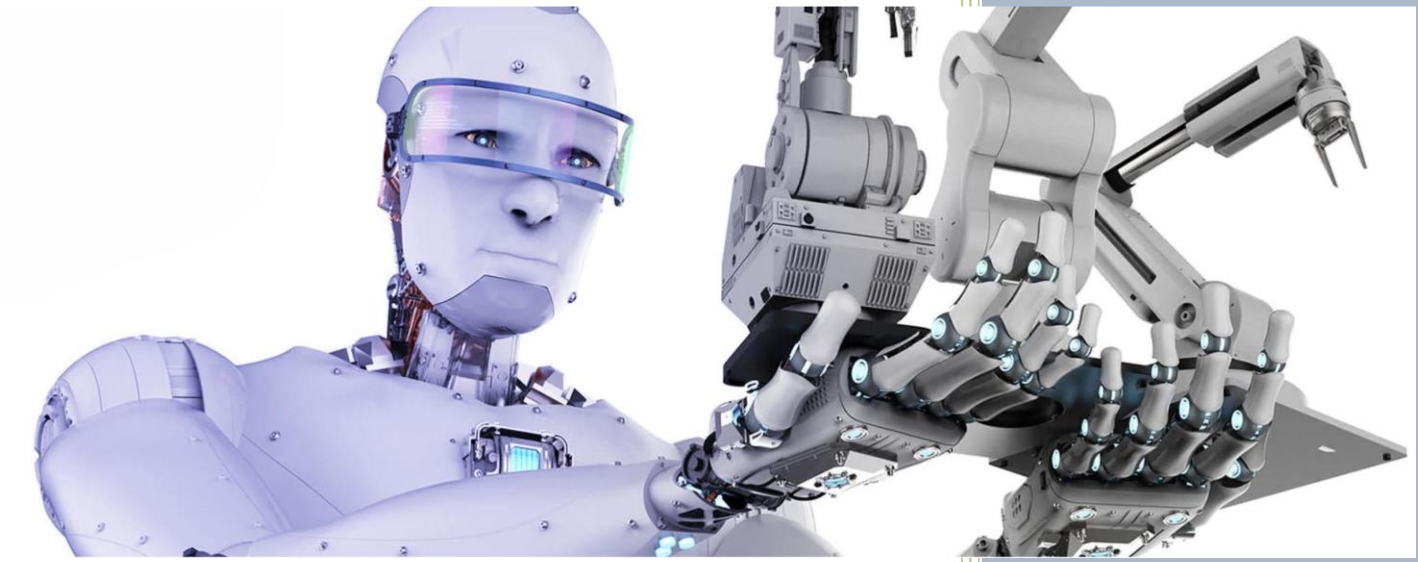
2022

Annual Report of Department of Robotics



Faculty of Mechanical Engineering

VŠB – Technical University of Ostrava

Czech Republic

18th January 2022

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

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

Annual Report

2022

Department of Robotics

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

Head of Department: prof. Dr. Ing. Petr Novák
tel.: +420 59 732 3595
e-mail: petr.novak@vsb.cz

Assistant: Ing. Petra Pišťáčková
tel.: +420 59 732 1280
e-mail: petra.pistackova@vsb.cz

Address: **VŠB – Technical University of Ostrava**
Department of Robotics
17. listopadu 2172/15
708 00 Ostrava – Poruba
Czech Republic

Web: http://robot.vsb.cz/en

Social net (*only in Czech*)**:** https://www.**facebook**.com/robot.vsb.cz
https://www.**instagram**.com/katedra_robotiky/
https://www.**youtube**.com/user/robot354

1. CONTENT

1. CONTENT 3
2. DEPARTMENT PROFILE 5
3. STAFF 6
4. EDUCATION ACTIVITIES 7
4.1. Guaranteed Study Fields 7
4.1.1. Bachelor Fields of Study 7
4.1.2. Magister Fields of Study 9
4.1.3. Doctoral Fields of Study 12
4.1.4. Werner von Siemens Award 2021 13
4.2. List of Defended Theses 15
4.2.1. Bachelor Theses 15
4.2.2. Diploma Theses 16
4.3. List of PhD Students 17
4.4. Defended Dissertations 18
4.5. Student Projects 20
4.5.1. Student Grant Competition 2022 20
4.5.2. Anatolian Rover Challenge 22
5. PEDAGOGICAL COOPERATION 23
5.1. Significant Cooperation with Subjects in the Czech Republic 23
5.2. Significant Cooperation with Foreign Partners 25
6. SCIENCE-RESEARCH ACTIVITIES 26
6.1. Currently Solved Projects 26
6.2. Main Directions of Research and Development 26
6.2.1. Automation System for the Design of Industrial Robots and Manipulators 27
6.2.2. Automatic Design of a Robotic Manipulator 30
6.2.3. Implementation of an Industrial Robot into the IoT 31
6.2.4. Shape Adjustable Links of Robotic Systems 32

6.2.5. Control System of a Collaborative Robot for Use in Dynamic Environments 33

6.2.6. Training a Model for Color-independent Hand Segmentation from RGB-D Camera Images Based on Neural Networks 34

6.2.7. Finding the Optimal Pose of 2D LLT Sensors to Improve Object Pose Estimation . 36

6.2.8. Workplace Obstacle Detection for Human-robot Collaboration 37

6.2.9. Optimisation of the Number of Cameras on the Robotic Workstation 38

6.2.10. DGS 2022 40

6.2.11. Demonstrator of the Synthesis of Kinematic Structure Algorithm 41

6.3. Finished Projects 42

6.3.1. TeleRescuer 42

6.3.2. Hardy 43

6.3.3. TAROS 44

6.4. Newly Submitted Projects 44

6.5. New Laboratories and Equipment 45

6.5.1. Test Workplace of Experimental Robots 45

7. COOPERATION IN SCIENCE AND RESEARCH 47

7.1. Cooperation with Subjects in the Czech Republic 47

7.2. Cooperation with Subjects Abroad 47

7.3. Abroad stays of teachers, researchers, and students 48

7.4. Foreign guests 49

8. PUBLISHING ACTIVITIES 51

8.1. Articles in International Journals 51

8.2. Articles in Czech Journals 51

8.3. Contributions in International Conferences 51

8.4. Applied Outputs 52

8.4.1. Prototype, Functional Sample 52

8.4.2. Patent, Utility Model, Registered Design 52

8.4.3. Software 52

2. DEPARTMENT PROFILE

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

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

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

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

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

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

3. STAFF

Head of Department:	prof. Dr. Ing. Petr Novák
Vice Head:	assoc. prof. Ing. Zdenko Bobovský, PhD.
Secretary:	Ing. Václav Krys, Ph.D.
Assistant:	Ing. Petra Pišťáčková
Professors:	prof. Dr. Ing. Vladimír Mostýn
	prof. Dr. Ing. Petr Novák
Associate professors:	assoc. prof. Ing. Zdenko Bobovský, PhD.
	assoc. prof. Ing Tomáš Kot, Ph.D.
	assoc. prof. Ing. Milan Mihola, Ph.D.
Assistant professors:	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, Ph.D.
Researchers:	Ing. Ján Babjak, Ph.D.
	Ing. Dominik Heczko, Ph.D.
	Ing. Daniel Huczala, Ph.D.
	Ing. Jakub Mlotek
	Ing. Petr Oščádal
	Ing. Zdeněk Zeman
	Ing. Jan Bém
	Ing. Adam Boleslavský
	Ing. Jakub Krejčí
	Ing. Tomáš Spurný
	Ing. Rostislav Wierbica

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: Assoc. prof., 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.

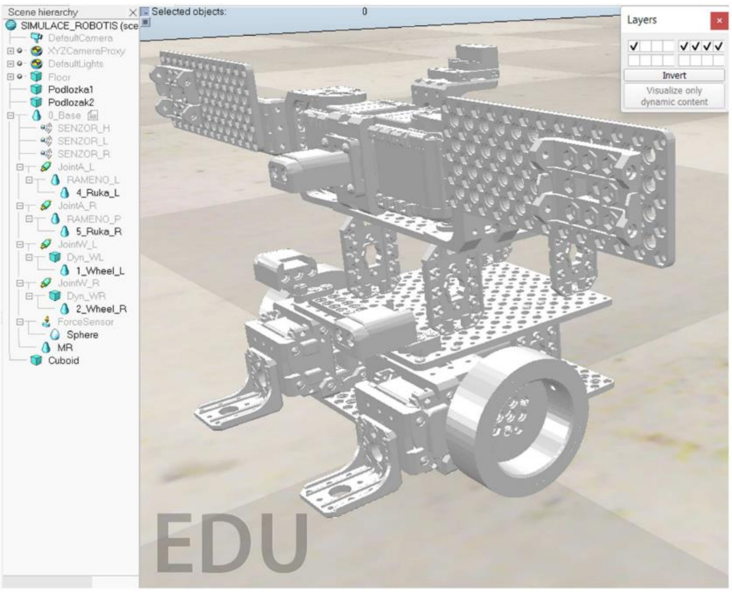


Fig. 4.1: (Bc.) David Benek, Digital twin of a wheel service robot, bachelor's thesis, supervisor: assoc.prof. Ing. Zdenko Bobovský, PhD.

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, 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. 4.2: (Bc.) Jan Szturc, Research module of a mobile robot, bachelor's thesis, supervisor: Ing. Tomáš Spurný

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. 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.

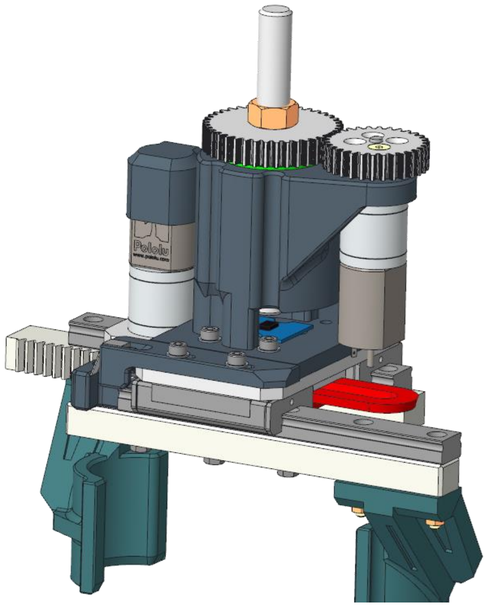


Fig. 4.3: (Ing.) Bc. Tomáš Poštulka, Manipulation module for mobile robot K3P4, supervisor: Ing. Robert Pastor, Ph.D.

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).

This study program was terminated in the 2022/2023 school year and replaced by the newly accredited Robotics study program of the same name divided into three specializations.

Title: **Robotics**

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

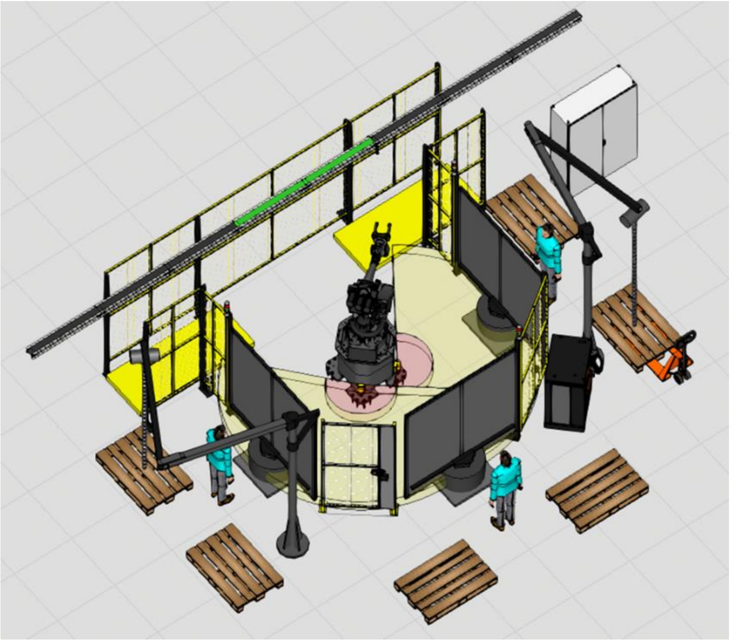


Fig. 4.4: (Ing.) B.Sc. David Smékal, RTP design - handling of parts in the paint shop, supervisor: Ing. Michal Vocetka.

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.

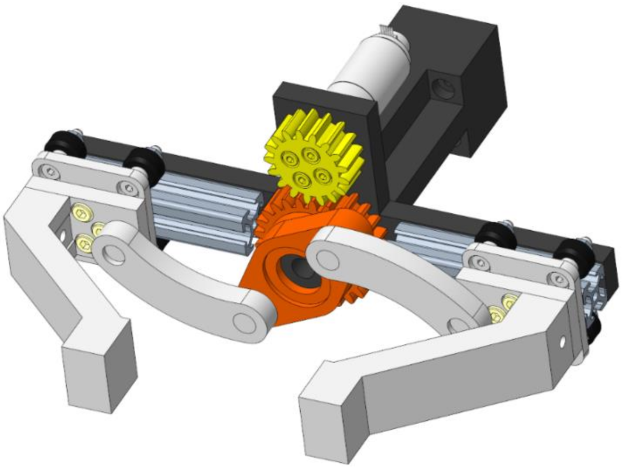


Fig. 4.5: (Ing.) B.Sc. Aleš Franc, Effector with sliding gripping elements, supervisor: assoc. prof. Ing. Milan Mihola, Ph.D.

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.

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.

