eva Galová – Simulation of a Palletizing Workstation – in cooperation with Ingeteam, a.s.

3.6.2 Significant cooperation with subjects in the Czech Republic

ABB

Once again, week-long internships of students (7th year of study) were realized at ABB, this year for the first time in the newly opened centre in Mošnov – the global ABB industrial robot refurbishment centre, where they perform a complete "disassembly/assembly" of industrial robots plus the necessary output measurements. Students in their final year of study can take a test and receive an official ABB certificate for the levels of operator, adjuster, specialist, and programmer.

AV ENGINEERING a.s.

As part of the department's long-term cooperation with this company, which is a supplier of software tools from PTC, we managed to secure the renewal of the licenses of ThingWorx and Vuforia tools for teaching purposes at a significantly reduced price.

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 is used in teaching the design of robotic workplaces for conceptual design of workplaces and verification of sequences of operations performed on them.

3.6.3 Significant cooperation with foreign partners

Slovakia

- Technical University of Košice – Faculty of Mechanical Engineering, Department of Production Technology and Robotics, Department of Industrial Automation and Mechatronics, Department of Applied Mechanics and Mechanical Engineering, Department of Technologies, Materials and Computer Support of Production, Department of Industrial Engineering and Informatics.
- Slovak Technical University of Bratislava – Faculty of Materials Science and Technology.

Poland

- Silesian University of Technology, Gliwice – Institute of Fundamentals of Machinery Design.
- Military Institute of Armoured and Automotive Technology, Sulejówek.

Austria

- University Innsbruck, Unit Geometry and CAD, Innsbruck.

Finland

- Department of Mechanical Engineering, Lappeenranta University of Technology.

Italy

- Fondazione Istituto Italiano di Tecnologia.
- DPIA - Dipartimento Politecnico di Ingegneria e Architettura, Università degli Studi di Udine, IT.
- Italian Institut of Technology, Dynamic Legged Systems – Walking robotic systems.
- LUT University, Laboratory of Mechani Design – Flexible robotic systems.

3.6.4 Foreign guests and students

Institute of origin	Topic	Date
University of Lublin	Discussion on collaborative robotics.	25. 4.
Military Institute of Armoured and Automotive Technology	Discussion on collaboration in the development of locomotion and sensing subsystems for robots in unstructured environments.	23. 5.
University of Lublin	ERASMUS+	23. 5. – 25. 5.
Slovak University of Technology in Bratislava	Collaborative discussion on the use of robotic systems for process operations.	3. 10.
Slovak University of Technology in Bratislava	ERASMUS+	3. 10. – 13. 10.
University of Zielona Gora	ERASMUS+	17. 10. – 20. 10.
Lublin university	ERASMUS+	17. 10. – 20. 10.
Technical University of Košice	Educational stay within the Višegrad project.	23. 10. – 26. 10.

3.6.5 Abroad stays of our department staff members

Target institute or event	Attender	Topic	Date
New York University Abu Dhabi	Ing. Adam Boleslavský	9th International Conference on Automation, Robotics and Applications (ICARA 2023).	9. 2. – 14. 2.
Carinthia University of Applied Sciences	Ing. Adam Boleslavský	Printing of test samples containing carbon fibre.	18. 6. – 25. 6.
University Rover Challenge	RoverOva team student	Participation in the URC competition in Utah.	26. 5. – 4. 6.
European Rover Challenge	RoverOva team student	Participation in the ERC competition in Kielce.	13. 9. – 17. 9.
Technical University of Košice	Ing. Petr Oščádal, Ph.D.	One week stay within the Višegrad project.	20. 11. – 23. 11.
Technical University of Košice	prof. Ing. Zdenko Bobovský, PhD.	Cooperation within the Višegrad project.	20. 11. – 21. 11.
Technical University of Košice	prof. Ing. Zdenko Bobovský, PhD.	Preparation of an international project.	11. 12. – 12. 12.
University of Innsbruck, Unit of Geometry and Surveying	Ing. Tomáš Poštulka	Establishing contact with a university department. Providing input on closed-structure mechanism issues.	16. 10. – 23. 10.
LUT University – University in Lappeenranta (Finsko)	Ing. Rostislav Wierbica	Visit to the local workplace, consultation of dissertation on kinematics and dynamics of robotic manipulators.	5. 1. – 3. 2.
Frankfurt University of Applied Sciences (Německo)	Ing. Rostislav Wierbica	Participation in an international meeting of PhD students entitled: Applied Doctoral Studies in European Universities.	13. 11. – 17. 11.
Finland, Department of Mechanical Engineering, Lappeenranta University of Technology, Lappeenranta	Ing. Jiří Suder, Ph.D.	Presentation of the results achieved by both departments.	25. 1. – 31. 1.
Austria, University of Innsbruck, Faculty of Engineering Sciences / Unit of Geometry	Ing. Jiří Suder, Ph.D.	Presentation of the results achieved by both departments.	2. 10. – 6. 10.
Conference RAAD 2023	Ing. Michal Vocetka, Ph.D.	32nd International Conference on Robotics in Alpe-Adria-Danube Region.	14. 6. – 16. 6.
SCHUNK SE & Co. KG	Ing. Michal Vocetka, Ph.D.	Conference Schunk Expert Days – Robotic Material Removal.	25.10. – 26. 10.

4 SCIENCE AND RESEARCH ACTIVITIES

4.1 Currently Solved Projects

Project name	Period	Budget (€)
Research and development of mobile manipulation tools using digitization tools	2023 - 2024	55k
Transformation of the form and content of higher education at VŠB, A4	2023 - 2024	40k
Transformation of the form and content of higher education at VŠB, A2	2023 - 2024	24k
National centers of competence MESTEC2 - Mechatronics and Smart Technologies for Mechanical Engineering: Adaptive robotic 3D printing	2023-2026	240k (from 16,4 M)
MATUR – Materials and technologies for sustainable development, OP-JAK	2023-2027	800k (from 18,5M)
Refresh - Research Excellence For REgion Sustainability and High-tech Industries, CZ.10.03.01/00/22_003/0000048 Industry 4.0 & Automotive Lab, Robotic and mechatronic systems	2023-2026	875k (from 104M)
Development of the infrastructural background of doctoral study programs, OP-JAK	2023-2024	1,4M (from 4,4M)

4.2 Main Directions of Research and Development

The current scientific-research profile and experience of the Department of Robotics can be described in words:

- Methodology and theory of conceptual design of robotic manipulators with computer support, including topological optimization.
- Design and optimization of kinematic structures of robots (industrial, service, mobile) and their parts with respect to surrounding obstacles and the required trajectory.
- System for quick selection and optimal positioning of the robot for a defined trajectory, optimizing the consumption of the robot, torque loads of the drives, minimizing the work cycle time.
- Design and development of control systems.
- Identification/assignment of a 3D scan of an "unknown" component (even a partially damaged one) to its 3D model in an existing database (acquiring documentation, its production by e.g. 3D printing).
- Elimination of the effect of temperature on the drift of the absolute accuracy of the robot's position.
- Optimized design of a distributed camera system for 3D scanning, 3D data preprocessing.
- 3D online monitoring of the workspace and its analysis (use, for example, for the system of automatic replanning of the robot's trajectory in a dynamic environment with obstacles, without the need to interrupt operation).
- Adaptive robotic measurements of 3D objects.
- Optimizing the number and placement of sensors with respect to the object of interest – Possible subsequent comparison with an existing 3D model.
- Soft and bio-robotics.

- Kinematic and dynamic analysis of mechanical systems.
- Synthesis of the kinematic structure of the robot, automatic design of 3D models of robotic arms according to the specified parameters using a database of elements.
- Research of collisionless mechanisms with a closed kinematic chain.
- Assisted assembly with a collaborative robot, use of deep neural networks.
- Human-Robot Interface (HRI) for more effective collaboration.
- Development of mechatronic systems for explosive environments (spark safety).
- We use: ROS, ROS 2, C++, C#, Python, CopeliaSim, Creo, SolidWorks.

The following chapters present part of the scientific and research topics that were solved by the staff and doctoral students of the Department of Robotics, mainly within the framework of the above-mentioned projects and were already published in the given year. All the topics were supported by projects:

- National centers of competence MESTEC2 – Mechatronics and Smart Technologies for Mechanical EngineeringDVC2: Adaptive robotic 3D printing,
- MATUR – Materials and technologies for sustainable development,
- Refresh - Research Excellence for Region Sustainability and High-tech Industries, CZ.10.03.01/00/22_003/0000048 Industry 4.0 & Automotive Lab, Robotic and mechatronic systems.

4.2.1 Design of an extruder with variable cross-section nozzle for 3D printing of plastics

The research deals with the design of an extruder with the possibility of continuously changing the diameter of the nozzle during 3D printing from plastic-based materials. The principle of changing the diameter of the nozzle is based on the jaw mechanism, where the shape of the cross-section of the output fiber is an n-gon, the number of sides of which depends on the number of jaws of the nozzle mechanism (currently six and eight jaw mechanisms are used). The material in the form of a fiber with a diameter of 2.85 mm is supplied to the extruder with the help of an external feeder. The actual construction of the extruder is adapted to be mounted on the UR3 collaborative robot. The control electronics is based on a combination of a Raspberry Pi 4 model B single-board computer and a BIGTREETECH SKR Pico V1.0 motherboard, enabling more advanced control and testing options with the help of the Klipper software add-on.

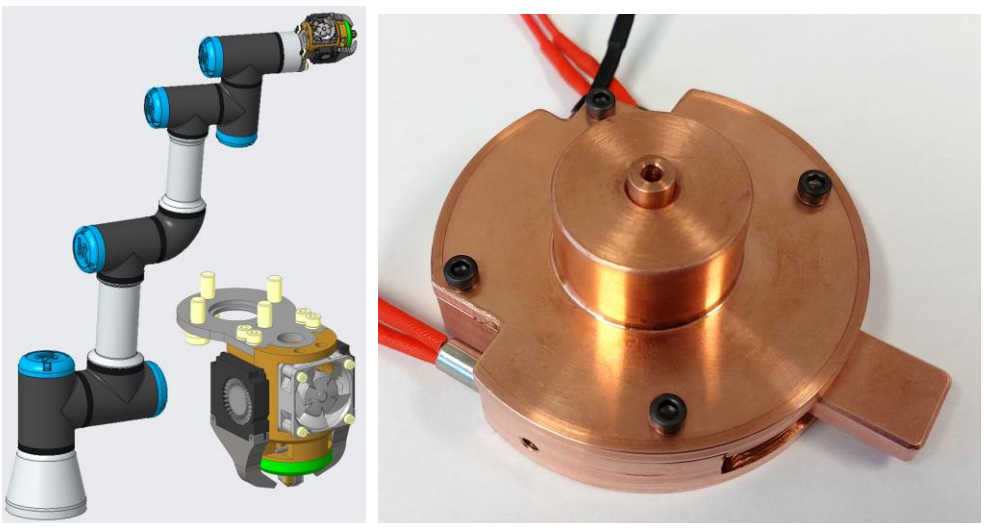


Fig. 4.1: Structural design of an extruder with a nozzle with a variable cross-section in combination with a collaborative robot UR3; Right – simplified design, nozzle variant supplemented with heating elements and a thermistor

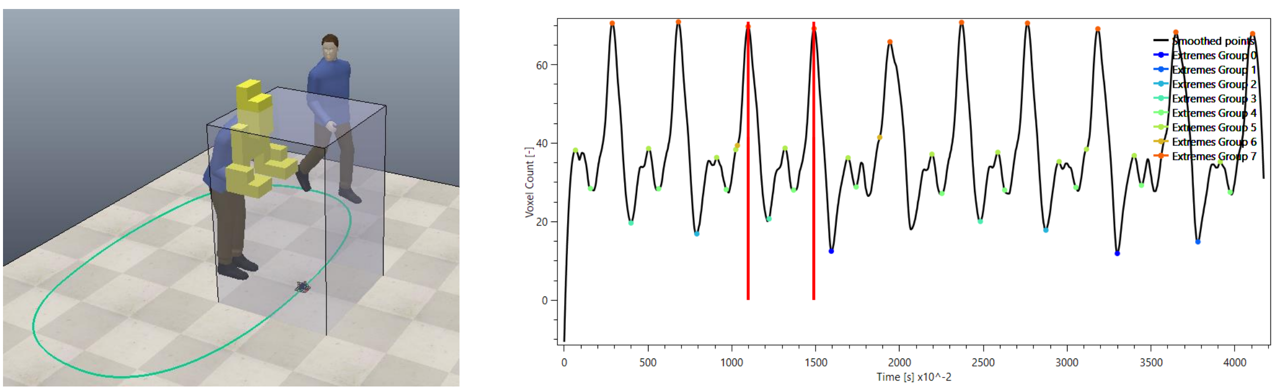
4.2.2 Design of a subsystem for human motion prediction in the robot workspace

This research deals with the prediction of human movement in the robot workspace. In the case where the motion of the worker in the robot workspace can be predicted, it is possible to adjust the robot trajectory so that the robot does not collide with the human and at the same time the robot reaches its goal in the shortest time. By reaching the goal in the shortest possible time, under the condition that the robot does not collide with the human, we can achieve the best possible result for keeping the production tact of the workplace. In order to predict the movement of the worker, we need to detect the worker itself in the robot workspace. To detect the worker, classification and sensing of the space with depth cameras is used. Determining the worker's duty cycle period then involves collecting data on the occupancy of the workspace by a human over time and analyzing this data to find the worker's duty cycle period. A good identification of the worker's duty cycle time is the first step towards human prediction.

A simulation scene was created with two workers disrupting a workspace (represented by a transparent block). When a human intrudes the space, a body part is detected at that location of the workspace and depicted in the voxel map as a yellow voxel (Fig. 4.2a).

Subsequently, an application was created to find the so-called "main period"/cycle of the worker while performing his/her work. The created application is able to find the period of the worker's work cycle based on the input data about the number of occupied voxels of the worker in the workspace. The application first converts the data from discrete values to continuous values, using a Savitzky-Golay filter, thus smoothing the data into a curve. Subsequently, local extrema are found and grouped according to the value of the extreme. In each group, in which approximately the same extremes are found, the period between all of them is calculated. Then all the periods are compared against each other and the one with the most frequent occurrence in the most groups is selected. This period is considered as the worker's clock period. Once we know the worker's period, we select from the groups the one that has the largest representation of this period and the period of first occurrence in it. This is how we arrive at finding the worker's tact (Fig. 4.2b).

Using the data collected in this way, it would then be possible to track the evolution of the worker's behaviour during his/her work cycle and subsequently predict his/her behaviour using worker cycle analysis. Next, we need to test the correctness of finding the search period on real data. Once the accuracy of finding the search period is proven sufficient, one can proceed to find and mark the moment of the beginning and end of the worker's work cycle, thanks to which it is possible to use the importance of the robot's workspace at a given moment to determine the occupancy of the workspace in time and thus predict the position of the human relative to the values of the past.



(a) *(b)*

Fig. 4.2: (a) simulation of detection of workspace intrusion by a worker; (b) plot of occupied voxels over time with the detected main period (in red)

4.2.3 Mechanism with closed chains kinematic in robotics

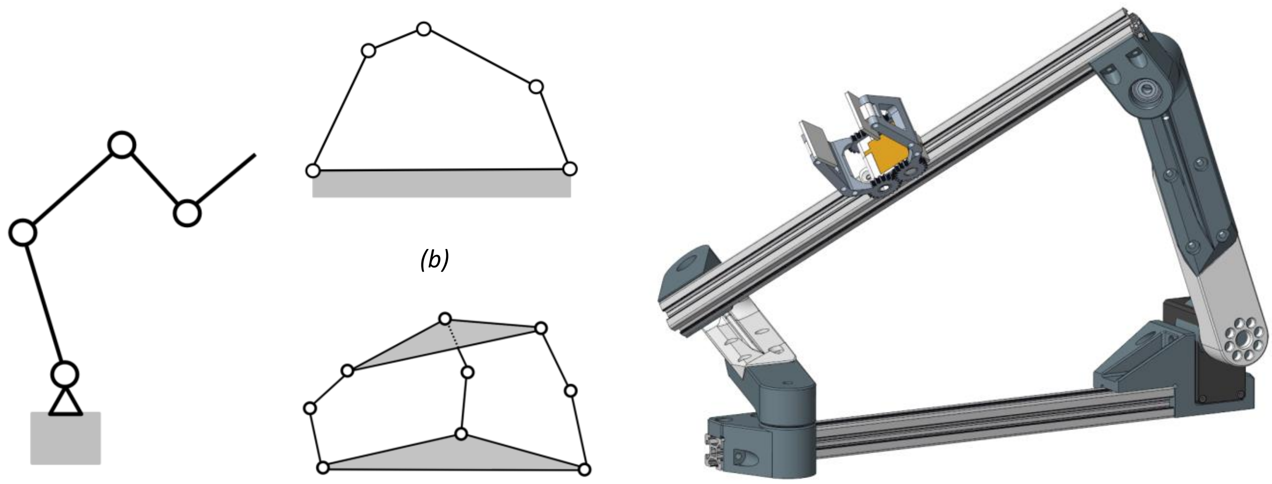
This research investigates the possible use of closed-loop mechanisms in the field of industrial robotics. The aim is to investigate the theoretical reduction of energy consumption during operation and to achieve a lower energy balance of the robotic process. Another advantage is lower acquisition costs, as the mechanisms have a lower number of actively driven axes than standard industrial robots. The use of enclosed mechanisms also theoretically enables higher handling speeds to be achieved, contributing to increased process efficiency.

Closed-loop mechanisms have their limitations and cannot be applied to all processes, but they can theoretically be used in areas that are very simple to robotize (robotizing a process would be unnecessarily costly) and at the same time considerably complex to use a single-purpose system.

General kinematic chains consist of individual members and links (kinematic pairs) and, depending on the way the members are connected to the frame, can be open or closed (Fig. 4.3). Mechanisms with a closed kinematic structure can be further divided into single-loop and multi-loop chains (Fig. 4.3 b, c). Research has focused exclusively on single-loop mechanisms with a closed kinematic structure.

A simulation model (Fig. 4.3 d) of a general closed-structure mechanism with 1 DoF and 4 arms ("Bennett mechanism") was created to verify the basic properties of the mechanism. The mechanism will be manufactured in the near future and testing work on it will commence thereafter. The measurements will investigate the effect of the manufacturing precision of the general closed mechanism on the moment load of the driven axis, the deformation of the mechanism from the object of manipulation and the energy balance.

At the same time, an application for the dimensioning of a general closed-structure mechanism with 1 DoF and 4 arms is being developed. The input parameters are given as points in space including orientation and the output will be Denavit-Hartenberg parameters.



(a) *(b)* *(c)* *(d)*

Fig. 4.3: (a) Open chain; (b) Closed chain – single loop; (b) Closed chain – multiple loops; (d) General closed structure mechanism with 1 DoF and 4 arms

4.2.4 Research of construction components of a robotic arm with controlled changeable shape

The idea of the research on design elements of a robotic arm with controllable shape change is to design a selected element of a robotic arm, more specifically a link robot. This support part is usually a hollow profile in service robots. The idea is to design a changeable robot link. With these changeable links, the robot can rebuild itself for a given operation to accomplish the task as efficiently as possible and with fewer joints. The next stage could be energy efficiency and reflected in the design of the robot shape. The changeable link needs to hold its shape and be rigid during the working deployment. During the execution of the work, the link should not be changeable but rigid to maintain the accuracy of the robot's movements. However, when the work cycle changes, the robot should be able to change to a more suitable shape due to these links.