Fig. 4.6: (Ing.) Bc. Jakub Mlotek, Modification and expansion of the mobile robot Viper, supervisor: Ing. Václav Krys, Ph.D..

4.1.3. Doctoral Fields of Study

Title: **Robotics**

Field of Study: 2301V013

Guarantor: prof. Dr. Ing. Vladimír Mostýn

Graduate Profile:

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

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.

4.1.4. Werner von Siemens Award 2021

The Werner von Siemens Award is organised by Siemens together with important representatives of universities and the Academy of Sciences of the Czech Republic, who are also the guarantors of the individual categories and participate in the evaluation of the best works. The award for the best thesis on Industry 4.0 went to Ing. Stefan Grushko, Ph.D. The award was given to the dissertation entitled " Motion planning for manipulator in dynamic environment using RGB-D sensor".

Fig. 4.7 Werner von Siemens Award 2021 – section Industry 4.0

Fig. 4.8 Werner von Siemens Awards 2021 in the Industry 4.0 section

Abstract of the dissertation:

The dissertation deals with the topic of trajectory planning of a manipulator in a dynamic environment using data from the RGB-D sensor. An example of such a dynamic environment is a shared workspace where a robot interacts with human workers. Cooperation between robot and human is a widespread topic within the concept of Industry 4.0, which opens up the possibility of creating workplaces with robots that can come into direct contact with employees during the work cycle. Such collaboration brings new opportunities to improve ergonomics and options for manufacturing automation. However, it also carries the risks associated with the possibility of a robot colliding with a human. Adaptive behaviour of the robot - replanning the trajectory with respect to the operator’s current position - can increase the efficiency and safety of cooperation since the robot will be able to avoid collisions and proceed in task completion. In such a situation, however, the user cannot know in advance what the robot’s trajectory will look like after replanning, which can cause discomfort along with reducing efficiency when interacting with the robot.

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.

4.2. List of Defended Theses

4.2.1. Bachelor Theses

Student	Supervisor	Topic
David Benek	assoc. prof. Ing. Zdenko Bobovský, PhD.	Digital Twin of a Wheeled Service Robot
Tomáš Drastik	Ing. Petr Oščádal	Automated Workplace for Demonstration Purposes
Aleš Franc	assoc. prof. Ing. Milan Mihola, Ph.D.	Effector with Sliding Gripping Elements
Lenka Hájková	assoc. prof. Ing. Zdenko Bobovský, PhD.	Digital Twin of a Robotic Manipulator
Daniel Hartmann	Ing. Petr Oščádal	Inovation of the Mobile Service Robot BigFoot
Daniel Kostka	Ing. Jakub Mlotek	Design of Suction Cup Effectors Using a Schmalz Vacuum Training Set
Radim Kroček	Ing. Jakub Mlotek	Effector Exchange System for the Workpalce with ABB IRB 1200 Robots
David Martynek	Ing. Zdeněk Zeman	Design of an Effector for Handling KLT Boxes
Libor Neuwirth	Ing. Václav Krys, Ph.D.	Mobile Robots for Logistics
Jan Palovský	Ing. Václav Krys, Ph.D.	Analysis of Means to Prevent Collisions of Robots with Humans
Martin Petřík	Ing. Ján Babjak, Ph.D.	Overview of Technical Means for ensuring safety of Robotized Workplaces
Vojtěch Skalka	Ing. Václav Krys, Ph.D.	Software Applications for Control and Management of Mobile Robots for Logistics
Lukáš Stypa	Ing. Václav Krys, Ph.D.	Design of an Automatic Test System
Radek Sukeník	Ing. Jan Bém	Locomotion Subsystem of the Competition Rover
Radim Vybíral	Ing. Petr Oščádal	State of the Art Analysis of Mobile Service Robots Based on NVIDIA Jetson Platform
Tomáš Vyroubal	Ing. Daniel Huczala, Ph.D.	The Design of Links for Robots with an Arbitrary Kinematic Structure

4.2.2. Diploma Theses

Student	Supervisor	Topic
Radim Bednárik	Ing. Václav Krys, Ph.D.	Simulations as a Support Tool in the Design of Robotic Workplaces
Karel Gattnar	Ing. Aleš Vysocký, Ph.D.	Design and Realization of a Collaborative Robotic Workplace with the Robot YuMi
Vojtěch Hanke	assoc. prof. Ing. Tomáš Kot, Ph.D.	Scanning Large Objects Using an Automated System
Jakub Chlebek	Ing. Petr Oščádal	Non-Standard Use of Collaborative Robots
Martin Kantor	Ing. Michal Vocetka, Ph.D.	Realization of Demonstration Tasks at the Workstation With Delta Robot.
Jan Kelar	Ing. Michal Vocetka, Ph.D.	Assembly Process Automation
Jiří Klus	Ing. Michal Vocetka, Ph.D.	Realization of Demonstration Tasks at the Workstation With the YuMi Cooperative Robot.
Jan Maslowski	Ing. Robert Pastor, Ph.D.	Arm Trajectory Planning Based on Visual Detection
Ondřej Moša	assoc. prof. Ing. Zdenko Bobovský, PhD.	Application for Control of Modular Robot with Serial Kinematic Structure
Tomáš Poštulka	Ing. Robert Pastor, Ph.D.	Manipulation Module for the K3P4 Mobile Robot
David Smékal	Ing. Michal Vocetka, Ph.D.	Automation of Parts Handling Process in the Paint Shop
Michał Staszowski	Ing. Jiří Suder, Ph.D.	Mechanical Design of Equipment for Automatic Unwinding and Straightening of Wire
Michal Zajíc	Ing. Aleš Vysocký, Ph.D.	Manipulator for a Workplace Camera Inspection

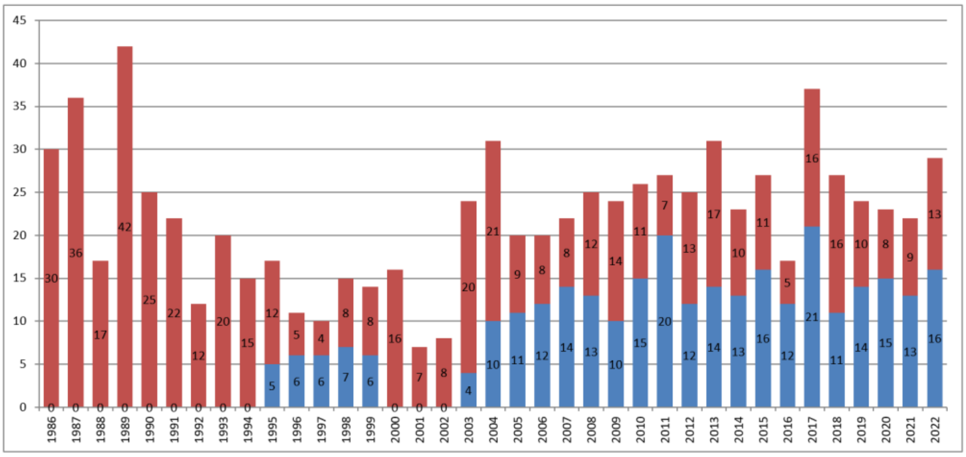


Fig. 4.9: Overview of numbers of graduates (former Manufacturing Systems with Industrial Robots and Manipulators and now Robotics) Departments of Robotics: Bc. – Blue, Msc. – Red

4.3. List of PhD Students

Student	Dissertation	Year	Form	Tutor
Ing. Dominik Heczko, Ph.D.	Increasing the accuracy of position and orientation of the objects placed by the manipulator	4*	F	assoc. prof. Ing. Zdenko Bobovský, PhD.
Ing. Daniel Huczala, Ph.D.	The Synthesis of Kinematic Structure of Robotic Manipulators	4*	F	assoc. prof. Ing. Tomáš Kot, Ph.D.
Ing. Michal Vocetka, Ph.D.	Manipulator accuracy improvement	4*	F	assoc. prof. Ing. Zdenko Bobovský, PhD.
Ing. Jakub Mlotek	Shape Adjustable Links of Robotic Systems	4	F	assoc. prof. Ing. Zdenko Bobovský, PhD.
Ing. Petr Oščádal	Robot Arm Trajectory Optimization under Dynamically Changing Work Space	4	F	assoc. prof. Ing. Zdenko Bobovský, PhD.
Ing. Zdeněk Zeman	Topological Design of Robotics' Arms	4	F	prof. Dr. Ing. Petr Novák
Ing. Jan Bém	Modularity as a Key Aspect in Robotics	2	F	assoc. prof. Ing.Milan Mihola, Ph.D.
Ing. Adam Boleslavský	Automation of the Design Process of Mechatronic Devices	2	F	assoc. prof. Ing.Marek Babiuch,Ph.D.
Ing. Jakub Krejčí	The concept of IoRT (Internet of Robotic Things) and its use	2	F	assoc. prof. Ing.Tomáš Kot, Ph.D.
Ing. Tomáš Spurný	Motion Planning of a Robot Arm under Dynamically Changing Work Space	2	F	assoc. prof. Ing.Milan Mihola, Ph.D.
Ing. Rostislav Wierbica	Optimization of kinematic structure of a robotic manipulator for a given task	2	F	assoc. prof. Ing.Milan Mihola, Ph.D.
Ing. Tomáš Poštulka	Assisted assembly with a robot	1	F	prof. Dr. Ing. Petr Novák
Ing. Jan Maslowski	Calibration of a multi-camera system sensing the workspace	1	F	prof. Dr. Ing. Petr Novák
Ing. Luboš Varecha	The influence of the position of the manipulator on its accuracy	1	C	assoc. prof. Ing. Zdenko Bobovský, PhD.
Ing. Ondřej Moša	The influence of the shape of the variable support elements of the manipulator on its accuracy	1	F	assoc. prof. Ing. Zdenko Bobovský, PhD.
Ing. Jakub Chlebek	Shortening the working cycle of manipulators	1	F	assoc. prof. Ing. Tomáš Kot, Ph.D.

*) Successfully finished doctoral studies in 2022

P/C – full-time/combined form of study

4.4. Defended Dissertations

Ing. Dominik Heczko, Ph.D.

Title: **Increasing the accuracy of position and orientation of the objects placed by the manipulator**

Supervisor: **assoc. prof. Ing. Zdenko Bobovský, PhD.**

Annotation

The presented dissertation deals with increasing the position accuracy of objects during their placement or assembly by a robot. Industrial robots are commonly used in assembly lines, where bin-picking, which is the removal of disordered objects from a pallet or box, is becoming increasingly used. This pick-and-place application is solved by a vision system and a robot that places the grasped objects on a conveyor that moves the objects on the technology line for further processing. This work presents the possibility to eliminate the conveyor which can be achieved by performing the assembly process directly after grasping the object via bin-picking system. The thesis focuses on refining the object pose estimation in a gripper of the robot (in 3D space) by Iterative Closest Point algorithm. To refine the pose estimation, the correct input data to the ICP algorithm are crucial, which is achieved by scanning the relevant features, the geometric primitives of the object. The introductory part of this dissertation is devoted to commercially available bin-picking systems and an overview of the current state of the art with possibilities for refining the assembly or manipulation process. Then, the objectives of the thesis are stated based on a survey of the current state of the art and in the context of projects carried out by the Department of Robotics. The actual part of the thesis is divided into subchapters according to the different objectives of the thesis. This article describes a methodology for positioning sensors relative to the scanned object (and various materials) to increase the reliability of data collection. Based on the obtained characteristics, a simulation model is developed for virtual scanning and simulation purposes. Subsequently, a sensor placement methodology is developed to refine the pose estimation – finding the optimal pose of the sensors relative to the scanned object with respect to the collected data for input to the ICP algorithm. The simulation model and pose estimation are verified on a real system.

Ing. Daniel Huczala, Ph.D.

Title: **The Synthesis of Kinematic Structure of Robotic Manipulators**

Supervisor: **assoc. prof. Ing. Tomáš Kot, Ph.D.**

Annotation

This dissertation thesis deals with the topic of synthesis of kinematic structures of serial robotic manipulators. Beside a solution to this problem, it provides a state-of-the-art and a brief theoretical background on the topic, and an analysis of robotics and optimization toolboxes in MATLABTM software, which is later used for implementation. Two preliminary tasks were solved prior to the description of the synthesis algorithm itself. First, an analytical method is presented that determines the kinematic structure of a robot for a single pose. It serves as an initial estimation of the kinematic structure and avoids randomness in the optimization process. Due to that, comparison of the performance of various robot kinematic representations and optimization constraint design methods is possible. The second preliminary task deals with automatic conversion between three selected kinematic representations: Denavit–Hartenberg convention, Tait–Bryan (roll-pitch-yaw) angles parameters with translational displacement of XYZ axes, and Product of Exponentials representation. The synthesis algorithm itself applies numerical optimization techniques to search for the local minimum of a function. It brings innovation such as the implementation of multiple representations, multiple constraint design methods, and most importantly, the possibility of combining results with each other, which was shown to significantly increase the quality of the results. In addition, a performance comparison of representations and constraint design methods is provided and discussed. In summary, the choice of representation and constraint design method has a strong impact on the output. The last part of the thesis presents a method for placing physical joints of a synthesized manipulator in positions where no collisions within a given environment appear. An experimental manipulator is designed, assembled, and proven to perform a given task.

Ing. Michal Vocetka, Ph.D.