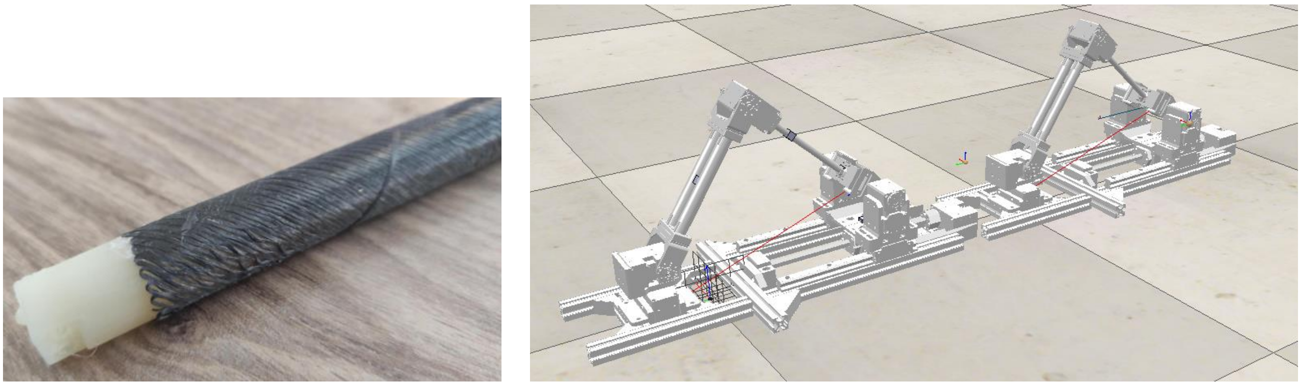
Thus, based on the previous research, a later use for robots with non-standard shaped lines is considered. Previous research has been interested in these robots, but not in the possibility of giving these robots the ability to reconfigure. When there has been research that these robots could be reconfigured, the process has never been automated.

So far, test elements have been fabricated that need to be tested in a dynamic environment to determine if the link will be stiff enough to operate the robot. One of the test specimens, whose shape change is based on thermal change, is shown below in figure (a). Utilizing thermal change of material for bending is one way to achieve bending and subsequent desired stiffness. This direction builds on previous attempts by colleagues. However, it is not the only way to achieve shape changes.

The plan next is to test whether the principles of line shape change have performed as expected and with what accuracy. Accuracy and repeatability are some of the measured parameters that will be monitored in a cyclic dynamic environment.

Most of the current test elements were created using 3D printing. In the future it is considered to continue in this direction. However, it may turn out that other manufacturing methods will produce much better results.

The second figure next to (b) shows the developed mechanism designed to bend the test lines. It was currently undergoing test work in terms of bending methodology. This is because it is important to consider the actual behaviour of the cross-sectional structure of the proposed test element. In future work, elements designed to be modified by heating will be inserted here.



(a) *(b)*

Fig. 4.4: (a) test sample created using 3D printing; (b) simulation of the mechanism in CoppeliaSim environment

4.2.5 Smart voxelization of a pointcloud into a fixed grid

Point clouds provided by laser scanners and depth cameras are a popular source of information for monitoring the shared workspace of cobots and humans. Raw pointclouds from sensors represent an unmodified data set acquired in real time. The main advantage of raw data is its ability to capture the exact shape and details of the objects being imaged. However, working with raw data can be inconvenient in many ways, especially due to the large volume of data, which can be memory intensive to manage during processing. Due to these problems, structured data storage methods are approached that can help to eliminate these problems. In the area of robot workspace monitoring, voxel representation of points is widely used.

When voxelizing a pointcloud into a fixed grid, pointcloud noise can cause the pointcloud point to occupy the voxel incorrectly. This effect (see Fig. 4.5) is most noticeable when the edge of the object being imaged is near the interface of two voxels.

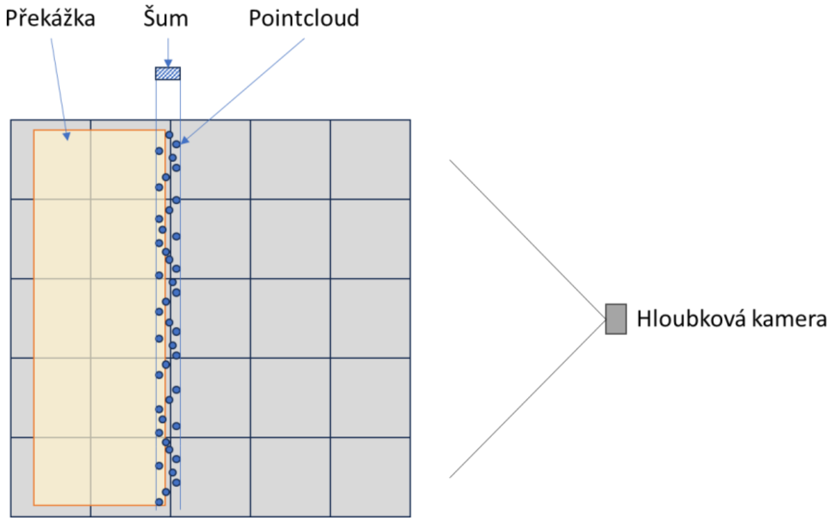
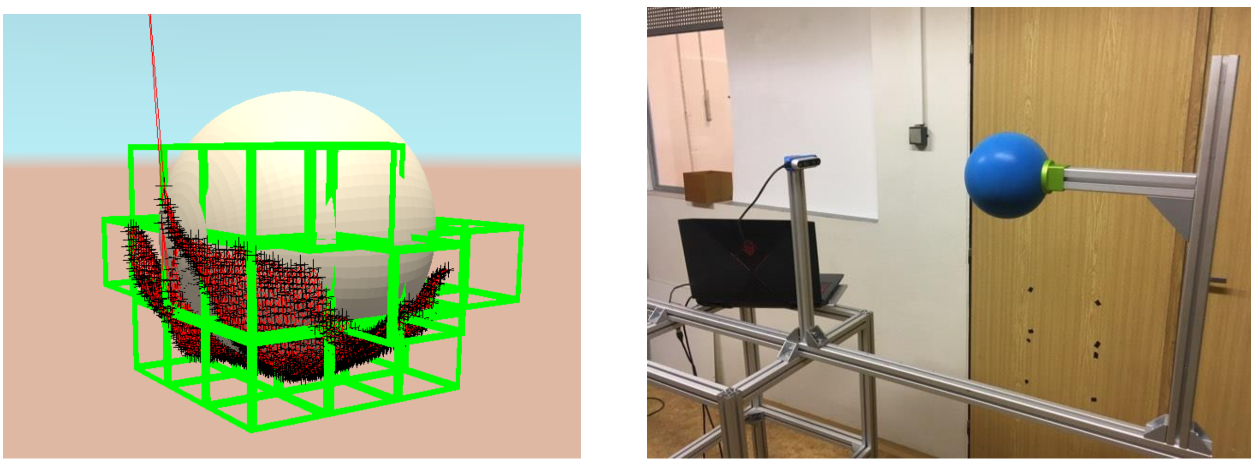


Fig. 4.5: Noisy depth data on the surface of the sensed object

We focused on researching voxelization methods that aim to eliminate this effect. Since testing voxelization methods on real hardware is a time-consuming process, we decided to create a simulation application (see Fig. 4.6 a), that allows us to simulate the capture of different objects by a depth camera. In the simulations, we were able to design several suitable methods, which are further tested on a measurement stand (see Fig. 4.6 b) with real hardware.



(a) *(b)*

Fig. 4.6: a) Simulation application; b) Stand for testing voxelization algorithms

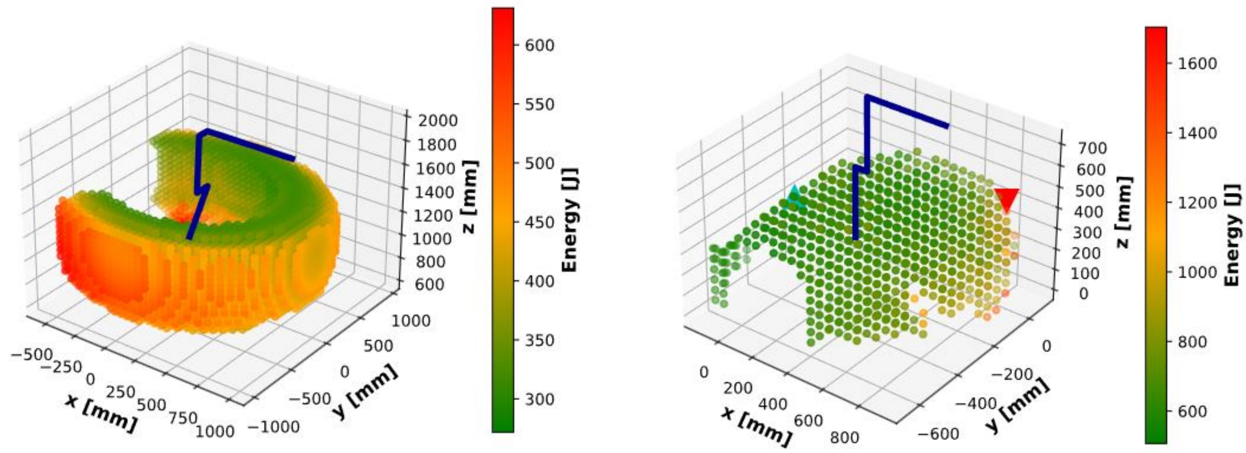
4.2.6 Energy optimization of workplaces with industrial robots

The motivation for energy optimization of robotic workplaces is primarily to reduce the economic burden of these workplaces, to save money in industry and to reduce the carbon footprint of production, which is part of the Industrial Revolution 5.0.

In this research, certain inputs are assumed - these are a given robotic workstation, a given trajectory and a given robot. The goal of this research is not to find the optimal trajectory, but to find the optimal location of the trajectory with respect to the robot in the robot workspace, and also to find the optimal robot configuration for a given trajectory. The search for trajectory positions in space is performed to compare the energy consumption at different locations in the robot's workspace. When designing a workspace, it may happen that the robot is placed in a position that is energetically disadvantageous, while there may be a position in which the robot performs the same task with less energy consumption. So, as part of the optimization process, the entire workspace of the robot in which the task can be performed is searched. After this, all valid positions found are compared in terms of robot energy consumption.

To evaluate the results, two case studies were conducted with two different trajectories and two different robots. To evaluate the results, two case studies were conducted with two different trajectories and two different robots. As the first case study, a task that could simulate robotic deburring is chosen. The robot used is an ABB IRB1600 - 10/1.2 considering an end effector of 2.8 kg. The robot endpoint speed is 100 mm/s and the cycle time is 12.05s. The simulation model is created in RobotStudio. The experiment still considers the same circular trajectory. As a second case study, a task that could simulate the robotic application of sealant is chosen. An ABB IRB 140 - 6 / 0.81 is used as the robot, considering an end effector of 1 kg. The robot endpoint speed is 100 mm/s and the cycle time is 18s. Different shaped planar trajectory is considered in the experiment.

The results from the first case study show that the influence of the trajectory position and the robot configuration used is significant. In this case, 3 possible robot configurations were used to perform the task. The least energy intensive position has a power consumption of 218 J, while the most energy intensive one has a power consumption of 631 J. Which is a difference of 65.5%. The results of the second case study with the ABB IRB 140 robot confirm the results of the previous study - the influence of the position of the trajectory and the robot configuration used on the energy consumption is also evident here. In this case, 4 possible robot configurations were used. The least energy consuming position consumes 481 J, while the most energy consuming position consumes 1703 J. This is a difference of 71.8%.



(a) *(b)*

Fig. 4.7: Display of selected energy maps; (a) ABB IRB 1600 robot; (b) ABB IRB 140 robot

4.2.7 Calibration of the multicamera system

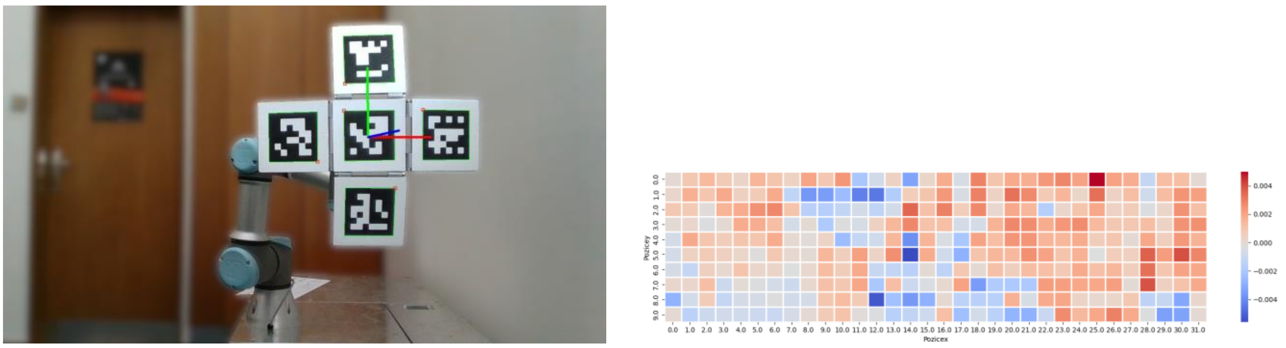
The research focuses on increasing the accuracy of the calibration of the multicamera system in the robot workspace in order to more accurately determine the position of the individual cameras relative to each other and thus refine their position relative to the robot workspace. A 3D gridboard with ArUco markers that are rotated relative to each other is used for calibration. Each ArUco marker on the calibration pattern serves as a separate reference point. The transformation between these points is known. Refining the calibration of individual cameras will lead to a more accurate determination of the spatial relationships between the robot workspace and the objects to be detected by the camera system.

An experiment was designed to find out what is the appropriate setting of the individual angles of the gridboard to make the detection of its overall position more accurate.

As part of the measurement experiment, a 3D gridboard with ArUco markers was placed on the UR3 robot. To obtain data on the spatial arrangement of the gridboard, the robotic system was placed in the field of view of the camera, which was systematically divided into a grid. A camera image was taken for each gridboard position in this grid. In this way, datasets of gridboard images were created throughout the camera field of view with different angles of gridboard setup.

To process the large dataset, software was developed that scans individual frames of the dataset and performs analysis. During the analysis, individual ArUco gridboard markers are extracted from the image and their position and orientation relative to the camera is calculated. These positions are then transformed to the gridboard's center point to determine its final position. This software, together with the datasets created, can also be used in the future to refine the calibration matrices of the individual cameras used at the site and thus further increase the resulting accuracy of the system.

Most workplaces use depth cameras that capture the depth of the image in addition to the RGB image. Therefore, it is advisable to consider the use of depth data from individual cameras themselves and use point cloud fusion methods to increase the accuracy of determining individual camera positions in the workspace.



(a) (b)

Fig. 4.8: (a) gridboard on robot UR3, the picture shows the centre of the gridboard; (b) graph of differences between the detected gridboard orientation and the actual value at individual points of the camera field of view grid (differences are given in radians)

4.2.8 Use of a collaborative robot for additive manufacturing of parts

Within the frame of a project, our department is developing a nozzle for additive printing with a variable diameter of the filament, and its own software that is able to utilize the advantages of this nozzle when printing with a collaborative robot.

The main part of this software is a custom slicer, i.e. a system that generates all the nozzle motion paths necessary for the correct printing of the desired 3D model. The input is a model of the object in the STL format, which is sliced into individual print layers. In each layer, contour curves (perimeters) are subsequently generated to create the desired smooth surface shape of the final product and fill patterns are generated to ensure body cohesion and strength parameters while saving printing material. The innovation of our solution compared to existing commercial and free slicers is primarily the use of the possibility of continuously changing the diameter of the filament, which could optimize the printing process by increasing the speed while maintaining the desired surface details or improving the strength characteristics of the product.

The software also includes a controller that will allow 3D printing to be performed using a collaborative robot with six degrees of freedom instead of a conventional 3D printer with three degrees of freedom. This will not only allow for printing much larger objects (using a suitable robot), but in the future will also allow usage of more complex printing surfaces than conventional horizontal layers. We are currently using the UR3 robot; the same software can be used for the larger UR5 and UR10 robots. The communication with the robot during printing is at a frequency of 250 messages per second, thus achieving high precision movements.

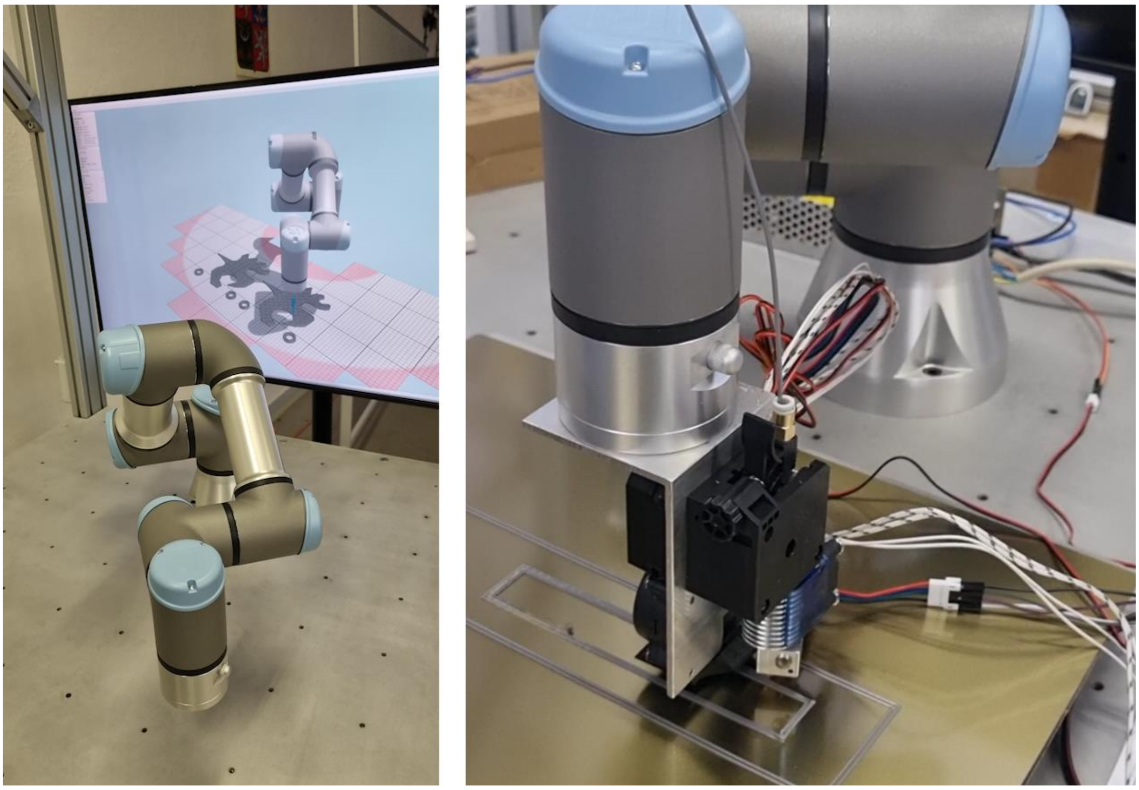


Fig. 4.9: Demonstration of 3D printing using a robot; left – visualization of the robot while controlling the real robot (without a print head); right – testing a print head prototype

4.2.9 Industrial robot drift compensation

The department has been working on this issue before and in 2023 the results of further tests and measurements were published at the RAAD 2023 conference in Bled, Slovenia (DOI: 10.1007/978-3-031-32606-6_33). At the end of this year, preparations began for the extension of the already proven methodology from specific targets to a pre-defined trajectory. From this extension, we hope to increase the precision in a robotic 3D print, which is also addressed by the Department of Robotics.