Title: **Manipulator Accuracy Improvement**

Supervisor: **assoc. prof. Ing. Zdenko Bobovský, PhD.**

Annotation

The presented thesis deals with the possibilities of increasing the precision of six-axis angular manipulators with respect to the properties of its mechanical structure. The paper describes the procedures and the achieved results of the two proposed research areas. The introduction of this thesis describes the causes of errors of industrial robots. A standard that defines the measurement of a key operating parameters, engineering and scientific procedures for error detection and possible compensation as well as suitable systems for measuring the precision of robots is also described. Furthermore, the aims of the work are set, these are based on a specific research task that have been and are being solved at the Department of Robotics. The work itself is divided into chapters according to the topics addressed. The first research area is the research of the influence of the approach direction on the achievable repeatability. In the framework of this research, the influence of the approach direction on the measured target, on the achievable repeatability was investigated using multiaxis accelerometers and a high-speed DIC camera system. Several experiments were performed to confirm this influence and at the same time to exclude the influence of the obtained results by other influences such as specific position, weight of the carried object of manipulation, approach speed or influence of a specific robot. Experiments performed for this research were performed on two ABB IRB1200 5/09 robots. As part of the subsequent research in the field of increase of the accuracy of manipulators, the degree of influence of the change in the temperature of the robot arm on the achievable repeatability was experimentally determined. For the needs of this research, a pair of ABB IRB1200 5/09 robots and a UR10e robot were equipped with temperature sensing equipment for on-line measurement and a single-purpose measuring nest with confocal and two laser profilers for multi-axis measurements was also prepared. The aim is to propose a procedure for drift compensation, based on the current temperature of the robot arm. At the conclusion of this paper, you can find an evaluation of the results.

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 2022

The project of the student grant competition "The use of digitalisation in the design of robotic systems" was divided into three main activities so that it was possible to involve as many doctoral and master's degree students as possible in their solution. 32 doctoral and master's degree students took part in the project. 10 articles were published as outputs of the project. 7 of them were published in journals with impact factor (3x Q1 and 4x Q2).

Main project activities:

- Creation and verification of methodologies for the design of robotic workplaces with the support of digitalization tools
- Creation and verification of methodologies for the design of mobile robots with the support of digitalization tools
- Methods and procedures for collecting data and operating parameters of robotic systems for their use in digital twins

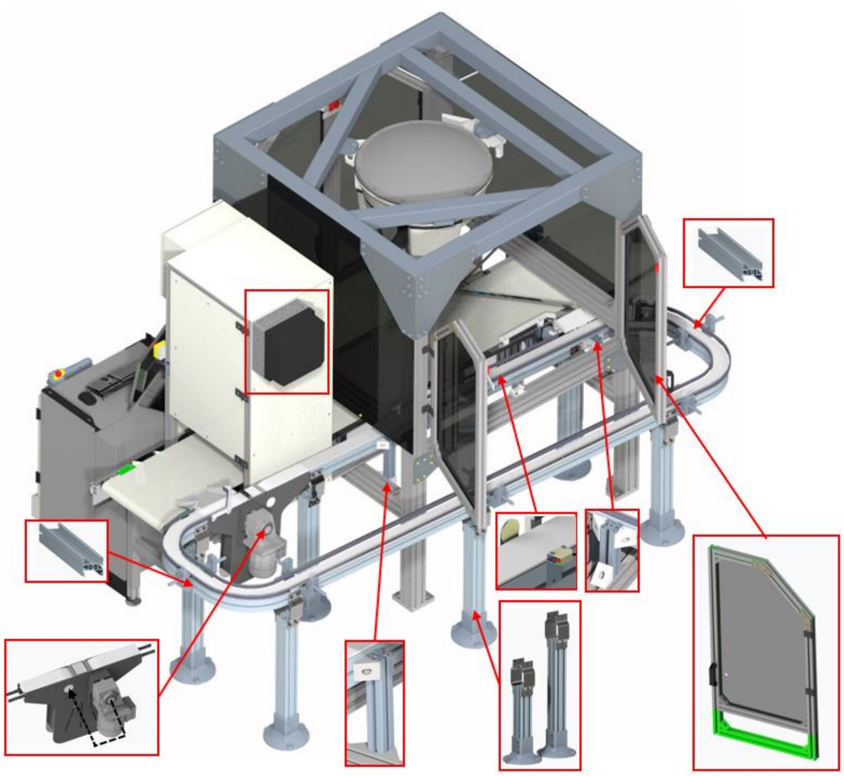


Fig. 4.10: Preview of the 3D model of the modified workplace with IRB 360 robot with integrated segmental conveyor and illustration of the modified parts of the workplace

In 2022, a total of 12 theses (3 dissertations and 9 diploma theses) supported or related to the SGS project were defended:

- Ing. Dominik Heczko, Ph.D. – Increasing the accuracy of position and orientation of the objects placed by the manipulator
- Ing. Daniel Huczala, Ph.D. – The Synthesis of Kinematic Structure of Robotic Manipulators
- Ing. Michal Vocetka, Ph.D. – Manipulator accuracy improvement
- Ing. Radim Bednárik – Simulations as a Support Tool in the Design of Robotic Workplaces
- Ing. Jakub Chlebek – Non-Standard Use of Collaborative Robots
- Ing. Martin Kantor – Realization of Demonstration Tasks at the Workstation With Delta Robot
- Ing. Jan Kelar – Assembly Process Automation
- Ing. Jiří Klus – Realization of Demonstration Tasks at the Workstation With the YuMi Cooperative Robot
- Ing. Jan Maslowski – Arm Trajectory Planning Based on Visual Detection
- Ing. Ondřej Moša – Application for Control of Modular Robot with Serial Kinematic Structure
- Ing. Tomáš Poštulka – Manipulation Module for Mobile Robot K3P4
- Ing. David Smékal – Proposal of a Solution of Robotized Manipulation of Parts in a Paint Shop

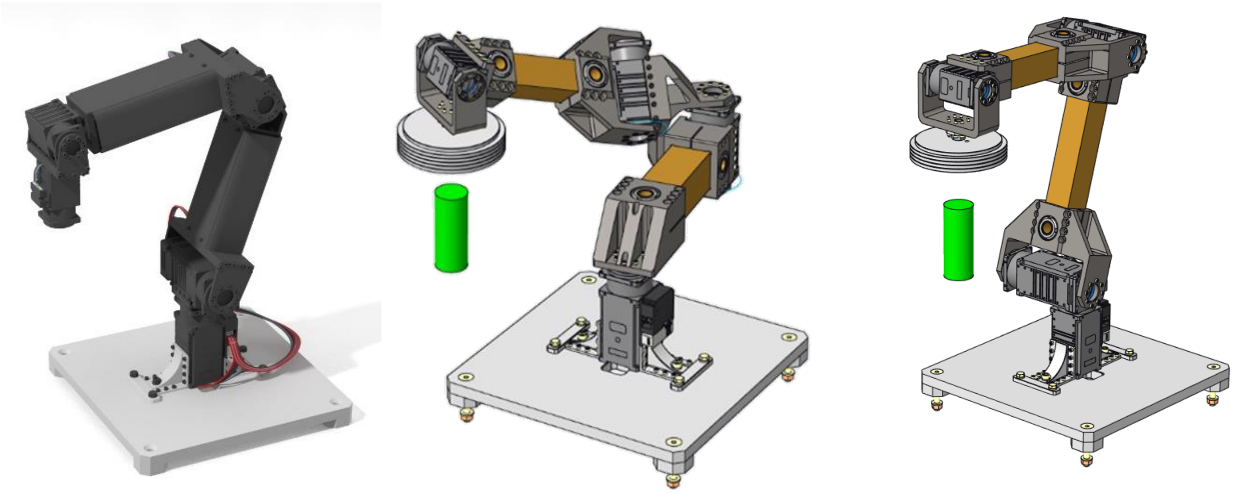


Fig. 4.11: Testing of generated manipulator structures for a given manipulation task

4.5.2. Anatolian Rover Challenge

The RoverOva competition team, organized by students of our department, participated in the Anatolian Rover Challenge in Turkey. This was the first year of the competition and therefore an unfamiliar environment for all participating teams. Our team went to Istanbul with 7 people and after four days of competition, they came in fourth place. At the same time, in addition to the main competition, there were several side challenges from which we took home the awards for best manipulator and best terrain traversability.

In preparation for the competition, the K3P4 competition rover was significantly rebuilt in early 2022 to a more robust chassis kinematics with softer 3d printed tires. These changes allow the rover to traverse obstacles taller than the diameter of its wheels. At the same time, we have expanded the rover's communications equipment to include redundant communication channels in case of signal failure. In connection to this project, three bachelor's and two master's theses were defended in 2022

Fig. 4.12: Our competing team on ARC 2022 in Istanbul

Fig 4.13: Competitive mobile robot K3P4 (left) at ARC 2022 in Istanbul

5. PEDAGOGICAL COOPERATION

5.1. Significant Cooperation with Subjects in the Czech Republic

- ABB – Once again, week-long internships of students (5th 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.

- 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.

- 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.

- IngeTeam – expert lecture for students and thesis topics.

- Siemens, Frenštát pod Radhoštěm – student internships and thesis topics.

- Mebster – expert lecture for students.

Fig. 5.1: Students of the department on a professional internship at the ABB repair center

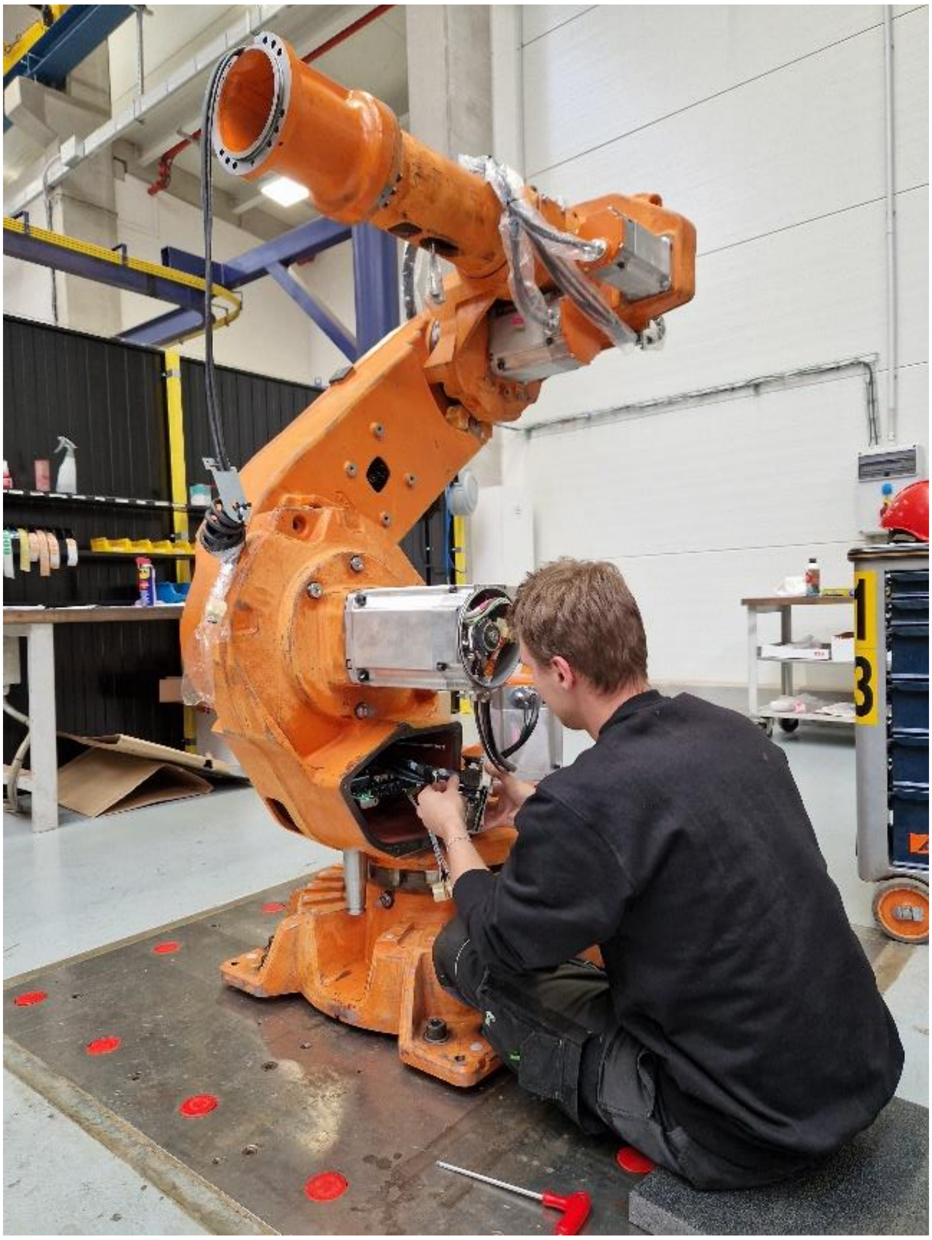


Fig. 5.2: Work on an industrial robot during a professional internship at the ABB Rework Center

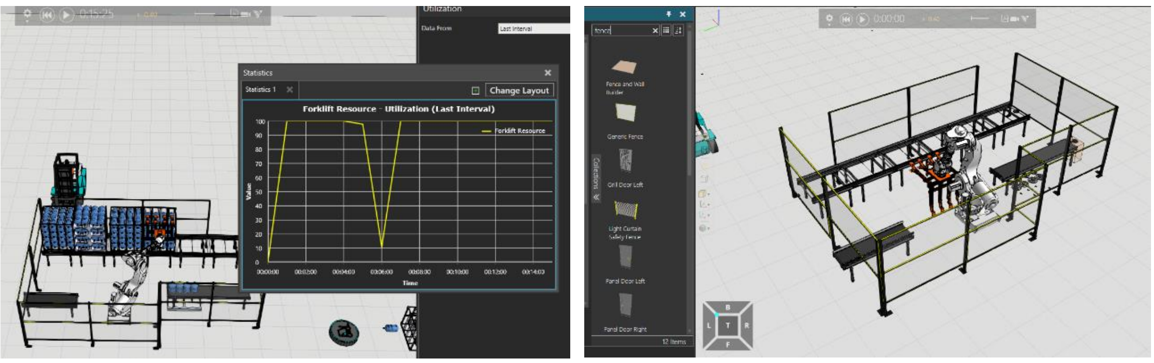


Fig. 5.3: Simulation models of robotic workplace in SW Visual Components

5.2. Significant Cooperation with Foreign Partners

Slovakia

- Technical University of Košice, Facult of Mechanical Engineering,
- Slovak Technical University of Bratislava - Faculty of Materials Science and Technology.