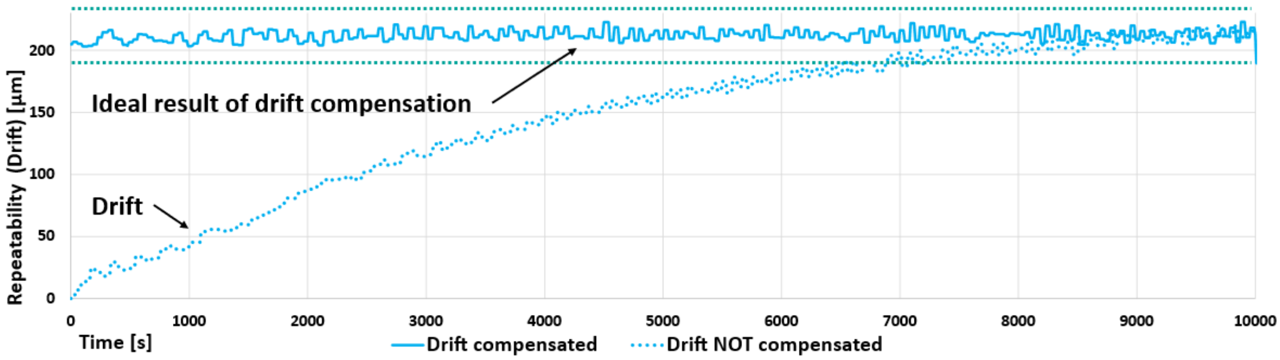
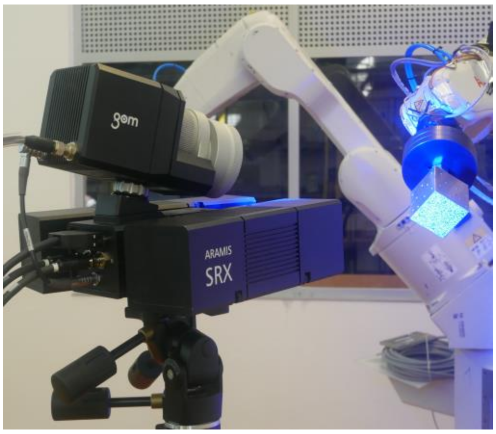
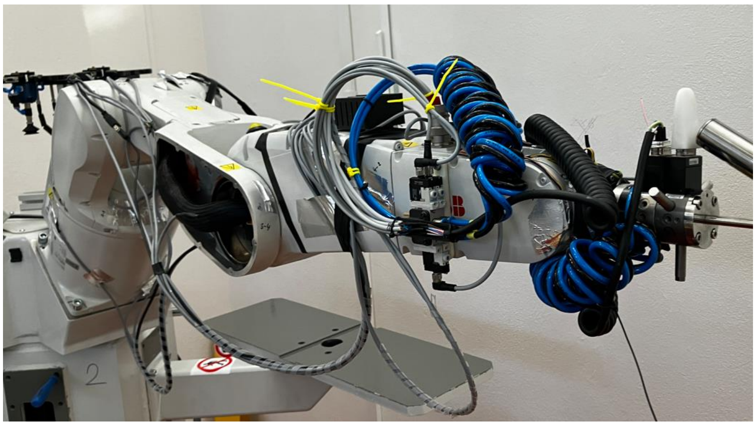


Fig. 4.10: The difference in repeatability with and without active drift compensation (robot UR10e)

Within the preparation for further development work, the ABB IRB1200 5/09 test robot with the Absolute Accuracy option was equipped with the Schunk SWS005 automatic tool change system and new cabling for real-time robot temperature measurement. A demonstration of the high-end metrology equipment in the specific conditions of the centre of robotics was also carried out. This was performed by the MCAE Systems company and the GOM Aramis high speed DIC system was demonstrated.



(a)



(b)

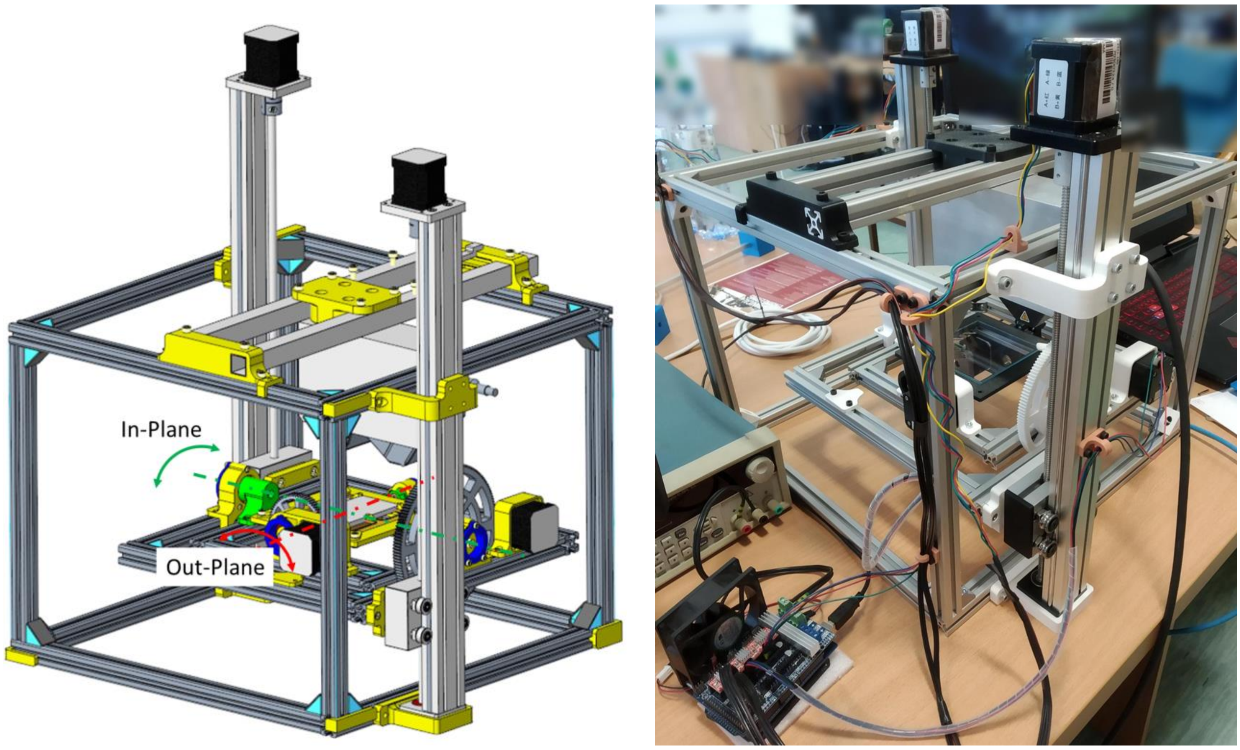
Fig. 4.11: (a) precision measurements with GOM Aramis high speed DIC; (b) overall revitalization of the temperature sensing apparatus, extension of the ABB IRB1200 5/09 with automatic tool change system.

4.2.10 Enhancement of the laser sensor simulation model

In industry, 2D laser, linear, triangulation sensors (LLT) are often used to measure and inspect functional surfaces of manufactured parts or to collect point clouds for further processing. LLT sensors are highly accurate and very fast and can measure several thousand points within milliseconds. However, these sensors are sensitive to the geometry and optical properties of the scanned surfaces. For LLT sensors, it is important that at least some light is reflected from the surface to the sensor receiver. This is especially problematic when scanning glossy, very smooth and transparent surfaces where the beam can bounce off the surface outside the sensor and the laser line is not detected.

In previous research, we have investigated the effect of the angle of incidence of the laser beam on the intensity of the reflected laser beam for different materials. The measured dependencies help in positioning the sensors relative to the scanned parts to increase the reliability of data collection.

In this part of the research, we extended the existing data collection to include in-plane angles (previously only out-plane angles), as shown in Fig. 4.12a. For data collection, a positioner (see Fig. 4.12b), is used in which a sample is inserted and the characteristic for the material at each pose is measured by sequentially rotating each axis. The axes are driven by stepper motors and the position of each axis is controlled by the LLT sensor that allows measure the angle of the given plane.



(a) *(b)*

Fig. 4.12: (a) CAD model of positioner; (b) experimental workplace.

4.2.11 Optimization of the duration of design studies of standard parts using machine learning

As part of research in the field of robotic arm design automation, optimization of the design duration was considered using machine learning methods. This was done based on the results of experimental designs of robotic arms, where it was revealed that the design of individual arm components through design studies takes up the majority of the total time for robotic arm design.

The optimization of the design study duration was achieved by collecting data on input loads and resulting identified dimensions of components in each design of standard elements from which the arm is constructed. Based on this data, predictive models were created using suitable machine learning methods. These models are capable of optimizing component dimensions much faster within the design process compared to traditional design studies. However, it is important to note that predictive models inherently have some level of error. Therefore, this method increases design speed at the expense of precision.

Within design studies of bracket and flange components of robotic arms, most of their dimensions are defined by the connection dimensions of the drive units and other related elements, such as standardized cross-sections of the arms. In the optimization of these components, only their thicknesses and lengths are adjusted. For example, if there are 10 different sizes of drive units in the database, there are also 10 corresponding sizes of bracket components. For each size, a dataset of loads and corresponding resulting dimensions was created through design studies, where the input was the load on the brackets, and the output was the optimized thickness for a given deformation condition. A predictive model was then trained using machine learning on this prepared dataset. The table below shows a comparison of results from the trained model and results from strength studies.

Choosing the appropriate bracket thickness using the predictive model takes only a few tenths of a second. Choosing the appropriate bracket thickness using design studies takes, depending on the number of checked thickness values, from 30 seconds (if the first value satisfies the deformation condition) to 15 minutes in the case of examining 30 different thickness values. Utilizing these predictive models can save a significant amount of time in the design process.

In the research of automated arm design, the trained predictive models are used to increase the precision of design studies while maintaining their duration. The predicted thickness value represents an estimate that is refined within the design study for increased accuracy.

Tab. 4.1: Comparison of Prediction Results and Design Studies

Material	Force F_x	Force F_y	Force F_z	Thickness t Study	Deformation Study	Thickness t Prediction	Deformation Prediction
Hliník	55 N	38 N	69 N	15,0 mm	0,047 mm	15,9 mm	0,046 mm
	120 N	135 N	40 N	16,0 mm	0,041 mm	15,0 mm	0,046 mm
	200 N	45 N	158 N	21,0 mm	0,048 mm	23,9 mm	0,046 mm
Ocel	55 N	120 N	85 N	11,0 mm	0,047 mm	11,3 mm	0,044 mm
	154 N	250 N	235 N	16,0 mm	0,044 mm	15,7 mm	0,047 mm
	358 N	250 N	154 N	16,0 mm	0,044 mm	16,1 mm	0,044 mm

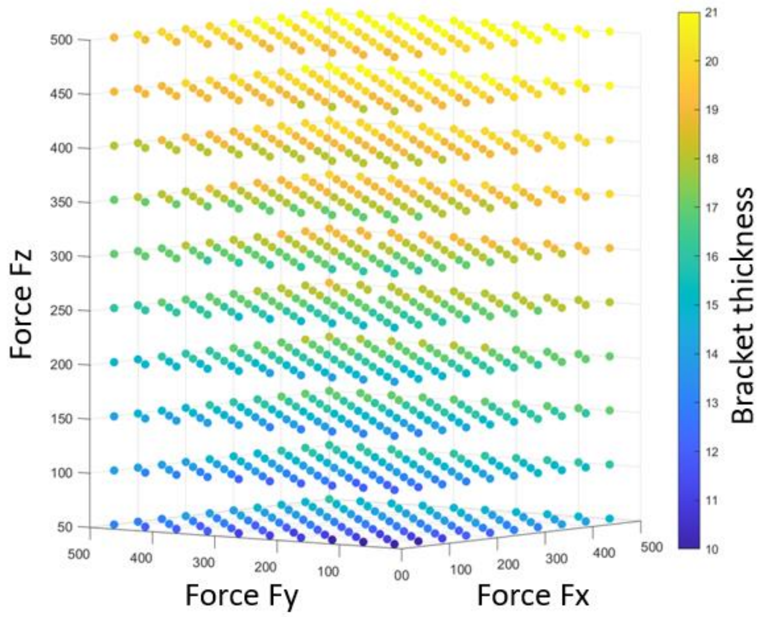


Fig. 4.13: Graphical representation of a model for predicting the thickness of a bracket, material Steel

4.2.12 Print head with adjustable nozzle diameter

During the period from January to June 2023, research was conducted on the principles of existing technical solutions for print heads with a variable nozzle diameter, including patent protections. Three concepts for changing the nozzle diameter were proposed during this period, with several variants designed for each. Due to protection reasons, it is not possible to specify in detail the functioning of the nozzle. Each variant was then converted into prototype versions to verify the functioning of the principle of changing the diameter of the output filament. The first tests of filament diameter changes were conducted on a testing stand, as shown in the following image.

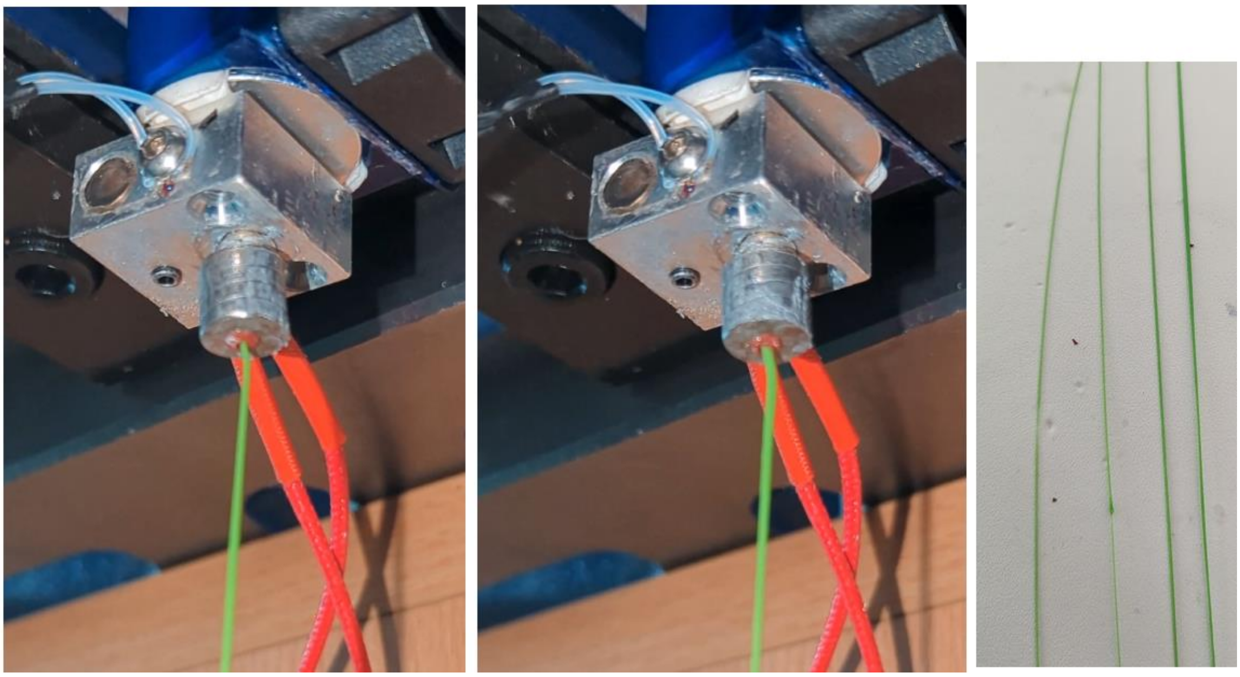


Fig. 4.14: Demonstration of testing a nozzle with variable diameter. On the left, the stand during flow with a small output hole, in the middle, the stand during flow with a large output hole, and on the right, the resulting printed filaments with varying thicknesses

Practical testing on the stand is currently measuring essential parameters for the detailed design of the print head (necessary nozzle temperature, minimum and maximum obtained diameter of the output filament, etc.). In the coming months, the collected data will be evaluated, and a design for the suitable shape of the nozzle will be made based on simulation models. On these bases, the previous design of the extruder will be modified, which will then be manufactured and tested in more detail.

An extruder was purchased and then structurally modified for connection to a UR3e robot to test the software and the principle of printing by a robot. A printing base was also acquired and structurally modified.

4.3 Finished Projects

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

4.3.1 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-Sieghart, 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 the 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.

For more information, please visit:

- http://robot2.vsb.cz/telerescuer
- http://www.telerescuer.polsl.pl/

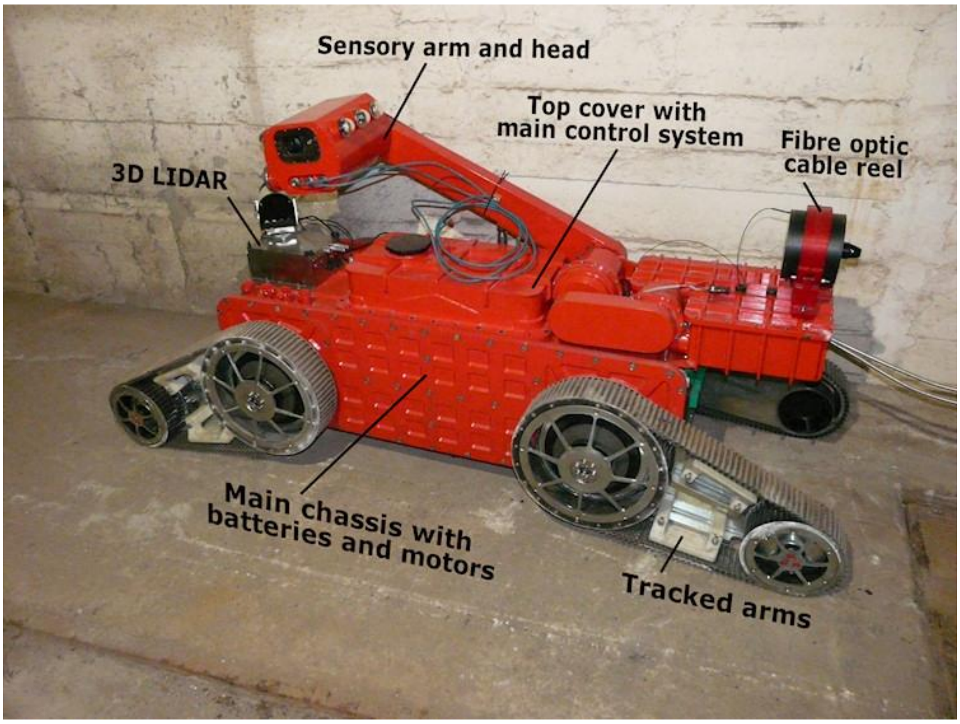


Fig. 4.15: TeleRescuer – main subsystems of the robot

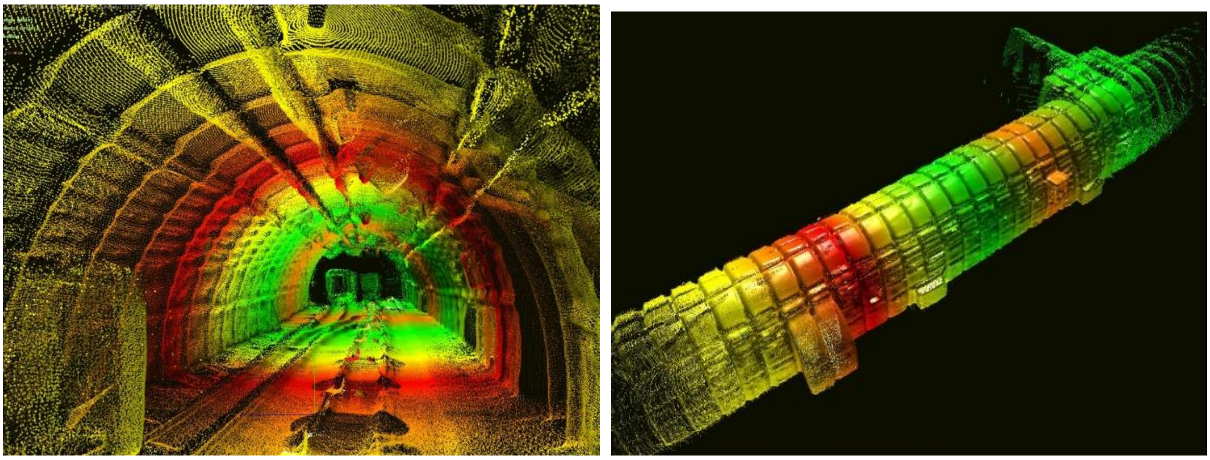


Fig. 4.16: Visualization of a coal mine corridor 3D map (point cloud)

4.3.2 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.

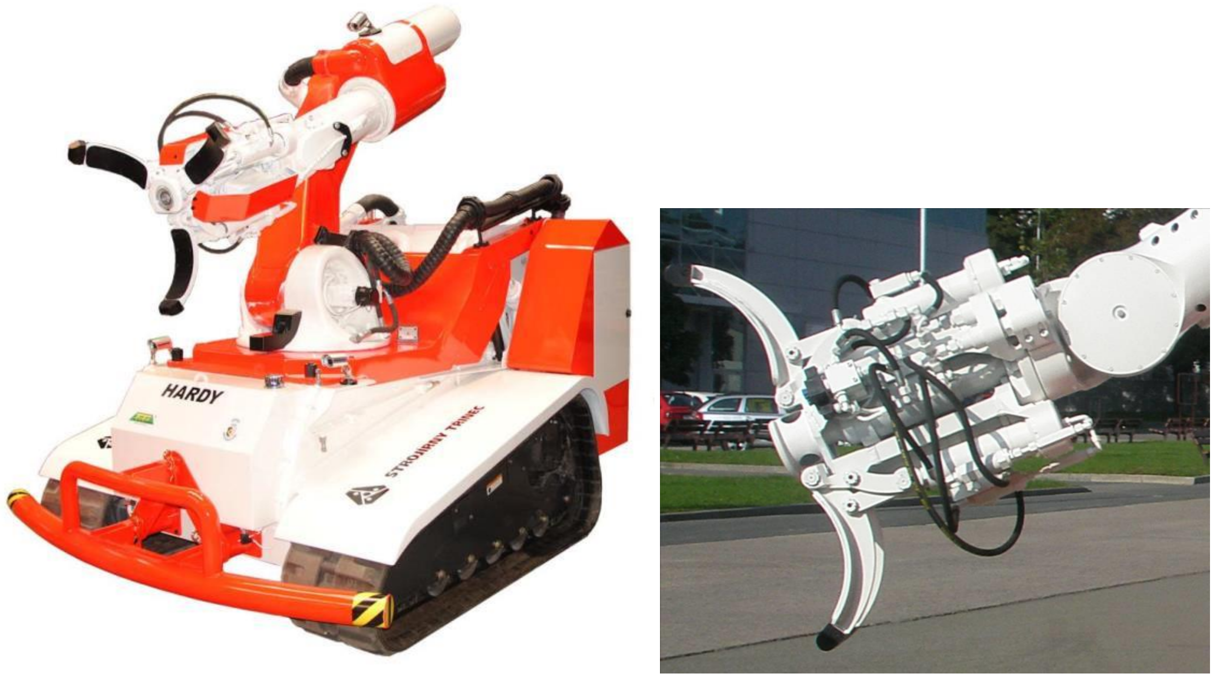


Fig. 4.17 Robot Hardy and its multipurpose gripper with the integrated water nozzle

4.3.3 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.

A video of the robot in action is available on: https://www.youtube.com/watch?v=nRejyA3d8bM

Fig. 4.18 Mobile robot TAROS

4.3.4 Control system of a collaborative robot for use in dynamic environments

Although a potential collision between a collaborative robot and a human operator in a shared work environment does not pose a health risk, it is still an unwanted delay in the production cycle as the robot enters an emergency shutdown state. Therefore, research is underway on various methods to enable a fully shared workspace where the robot and human operator not only do not threaten each other, but also do not restrict each other. One typical task is the automatic adjustment of the robot's trajectory in response to the occurrence of dynamic obstacles (typically the operator's hands or objects carried in the hands).

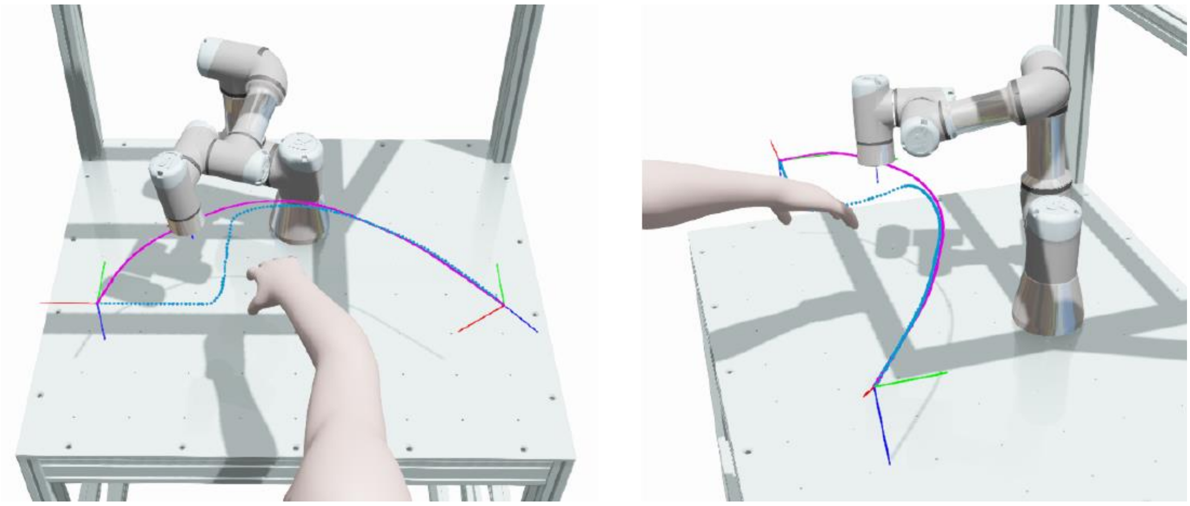


Fig. 4.19 Simulated demonstration of the principle of the elastic band method for avoiding dynamic obstacles

4.3.5 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.

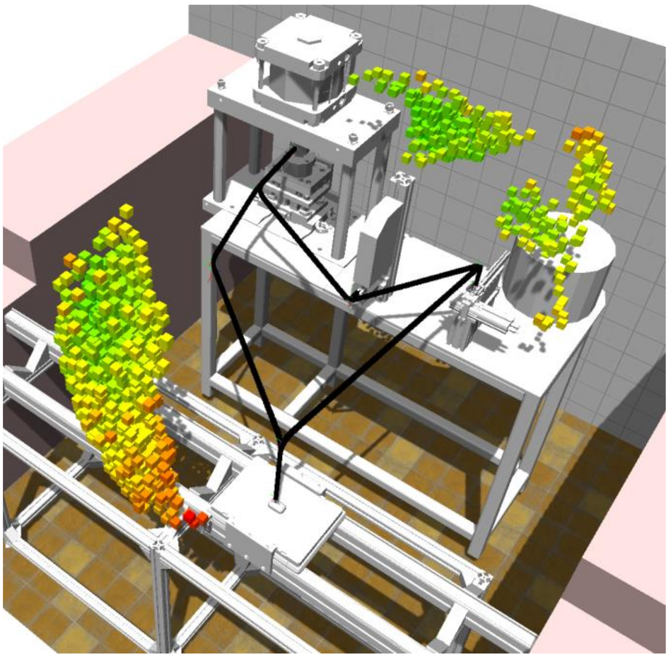


Fig. 4.20 All possible locations of the UR10e robot base in a workplace; colour coding represents evaluation of the locations (green = better)

4.3.6 Automated search of documentation of an unknown object

Computer recognition of 3D objects has a direct application in practice, e.g. in the repair of complex machinery or in the automotive industry, where the number of components is in the order of thousands. A typical task in operation, e.g. on a production line, is to identify a given component in a computer database of 3D models (formerly drawings). It is obvious that for a person this is a demanding activity that requires knowledge of the database, i.e. a relatively high but narrowly focused qualification, and great concentration. It is highly desirable that this activity be automated. In this paper, we propose and test one possible approach to automatic 3d object recognition.

We propose the sequential use of two methods. The first method is Principal Component Analysis (PCA), which is fast. This method may not lead to a unique match, but rather to a small pool of candidates. That is why we are developing yet another method, which is based on the decomposition into planar and cylindrical primitives. The latter is robust, meaning it usually results in a unique match. The method exhibits higher computational complexity, which is not critical since we apply it to a small collection of models preselected by the first PCA method.

The goal is to assign a 3D object (machine part) to its existing 3D model in the database.