Poland

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

Austria

- University Innsbruck, Unit Geometry and CAD, Innsbruck.

Finland

- Department of Mechanical Engineering, Lappeenranta University of Technology.

6. SCIENCE-RESEARCH ACTIVITIES

6.1. Currently Solved Projects

Name	Period	Budget (Euro)
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)
The use of digitalisation in the design of robotic systems	2022	40,4k
National Competence Centre of Mechatronics and Smart Technologies for Mechanical Engineering	2021-2022	0,6M

6.2. 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 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. Automation System for the Design of Industrial Robots and Manipulators

As part of research into advanced mechatronic systems, a system for automating the design of robotic arms and manipulators was further developed. A block diagram describing the basic steps of the design process is shown in Fig. 6.1.

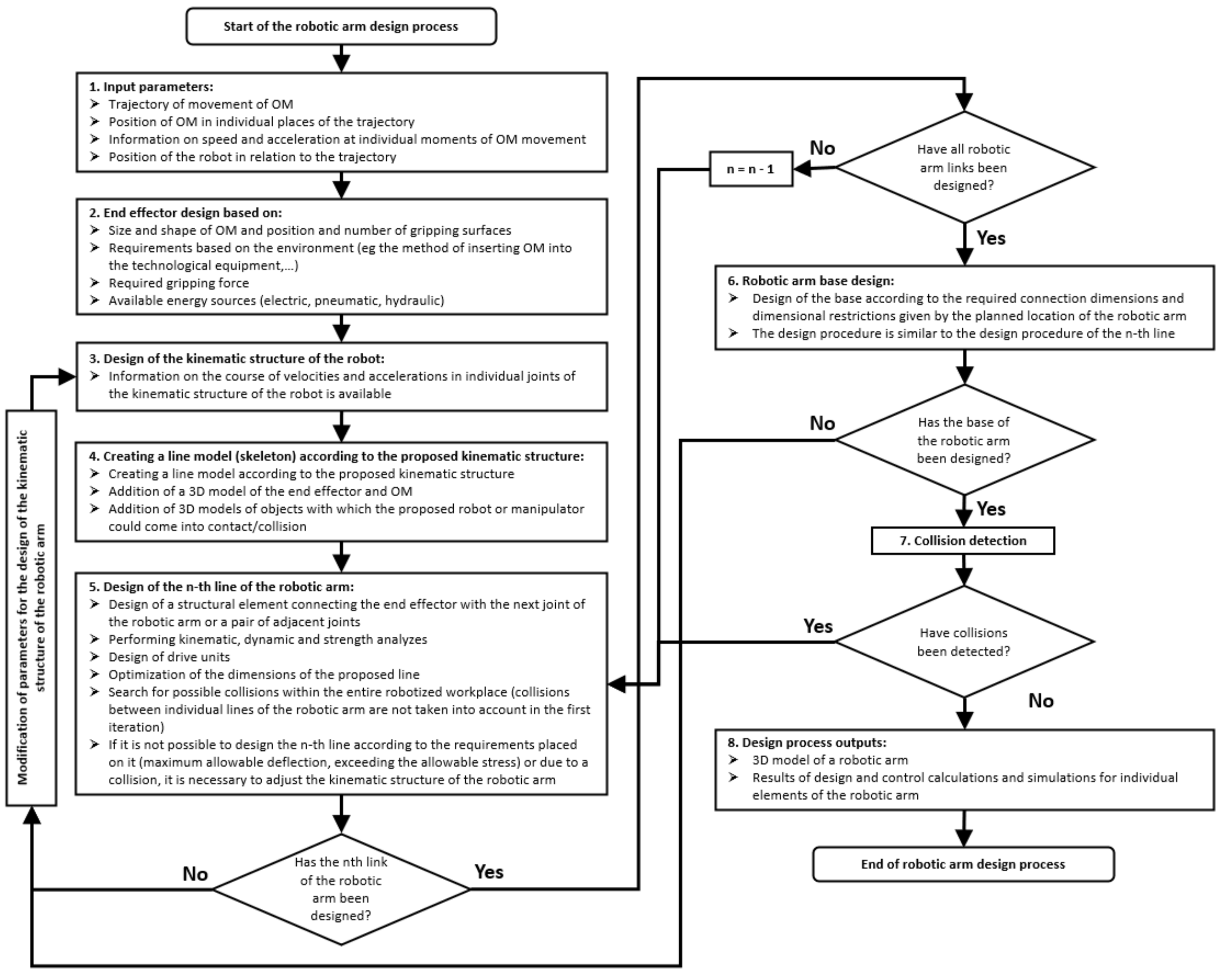


Fig. 6.1: Block diagram describing the automatic design process of robotic arms and manipulators

Based on the designed kinematic structures, individual elements of robotic arms and manipulators are gradually designed and optimized. The previously created software tools for the designs of power units and links of the proposed equipment were gradually improved. Software tools were newly developed, with the help of which it is possible, for example, to automate the process of creating simulation models in the CoppeliaSim software environment, to perform strength analyzes and dimensional optimization of individual structural elements in the CAD system SolidWorks, or to perform analyzes from the point of view of possible collisions in the same CAD system. These software tools were subsequently converted into the following six basic modules, which can be accessed via a web interface:

- Drive Picker
- Modeller (creating and editing 3D models)
- Robot Arm Profile Designer (design of support cross sections of robot arm links)
- Structural Analysis Module (strength control of parts and optimization of dimensions)
- Motion Analysis Module (motion analyzes of robotic arms)
- Knowledge database (database of 3D models, power units, ...)

The software tool Robot Arm Designer is in charge of their interconnection and the overall data report, with the help of which it is possible to fully automate the process of designing robotic arms and manipulators. The block diagram of this tool is in Fig. 6.2.

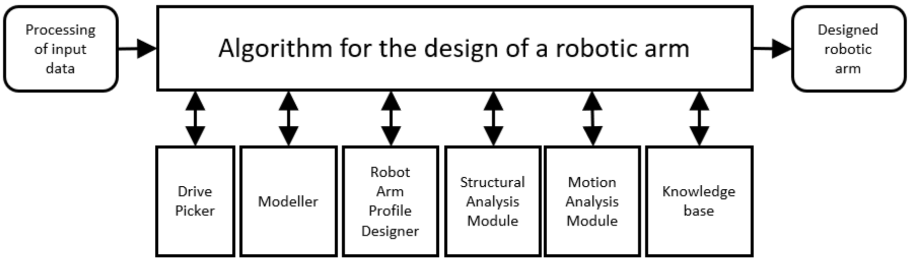


Fig. 6.2: Block diagram of the Robot Arm Designer software tool

The following articles were published in connection with the solution of this issue:

- Pastor, R., Mihola, M., Zeman, Z., Boleslavský, A. Knowledge-Based Automated Mechanical Design of a Robot Manipulator. *Applied Sciences*. 2022, 12(12), 5897.
- Zeman, Z., Mihola, M., Suder, J., Boleslavský, A. Automation of Partial Tasks in the Design of Robotic Arms. *MM Science Journal*. 2022, issue March, pp. 5513-5521. ISSN 1803-3126.
- Boleslavský, A., Mihola, M., Wierbica, R., Bém, J., Spurný, T. Research and Development of a Software Tool for Parametric Modeling of Robotized Workplaces. *MM Science Journal*. 2022, issue June, pp. 5675-5683. ISSN 1803-3126.
- Mihola, M., Zeman, Z., Boleslavský, A., Bém, J., Pastor, R., Fojtík, D. Automation of Design of Robotic Arm. MM Science Journal. 2022, issue October, pp. 5876-5882. ISSN 1803-3126.

As part of the testing, the individual modules of this software tool were used in the design of four robotic arms. The two arms were based on Dynamixel P-series power units, and its construction made substantial use of plastics and 3D printing technology. In Fig. 6.3a is a kinematic diagram of one of these robotic arms, on the basis of which a complete structural design was created (Fig. 6.3b). Then the arm designed in this way was manufactured, assembled, animated and subsequently tested (Fig. 6.3c).

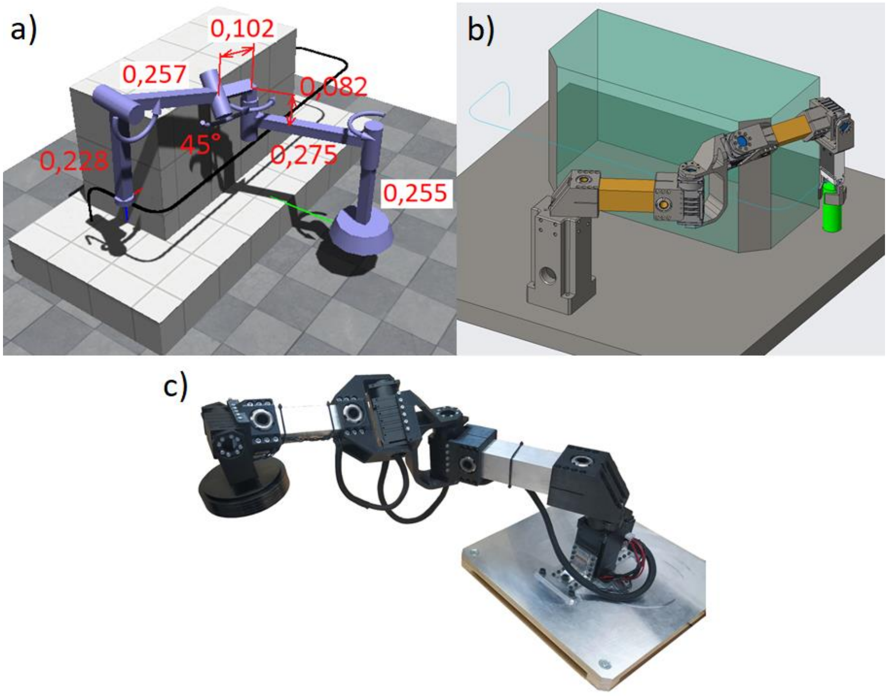


Fig. 6.3: Design procedure of the robotic arm V2M2_RD, from the kinematic structure, through the structural design in the form of a 3D model, to the real device

A similar procedure was followed for the other two robotic arms. In these cases, the arms were built on the basis of the Harmonic Drive drive units of the BDA series. Structural elements were mainly made of aluminum alloy. In Fig. 6.4 again shows the initial kinematic structure of the arm, its structural design in the form of a 3D model and the manufactured and assembled robotic arm itself.

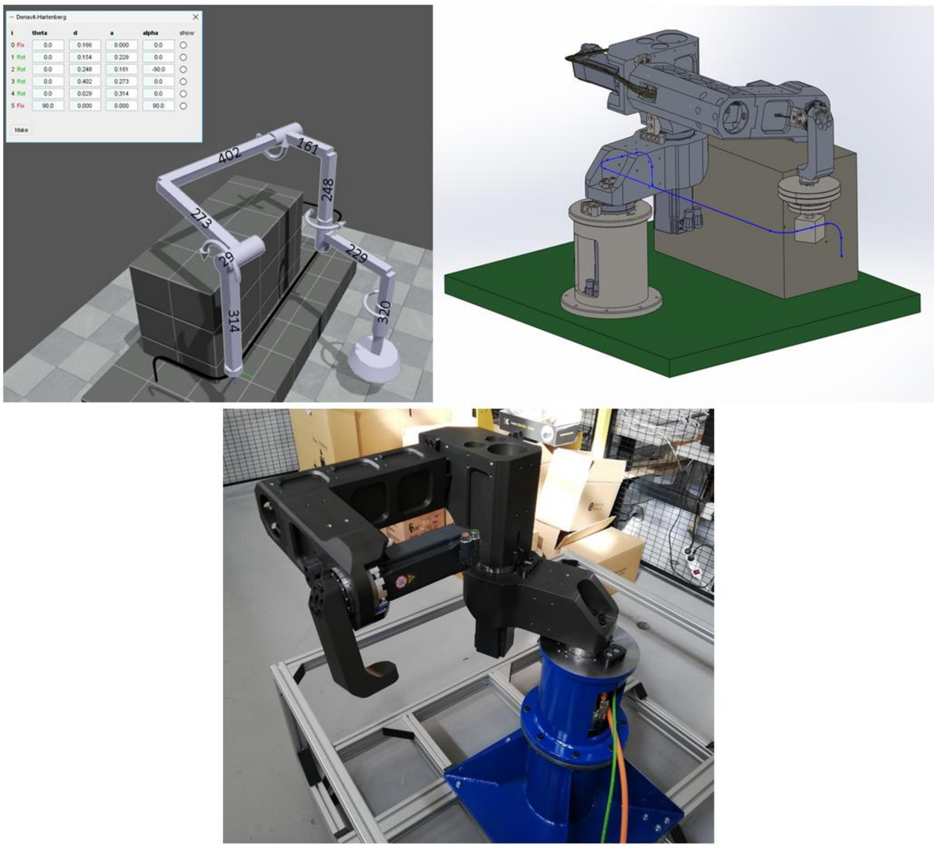


Fig. 6.4: Design procedure of the robotic arm V2M3_HD, from the kinematic structure, through the structural design in the form of a 3D model, to the real device

6.2.2. Automatic Design of a Robotic Manipulator

An automatic system was built for the design of the manipulator following the "Knowledge-based systems" methodology according to the current literature. However, instead of simply designing the kinematics or optimizing the dimensions, which are addressed in most of the literature on the subject, our system is capable of automatically creating the entire arm including CAD models, assembly and drawings.