Fig. 4.21 Illustration of the problem of finding documentation (drawings) of an unknown physical component

4.4 Newly Submitted Projects

Name	Period	Budget (€)
SP2024/082 – Research and development of means of perception of robotic systems	2024	40,4k
OP TAK Application – Platform for controlling autonomous robots in logistics applications using AI and 5G network	2024–2025	1,2M
TWIN4ROBOT HORIZON-WIDERA-2023-ACCESS-02-01 Proposal number: SEP-210975996	2024–2026	1,5M

Four more project applications are being prepared.

4.5 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/

In December of this year, the reconstruction of the 1st floor of the Old Canteen building in the dormitory area was started, which will expand the premises of the existing Robotics Center of our workplace. The reconstruction is financed by the project nfrastructural support of doctoral study programs VŠB-TUO, reg. no. CZ.02.01.01/00/22_012/0008111 (call OP Jan Amos Komenský, Development of the infrastructure background of doctoral study programs), OP-JAK MŠMT, EU and should be completed in the second quarter of 2024.

As part of the reconstruction, classrooms will be built – including facilities for domestic and foreign doctoral students:

Collaborative Robotics Classroom

- Ways and methods of detecting and locating staff within the workplace.
- Methods of visual and haptic feedback on the state of the workplace to the operator.
- Methods and design of effective security measures and their testing and control.
- Methodology for checking compliance with safety limits according to standards/technical specifications.

Service robotics classroom

- Object recognition and online correction of the robot's trajectory
- Detection and correction of incorrect orientation of the manipulation object
- Manipulation using 3D vision
- Adaptive robotic measurement of 3D parts and components (products),
- Optimization of the strategy of the measuring trajectory and the measuring workplace
- Point cloud search algorithms, development of metrics, parallelization of large-scale searches databases.
- Anti-collision systems of robots based on on-line adjustment of the trajectory.

Classroom of robotic and mechatronic systems in the I4.0 concept

- Robotization in small and medium-sized enterprises that do not have the support of large system integrators.
- Design of the optimal configuration of the robotic workplace according to the specified criteria using machine learning.
- Unconventional kinematic structures of manipulators and their optimization.
- Monitoring, evaluation and optimization of selected parameters of the robotic workplace.
- Increasing the accuracy of manipulators.

Design and simulation classroom of robotic systems

- Digital twin, cloud services, HW and SW resources.
- Sensory subsystems.
- Machine vision, hybrid systems.
- Use of virtual and augmented reality.

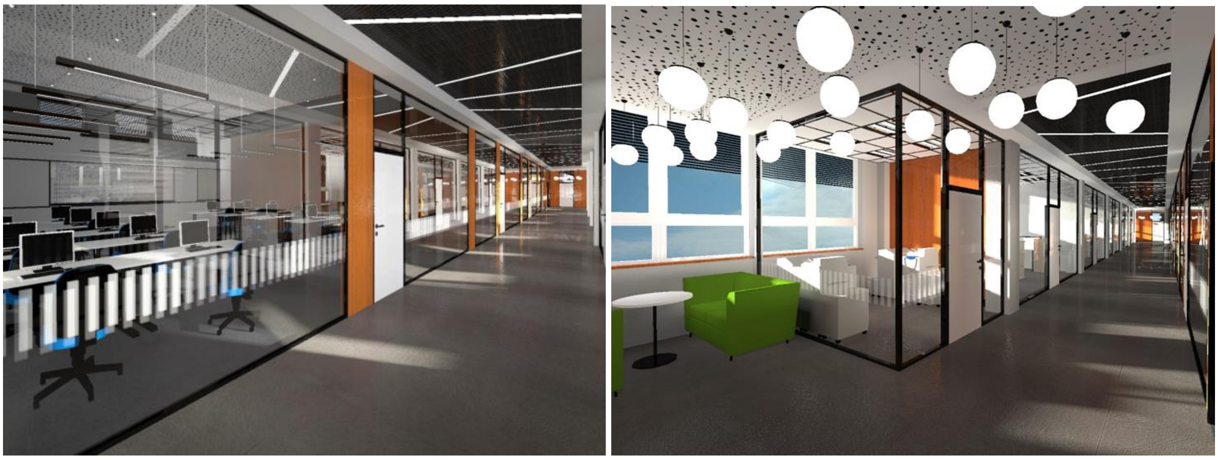


Fig. 4.22. Visualisation of the Robotics Centre after the reconstruction

4.6 Computer Classrooms

In the Robotics Center – a computer classroom with 20 PCs for teaching CAD systems moved to the former lecture room. Lectures take place in a newly acquired room in the premises of the Old Canteen KaMT27 (former meeting room of KTVS). This freed up the area of the laboratory where research activities can take place without disturbing the ongoing teaching.

The other two computer classrooms with approx. 10 + 9 PCs are in classrooms D122 and D123.

Fig. 4.23: Robotics Centre – workplace with collaborative and industrial robots

Fig. 4.24: Students learning collaborative and industrial robot programming

5 COOPERATION IN SCIENCE AND RESEARCH

5.1 Cooperation with Subjects in the Czech Republic

Within the framework of research and development in the field of industrial and 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.
- Elvac,
- ABB robotics,
- IFTSolutions,
- Excalibur Army (under Czechoslovak Group – CSG).

5.2 Cooperation with Subjects Abroad

Slovakia

- Technical University of Košice, Facult of Mechanical Engineering, Department of Production Technology and Robotics, Department of Industrial Automation and Mechatronics, Department of Applied Mechanics and Mechanical Engineering, Department of Technologies, Materials and Computer Support of Production, Department of Industrial Engineering and Informatics,
- Slovak Technical University of Bratislava - Faculty of Materials Science and Technology.

Poland

- Silesian University of Technology, Gliwice – Institute of Fundamentals of Machinery Design.

Austria

- Joanneum research – Institute for Robotics and Mechatronics, Klagenfurt am Wörthersee.
- University Innsbruck, Unit Geometry and CAD, Innsbruck.
- Carinthia University of Applied Sciences, Admire Research Centre, Villach.

Denmark

- IT University of Copenhagen, Robotics, Evolution, and Art Lab.

Finland

- Department of Mechanical Engineering na Lappeenranta University of Technology.

Italy

- Fondazione Istituto Italiano di Tecnologia.
- DPIA - Dipartimento Politecnico di Ingegneria e Architettura, Università degli Studi di Udine, IT.
- Italian Institut of Technology, Dynamic Legged Systems – walking robotic systems.
- LUT University, Laboratory of Mechani Design – flexible robotic systems.

6 PUBLISHING ACTIVITIES

6.1 Articles in International Journals

HAGARA, Martin, HUŇADY, Róbert, LENGVARSKÝ, Pavol, VOCETKA, Michal and PALIČKA, Peter. The Calibration Process and Setting of Image Brightness to Achieve Optimum Strain Measurement Accuracy Using Stereo-Camera Digital Image Correlation. *Applied Sciences*. 2023, vol. 13, issue 17. e-ISSN 2076-6341. Scopus, WoS, **Q3**

VARGA, Martin, VIRGALA, Ivan, KELEMEN, Michal, MIKOVÁ, Ľubica, BOBOVSKÝ, Zdenko, SINCAK, Peter Jan and MERVA, Tomáš. Pneumatic Bellows Actuated Parallel Platform Control with Adjustable Stiffness Using a Hybrid Feed-Forward and Variable Gain Integral Controller. *Applied Sciences*. 2023, 13(24), 13261. **Q3**

SUDER, Jiří, MLOTEK, Jakub, PANEC, Alan and FOJTÍK, František. Design of Printing Parameter Settings Methodology for FFF Printing of Waterproof Samples from a Flexible Material. *Acta Mechanica Slovaca*. 2023. 27(1). pp. 58-64.

LUKÁŠ, Dalibor and KOT, Tomáš. Hierarchical Real-Time Optimal Planning of Collision-Free Trajectories of Collaborative Robots. *Journal of Intelligent & Robotic Systems.* 2023, 107, article n. 57. Scopus, WoS, **Q3**

VYSOCKÝ, Aleš, POŠTULKA, Tomáš, CHLEBEK, Jakub, KOT, Tomáš, MASLOWSKI, Jan and GRUSHKO, Stefan. Hand Gesture Interface for Robot Path Definition in Collaborative Applications: Implementation and Comparative Study. *Sensors*. 2023, 23(9), 4219. Scopus, WoS, **Q2**

KREJČÍ, Jakub, BABIUCH, Marek, BABJAK, Ján, SUDER, Jiří and WIERBICA, Rostislav. Implementation of an Embedded System into the Internet of Robotic Things. *Micromachines*. 2023. 14(1), 113. Scopus, WoS, **Q2**

OŠČÁDAL, Petr, KOT, Tomáš, SPURNÝ, Tomáš, SUDER, Jiří, VOCETKA, Michal, DOBEŠ, Libor and BOBOVSKÝ, Zdenko. Camera Arrangement Optimization for Workspace Monitoring in Human–Robot Collaboration. *Sensors*. 2023. 23(1), 295. Scopus, WoS, **Q2**

6.2 Contributions in International Conferences

VOCETKA, Michal, HECZKO, Dominik, BABJAK, Ján, BOBOVSKÝ, Zdenko, KRYS, Václav, RUŽAROVSKÝ, Roman and BOČÁK, Robert. UR10e Robot Drift Compensation for Precision Measurement Applications. In *Mechanisms and Machine Science*. 2023. 32nd International Conference on Robotics in Alpe-Adria-Danube Region, RAAD 2023. pp. 281-288. ISBN 9783031326059. ISSN 2211-1098. Scopus

MLOTEK, Jakub, SUDER, Jiří, VOCETKA, Michal, BOBOVSKÝ, Zdenko and KRYS, Václav. The Effect of Deformation on Robot Shape-Changing Link. In *Advances in Service and Industrial Robotics. RAAD 2023. Mechanisms and Machine Science*. vol 135. Cham : Springer, 2023. ISBN 978-3-031-32605-9. Scopus

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

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