The design starts by defining the trajectory as a set of points in space with an associated time step. Next, the collision volumes are used to build a working environment and parameters for the genetic algorithm are determined. This algorithm then builds the manipulators and tests their kinematics in the environment. The optimized manipulator is the local optimum in the available search space.

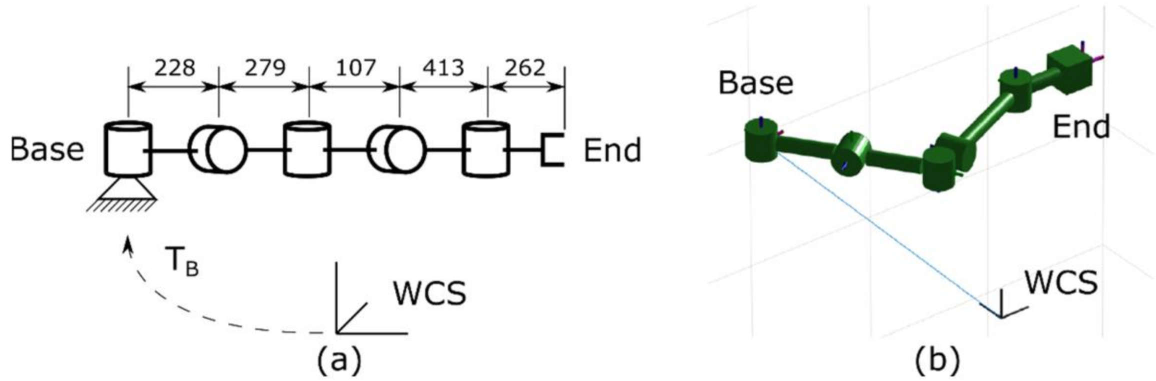


Fig. 6.5: Example of optimized manipulator kinematics

Next, the optimised kinematic structure is processed by a system that places machine parts on top of it. The actuators and brackets are pre-prepared in a database and the system selects the smallest and lightest parts so that the manipulator still meets the performance and strength requirements. This is an iterative process where the system automatically assigns the lightest parts at the beginning and then scales them up if they do not pass in the analyses. The iterative process repeats until the parts fail or the database runs out of parts. During these iterations, parts are tested by strength, collision, and dynamic analysis.

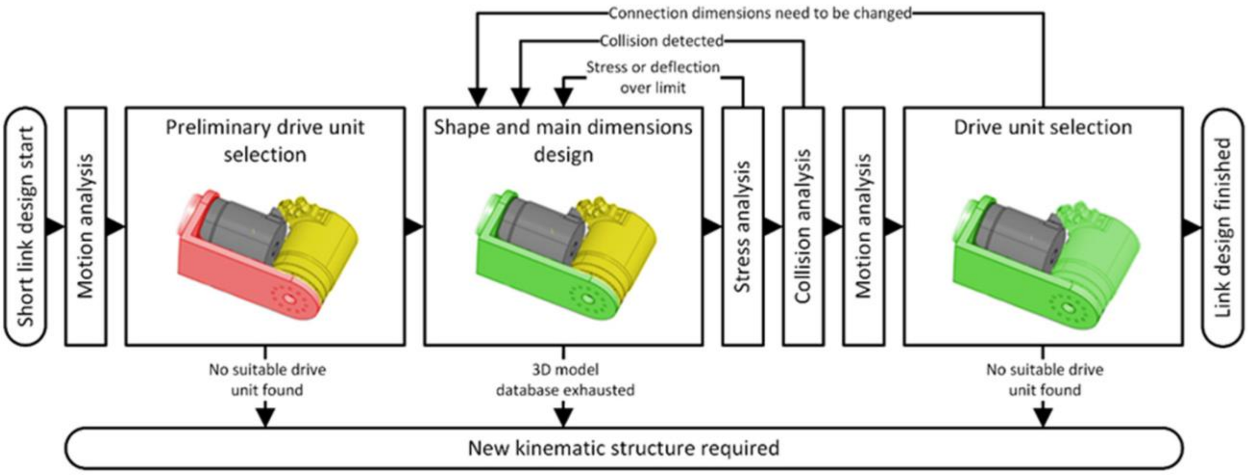


Fig. 6.6: Procedure for automatic design of manipulator parts

6.2.3. Implementation of an Industrial Robot into the IoT

This chapter describes the principle of the proposed loop system, which is used to collect data on the irb1600 industrial robot and distribute the information back to the peripherals. The system consists of two paths, internal and external. The proposed paths are used to route the collected data to the cloud system ThingWorx. Thingworx is used for this application as a data repository and data processing tool. The data is stored for the sake of long term observation and exploring the dependencies. By long-term monitoring of this data, it is possible to predict and prevent, for example, an impending failure of an industrial robot. Thus, downtimes could be planned efficiently on the production line. Long-term monitoring can also point to certain trends - for example in energy consumption. In contrast to long-term monitoring, post-processing involves the immediate evaluation of data, making the system able to react to certain situations immediately. When monitoring the oscillation of the robot's last joint, the system can reduce the speed and thus partially compensate for the overall docking. Basically, the idea of the whole system is to dynamically control the robot's behavior based on both long-term monitored data and data collected in real time. The data can also be visualized. This is implemented using the environment created in Thingworx or in augmented reality. The software tool Vuforia is used for visualization in augmented reality.

The control unit of the industrial robot enables the collection of data from the joints of the industrial robot. These are the parameters of joint speed, joint torque and joint position. This data is read and written in the control unit in a loop. The data is then published to the network using an OPC server. The OPC server is connected to the Kepware middleware, which then sends the data to Thingworx. The middleware ensures the "readability" of the data for Thingworx. This path is also used to send data back from the cloud to the robot controller. It is thus possible to override the parameters that control the robot's behavior.

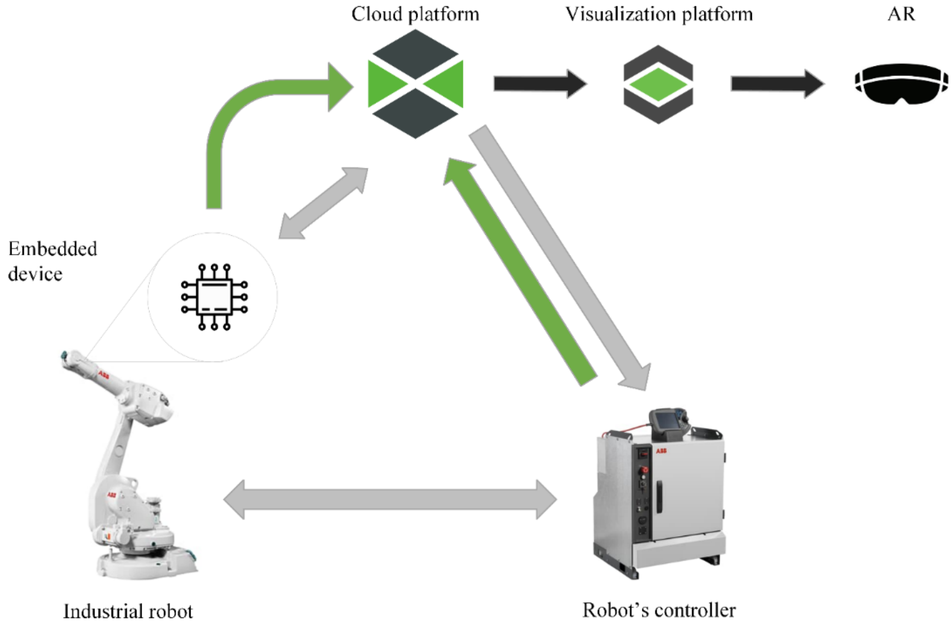


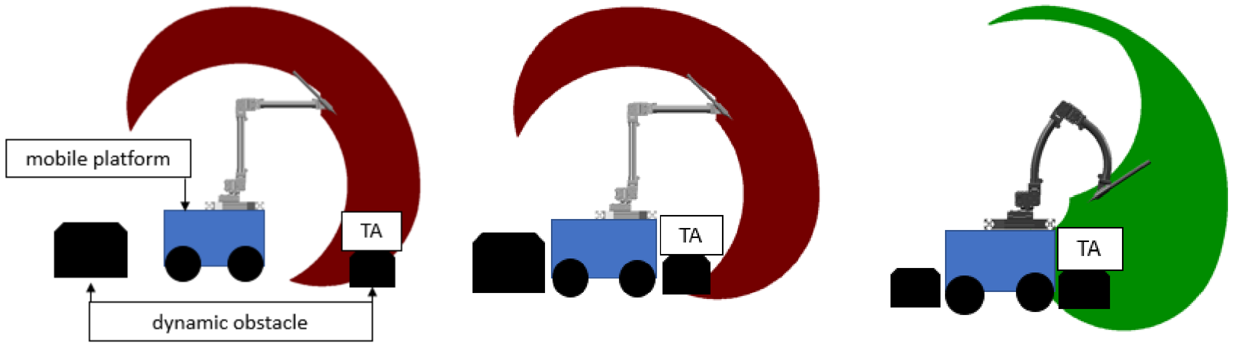
Fig. 6.7: The diagram in the figure describes the principle of data flow in the proposed loop systém

In order to expand the number of monitored parameters, an embedded system was designed that collects data directly on the robot. This provides additional information not only about the robot, but also about the robot environment in which it operates. This system is described in detail in the paper:

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

6.2.4. Shape Adjustable Links of Robotic Systems

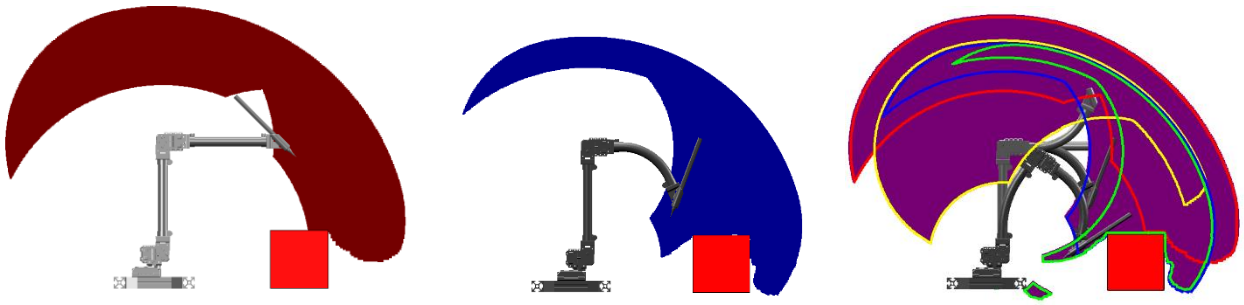
Manipulators with a rigid kinematic structure are not flexible, they do not adapt to specific tasks where a change in the shape of the workspace is required. This can very often occur with manipulators on a mobile platform see. Fig. 6.8a, where the task area (TA) is usually not clearly defined. There can be situations where the mobile platform and kinematic structure of the manipulator is unable to reach the task area due to obstacles in the environment Fig. 6.8b. Then changing the shape of the links can change the shape of the working envelope so that the manipulator can reach the task area again Fig. 6.8c.



(a) (b) (c)

Fig. 6.8: (a) manipulator with straight links on a mobile platform with TA in the working envelope; (b) manipulator with straight links on a mobile platform in a built-up area with TA outside the working envelope (c) manipulator with shaped links on a mobile platform in a built-up area with TA in the working envelope

Shape Adjustable Links of Robotic Systems at this stage is concerned with the effect of the shape of the links on the working envelope of the manipulator. On its size and shape. How the shape of the links in the structure affects the reach around the inserted obstacle into the working envelope Fig. 6.9. Next, it investigates the effect of the shape of the manipulator in executing the specified trajectory.



(a) (b) (c)

Fig. 6.9: (a) manipulator working envelope with straight links around the obstacle; (b) manipulator working envelope with a shaped link around the obstacle (c) combined manipulator working envelope with shape adjustable manipulator links

The research is described in the paper:

MLOTEK, Jakub, BOBOVSKÝ, Zdenko, SUDER, Jiří, OŠČÁDAL, Petr, VOCETKA, Michal a KRYS, Václav. Shape-Changing Manipulator Possibilities and the Effect of the Deformable Segment on the Size of the Working Area. In *Mechanisms and Machine Science*. 2022. pp. 272-280. ISBN 9783031048692. ISSN 2211-1098. e-ISSN 2211-1099.

6.2.5. 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).

One method proposed in the Department of Robotics uses a modified trajectory planning algorithm called *elastic band*, which is typically used for trajectory planning of a mobile robot or autonomous vehicle. Our modification allows its use for real-time control of the manipulator arm, while the arm dynamically responds to moving obstacles. The principle of the elastic band is that the trajectory is represented by an imaginary rubber band stretched between the origin and the destination points (the use is for common pick & place handling tasks, where only the position of the pick and store point matters, not the shape of the trajectory between them), where internal compression forces keep the trajectory naturally in the shortest possible shape, i.e. a straight line. Obstacles detected by the camera system and represented as a set of voxels repel the elastic band, creating the shortest possible smooth curve around these obstacles.

The following figure shows a simulated simplified example where the robot moves between two points along a straight line (from left to right) and during this movement a human hand moves into the trajectory space from the front. The blue curve expresses the instantaneous actual trajectory (capturing the dynamic response to the hand movement), while the purple curve expresses the stabilised state of the trajectory (after the hand movement is completed and kept in place).

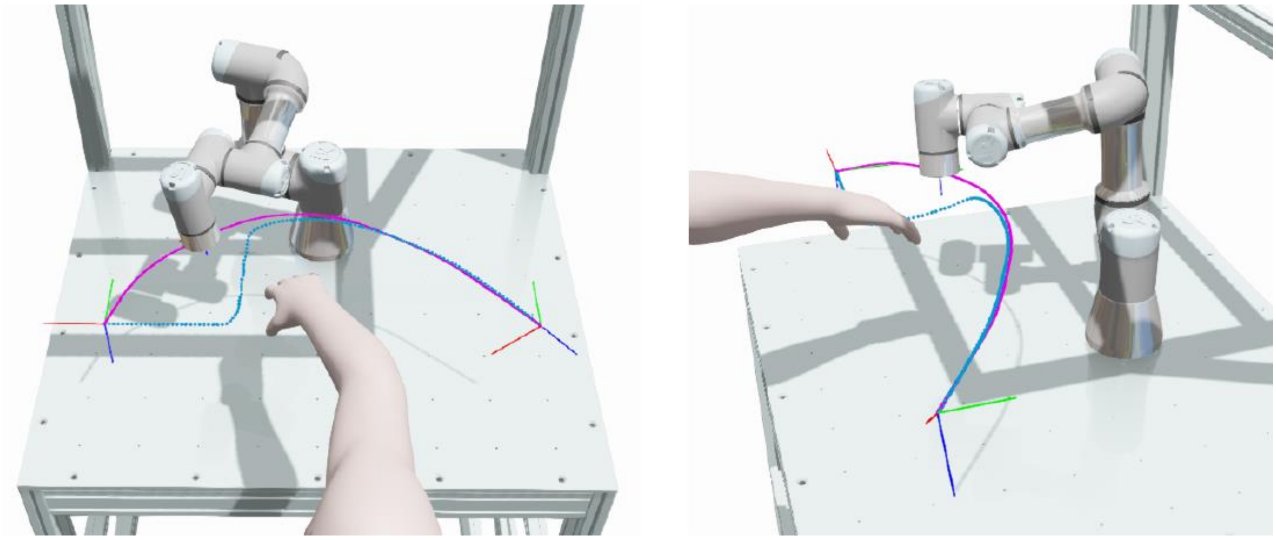


Fig. 6.10: Simulated demonstration of the principle of the elastic band method for avoiding dynamic obstacles

This research was carried out within the project Platform for Industry 4.0 and Robotics Research in the Ostrava agglomeration (CZ.02.1.01/0.0/0.0/17_049/0008425), the results were published in an impact journal:

KOT, Tomáš, WIERBICA, Rostislav, OŠČÁDAL, Petr, SPURNÝ, Tomáš a BOBOVSKÝ, Zdenko. Using Elastic Bands for Collision Avoidance in Collaborative Robotics. *IEEE Access*. 2022. vol 10, pp. 106972-106987. ISSN 2169-3536.

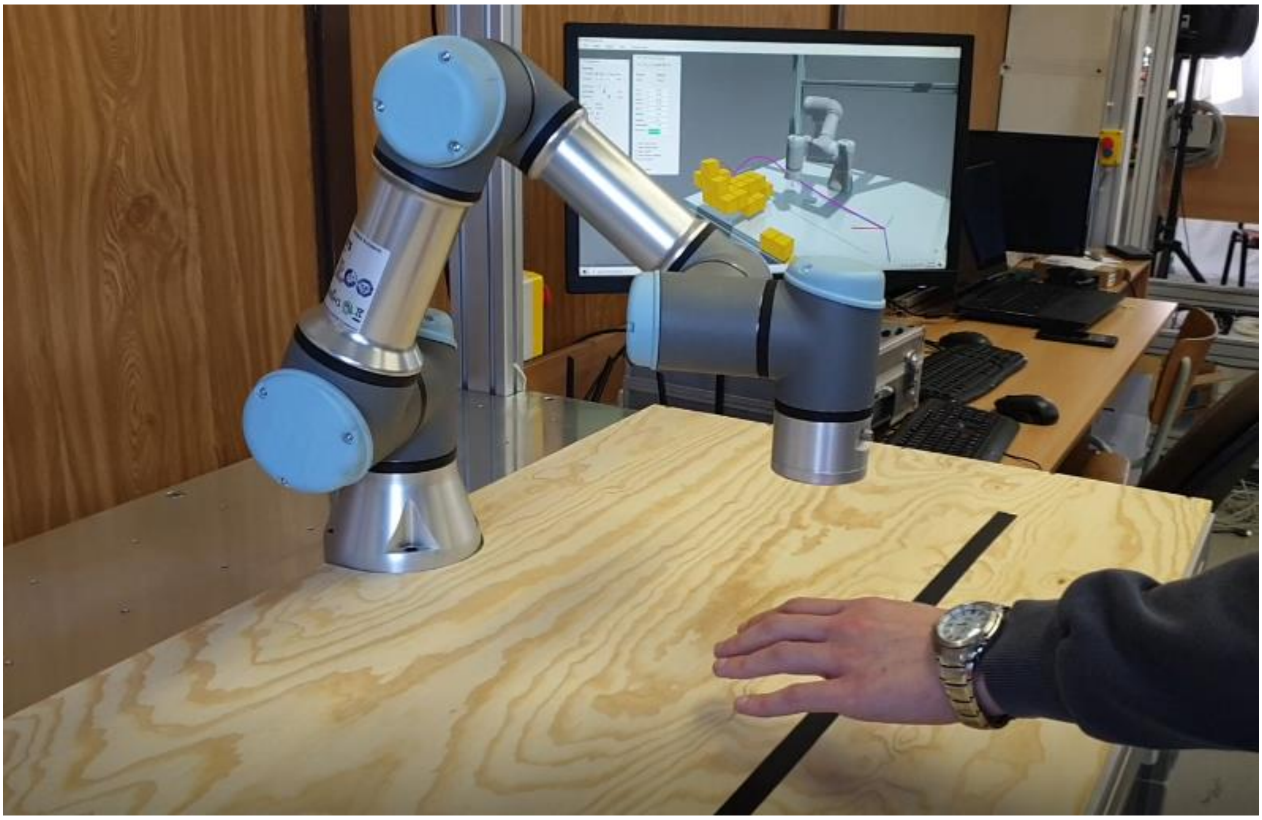


Fig. 6.11: Demonstration of the dynamic obstacle avoidance control system on a real robot UR3

6.2.6. Training a Model for Color-independent Hand Segmentation from RGB-D Camera Images Based on Neural Networks

In an industrial environment, it is common for users to wear protective gloves. For such conditions, we decided to implement a "color-independent" model for segmentation based on color and depth images acquired from a real camera. This goal was set due to the fact that commonly available modern solutions, such as MediaPipe and OpenPose, have difficulty recognizing gloved hands, especially when the rest of the human body is out of camera view. To solve this problem, we decided to implement a custom instance segmentation model that would work stably with gloves of any color.

Instance segmentation is related to the task of segregating objects in an image by defining their boundaries and the pixels that relate to them (in the case of 2D images). It is widely used in real-world applications such as self-driving cars, medical imaging, aerial crop monitoring and others.

The most important step in training a machine learning model is to obtain a considerably large dataset to represent real situations with sufficient accuracy over a wide range of circumstances and contexts. A typical approach to obtaining such a dataset is to manually label the search region for tens or hundreds of thousands of images or to use a third-party labeled dataset available on various platforms. The labeled search region along with the original images can then be used to train a customized neural network.

However, we chose to take a different approach, where both the camera images and their labels are synthesized in the simulation.

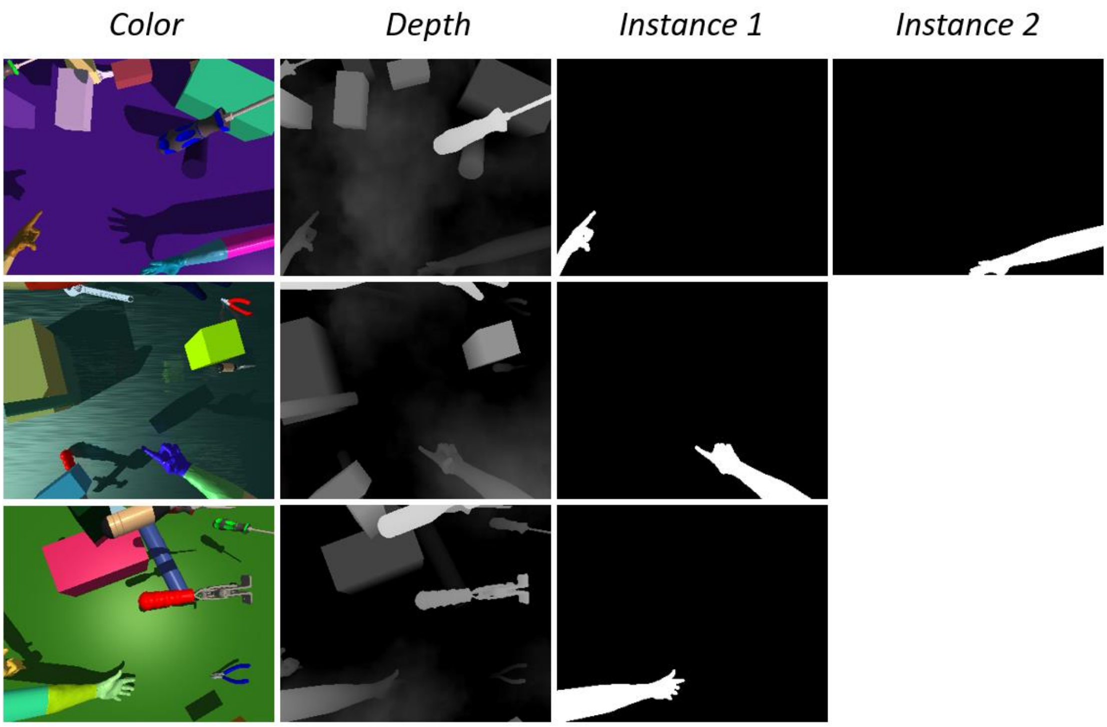


Fig. 6.12: Sample images from the generated dataset. Each row represents the components of the sample dataset

In addition to avoiding tedious manual labeling, generating images in simulation has the added benefit of allowing the use of the Domain Randomization technique, which can significantly affect the ability of the trained model to generalize to important domain features. In our simulation, we randomize the following parameters: hand position and obstacles; their size; glove and background color; lighting conditions; and hand gesture.

The simulation scene created in CoppeliaSim is based on previous research where we used the platform to generate depth images for training image segmentation models. The dataset generator has been significantly extended and currently covers the following cases:

- One hand is present in the camera view;
- Two hands in the frame;
- A hand lying on a box;
- No hands in the frame, with a randomly positioned and articulated mannequin

The architectures tested included two state-of-the-art instance segmentation models, each with two variations in the size of the default structure:

- Mask R-CNN (backbones: Resnet50, ResNet101)
- SOLOv2 (backbones: Resnet50, ResNet101).

The results of models trained purely on the synthetic dataset matched and outperformed the SOTA solution. For example, compared to Mediapipe in our conditions, our result in the $AP_{0.5:0.95}$ parameter is as high as 52% compared to 17% for Mediapipe.

Fig. 6.13 Typical results obtained from an opaque industrial scene with RGB-D input (RealSense D435i) and SOLOv2 ResNet50

We also measured the inference time and associated frequency of image processing results for the RGB-D models.

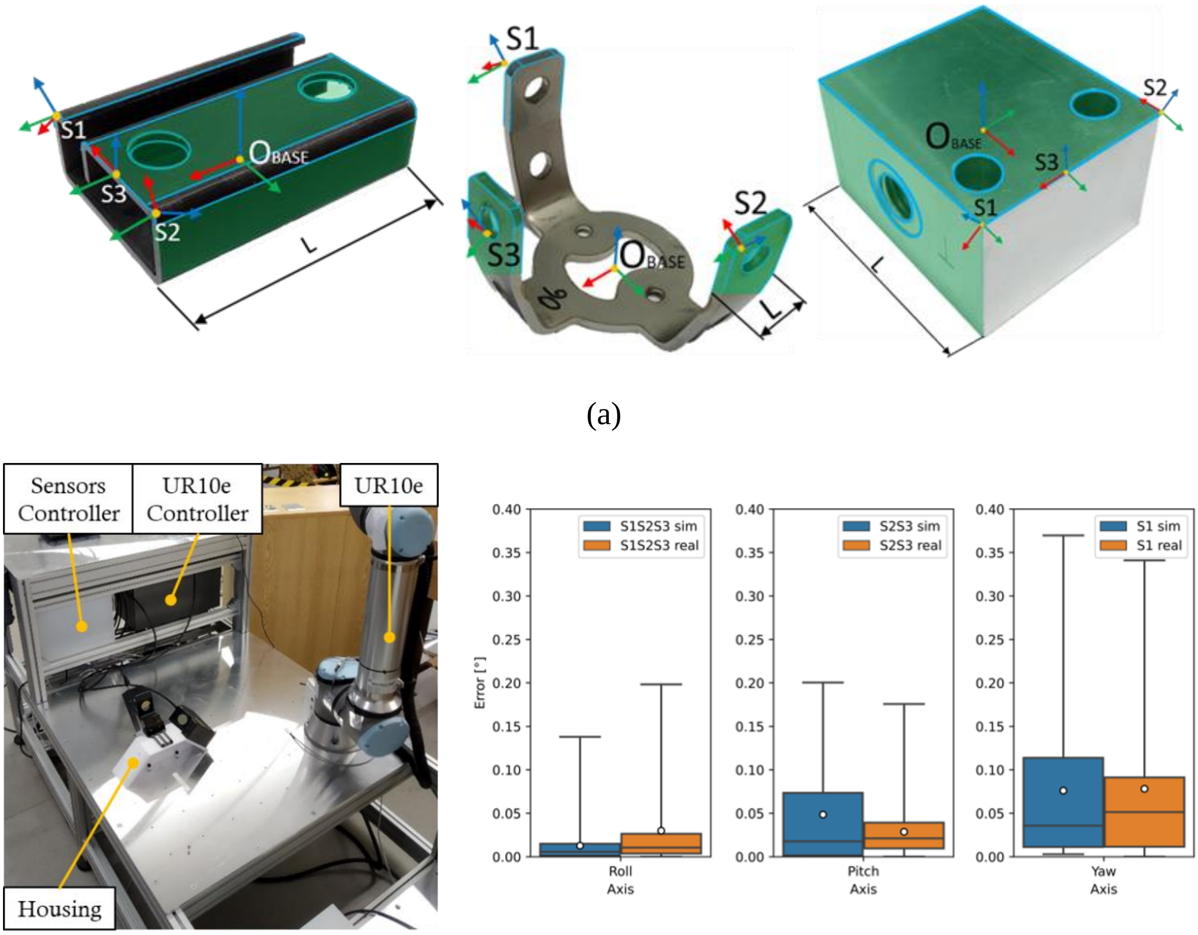
Tab. 6.1: Inference time values for RGB-D models

Model (RGB-D input)	Frequency of image display
SOLOv2 ResNet50	14 FPS
SOLOv2 ResNet101	11 FPS
Mask R-CNN ResNet50	9 FPS
Mask R-CNN ResNet101	8 FPS

6.2.7. Finding the Optimal Pose of 2D LLT Sensors to Improve Object Pose Estimation

In industrial manufacturing, accuracy and precision requirements in assembly and manipulation of objects keep increasing. For a precise assembly performed by an industrial robot, it is important to define the object's picking point and orientation so that the robot can accurately grasp the object and perform the assembly. These solutions are used for pick-and-place applications, such as unloading parts from a box or bin onto a conveyor or other device, where objects are aligned with various fixtures into precise picking positions. This time-consuming intermediate step can be eliminated by estimating the position of the object in the robot's gripper, and the required task can be performed immediately after grasping the OM. For accurate estimation of object position using the ICP algorithm, relevant data such as surfaces, edges, rounds, and other geometric primitives are important, as shown in figure (a) below. Finding the optimal position of LLT sensors for scanning these features would be very time consuming in a real environment, therefore a simulation environment was created to speed up this process. The methodology of placing the sensors relative to the scanned object can lead to minimizing the number of sensors used while keeping or increasing the accuracy of the pose estimation. The results of the simulation were verified on the UR10e robot workplace shown in figure (b) below. The pose estimation on the real system was very similar to that from the simulation environment, see figure (c). The research is described in detail in the paper:

HECZKO, Dominik, Petr OŠČÁDAL, Tomáš KOT, Adam BOLESLAVSKÝ, Václav KRYS, Jan BÉM, Ivan VIRGALA a Zdenko BOBOVSKÝ. Finding the Optimal Pose of 2D LLT Sensors to Improve Object Pose Estimation. Sensors. 2022, **22**(4). ISSN 1424-8220. Available at: doi:10.3390/s22041536.



(a)

(b) (c)

Fig 6.14: (a) objects for the experiment; (b) experimental workplace; (c) comparison of simulation and real measurements.

6.2.8. Workplace Obstacle Detection for Human-robot Collaboration

Workspace monitoring is one of the essential elements for a workplace where a hu-man is considered to interact with a robot. Reconstructing dynamic objects in the work-place can ensure safety for the operator and smooth operation of the workplace because the robot can react to changes in the free space for movement. The workplace reconstruc-tion process is standard through packages in the Robotic Operation System (ROS). These packages are designed for universal use. However, this has the effect of centralizing the computing power into a single device. Such a solution is less suitable for processing large volumes of data from multiple sensors because the user does not have a complete control over the computational processes.

Therefore, a new principle has been proposed that distributes the computational power among the individual devices. Each processing device allows filtering of the locally sensed data. The filtering is based on a 3D description of the workplace and the creation of a density camera depth map for each camera separately from their point of view. Filtering compares the actual depth map from the sensor and the calculated density depth map. The resulting data are information about undefined obstacles (arm, boxes etc.). These obstacles are subsequently processed by noise filtering. The resulting data from the individual distributed devices are combined in the main computer, which produces an overall description of the entire sensed workspace (Fig. 6.15).

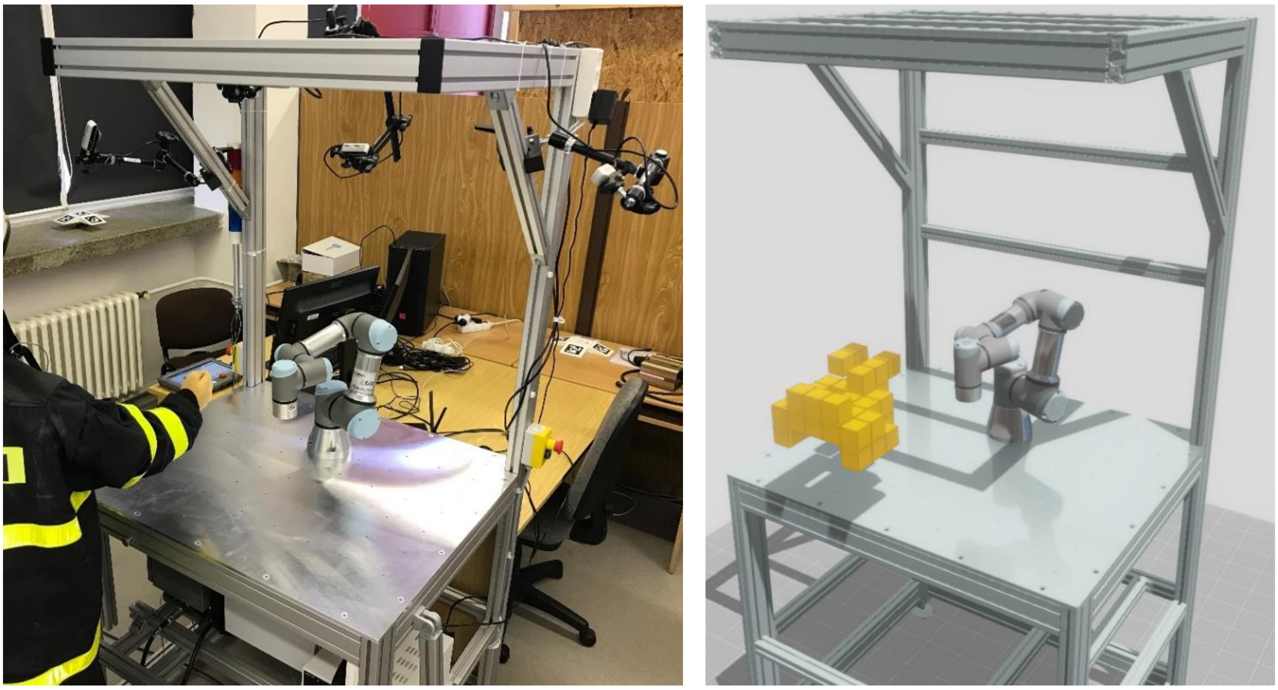


Fig. 6.15: Obstacle detection in the workplace with UR3 robot (a) real workplace with obstacles; (b) visualization of obstacles - yellow boxes

Using a distributed system, the calculation of dynamic obstacles can be minimized to under 30 ms. Thus, all camera data can be processed online using a 30 fps stream. The description of obstacles at the workplace can be further processed to re-plan the robot trajectory or to stop the robot completely to avoid endangering the operator or damaging the system. This issue was addressed within the project Platform for Industry 4.0 and Robotics Research in the Ostrava agglomeration and published in the following paper:

OŠČÁDAL, Petr, SPURNÝ, Tomáš, KOT, Tomáš, GRUSHKO, Stefan, SUDER, Jiří, HECZKO, Dominik, NOVÁK, Petr a BOBOVSKÝ, Zdenko. Distributed Camera Subsystem for Obstacle Detection. *Sensors*. 2022, 22(12), 4588.

6.2.9. Optimisation of the Number of Cameras on the Robotic Workstation

Optimizing the number of cameras in a robotic workplace deals with finding the optimal number of cameras to best monitor a given area. This process can be handled in different ways depending on the specific needs and requirements. One option is to use simulation or mathematical modelling to create a virtual model of the workplace and investigate what number of cameras is necessary to provide the best possible coverage. This can help determine the most appropriate locations for camera placement and ensure that they are as effective as possible. It is important to consider a variety of factors such as the size of the workplace, the footage and image resolution requirements, the technology available and the risk of injury.

Our research has developed a methodology for optimising the number of cameras for robotic workplaces. This methodology is based on the classification of the space (Fig. 6.16) into different types of activities that take place in the workplace. By evaluating these activities, we were able to identify critical areas for which increased camera surveillance is required. Based on this information, we designed an optimal configuration of cameras to ensure a sufficient level of coverage of the workspace.

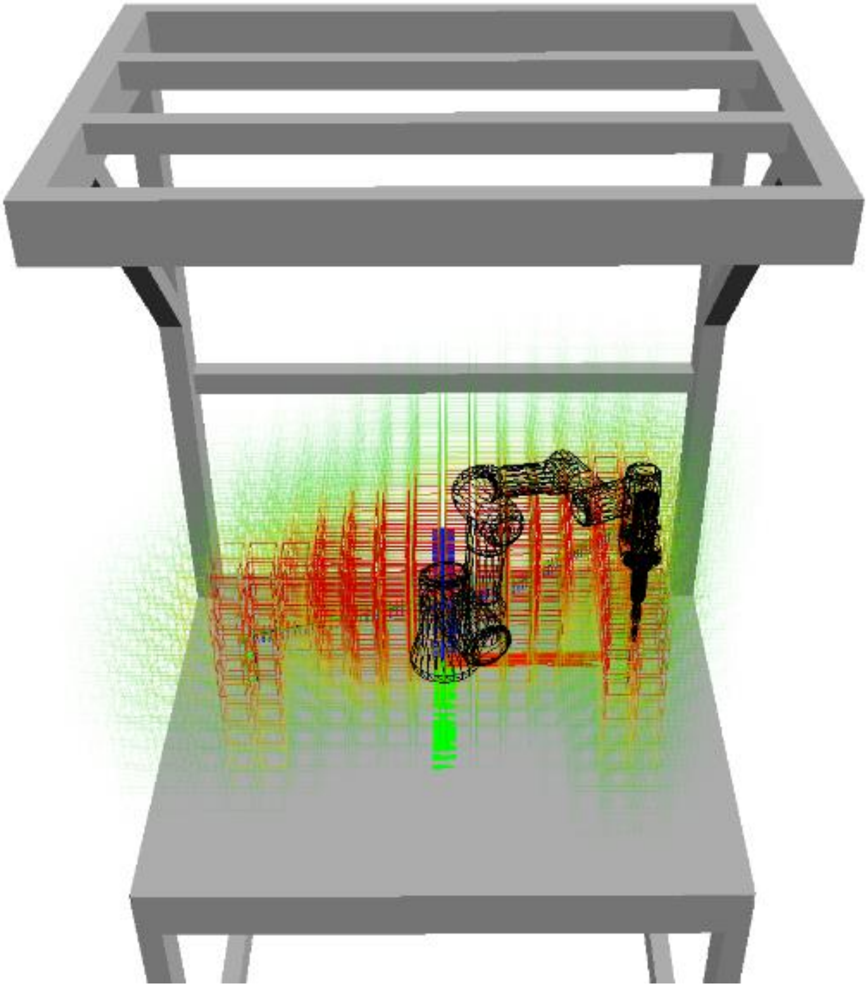


Fig. 6.16: Space classification (red boxes represent critical space)

A real experiment showed that the mathematical model can design the placement of cameras in our test site to capture an average of 37 % more area using one camera, 27 % more using two cameras, and 13% more using three cameras.

This issue has been published in the following paper:

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

6.2.10. DGS 2022

The project of the Doctoral grant competition "Development and optimization of rehabilitation devices" was divided into several main activities. The project is focused on the improvement and development of rehabilitation device for lower limbs. Device will be used for rehabilitation of patients after polytraumatic injuries, whose recovery requires a long-term rehabilitation process. There is a large number of these patients, and the workforce of rehabilitation workers is limited by time and physical demand. For this reason, there is almost impossible to provide better patient care.

Aim of this project is to develop fully automated rehabilitation device, which will accelerate recovery after complicated injury and will prevent possible physical disabilities (e.g. equinus contracture of Achilles tendon) caused by non-rehabilitation. Emphasis is on automatic and autonomous procedure. With that lowering the load of the hospital work forces while rehabilitating more patients at the same time with customized intention should be achieved.

Selection of the main activities of the project:

- Cooperation with experts from traumatology and rehabilitation departments of University Hospital of Ostrava.
- Increased knowledge in the field of rehabilitation and traumatology.
- Parameters for the correct functioning of the selected mechanism.
- Device design and functional simulation of desired movement.
- Results from necessary tests.
- Functional prototype of developed device.
- Design of a software application (precise and safe control strategy).
- Research report.

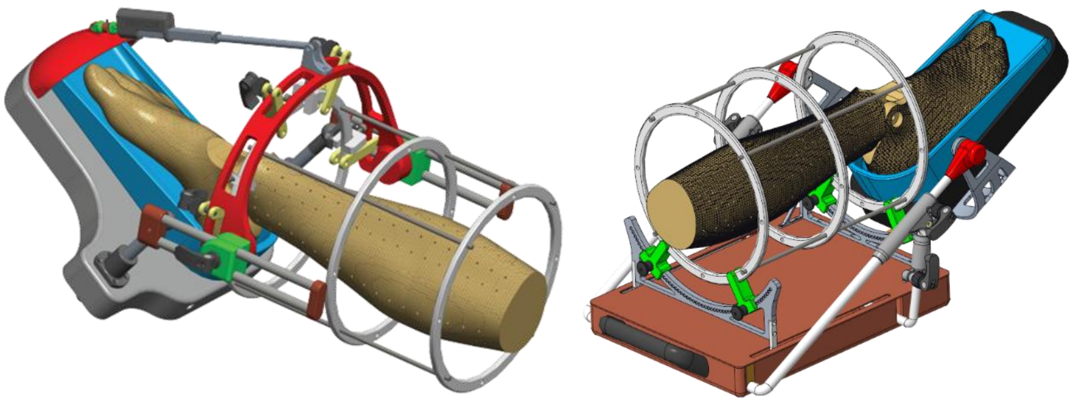


Fig. 6.17: Two variants of the proposed solution

6.2.11. Demonstrator of the Synthesis of Kinematic Structure Algorithm

Custom manipulators with arbitrary kinematic structure can be deployed in workplaces where typical 6-axis robot is energy costly or due to collisions with itself or the environment cannot be deployed at all. Our department developed an algorithm which can synthesize the kinematic structure (provide the optimal kinematic parameters), perform collision analysis, and suggest placement of motors and shape of links to build a custom robot that can fulfil a given task.

The algorithm applies fast local-minimum optimization and at the same time allows one to overcome a resulting minimum by re-optimization with altered robot kinematic representation (Denavit-Hartenberg notation, Product of Exponentials, or Tait-Bryan angles with translational parameters) or by changing the constraints formulation. Additionally, it was proven that the mathematical specification of constraints has a significant impact on the convergence of the synthesis. As part of the project work, a demonstration 3-revolute manipulator, which is able to achieve three positions in a collision environment, was also created using the developed algorithms. Its simulation and real assembly can be seen in the figure below. The results were published in IEEE Access journal, and along with a video from the simulation and experiment they are available on the publisher's webpage: https://doi.org/10.1109/ACCESS.2022.3186098.

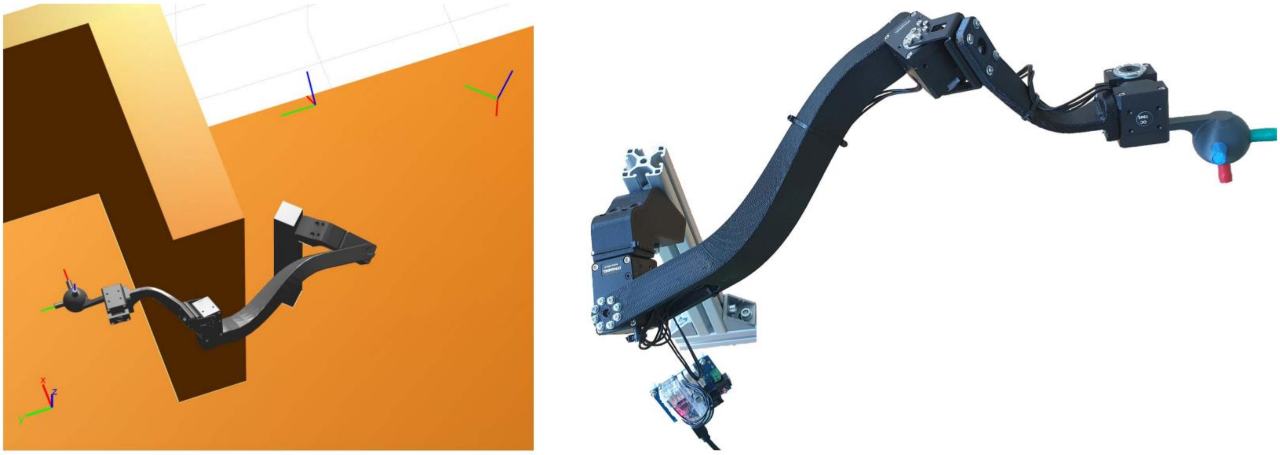


Fig. 6.18: Simulation of custom 3R manipulator (left), the given task (poses in space) is visualized using RGB frames; laboratory assembly of 3R manipulator (right).

Together with related algorithm for the synthesis, an analytical tool for conversion between the three robot kinematic representations was developed. It analyses an input robot representation, express the joints globally in matrix form, and map it to other representations with a possibility to generate a URDF (Unified Robot Description Format) file from any of them, so it can be easily inserted to a simulation software of that supports it. It works for revolute and prismatic joints and can interpret even arbitrary kinematic structures that do not have orthogonally placed joints. The algorithms with examples are freely available on the Github repository of the Department of Robotics using the link: https://github.com/robot-vsb-cz/robkin-interpreter

6.3. Finished Projects

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

6.3.1. 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-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.

For more information, please visit:

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

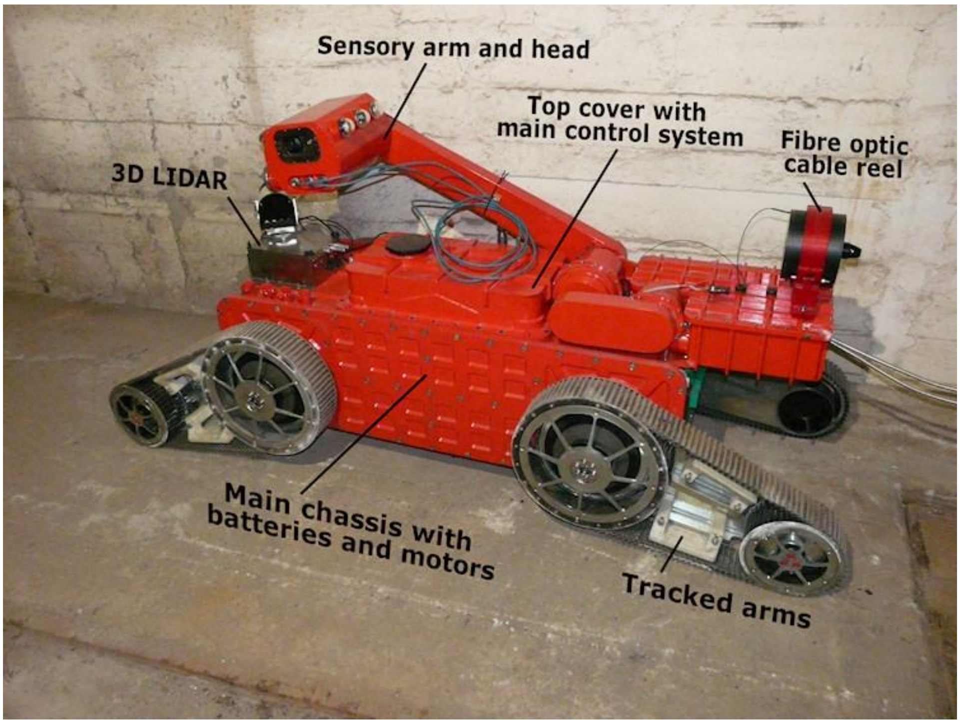


Fig. 6.19: TeleRescuer – main subsystems of the robot

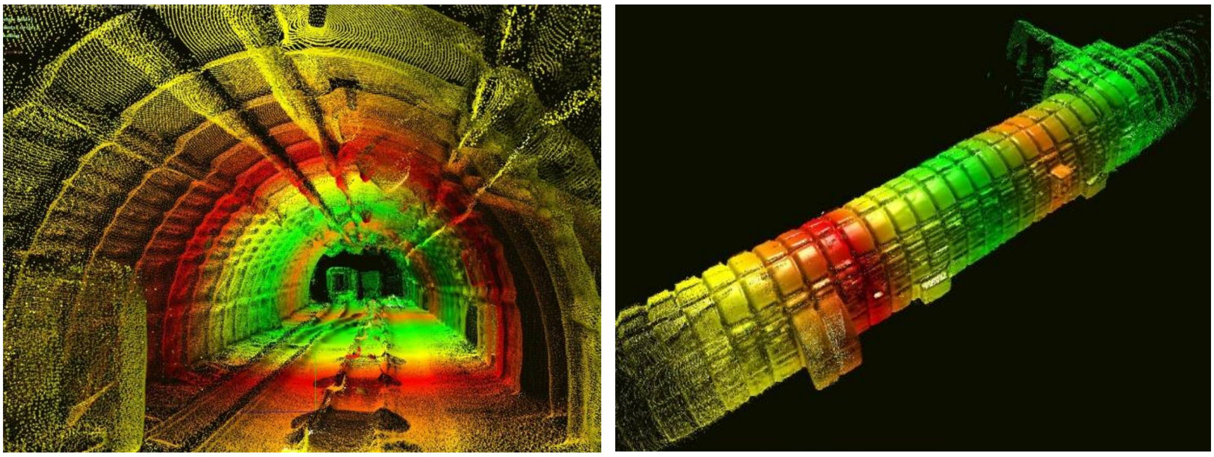


Fig. 6.20: Visualization of a coal mine corridor 3D map (point cloud)

6.3.2. 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.

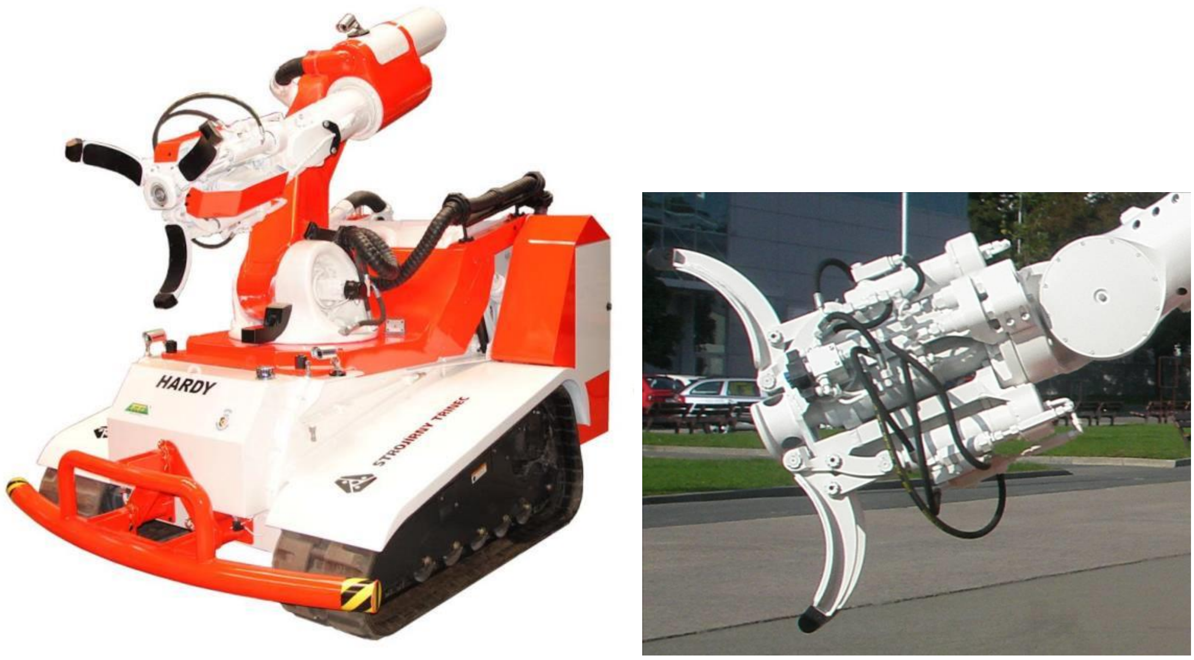


Fig. 6.21: Robot Hardy and its multipurpose gripper with the integrated water nozzle

6.3.3. 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&t=10s

Fig. 6.22: Mobile robot TAROS

6.4. Newly Submitted Projects

Name	Period	Budget (Euro)
Research and development of means of mobile manipulation using digitalisation tools	2023	40,4k
NCK MESTEC2 TN02000010/09 :Development of technologies and equipment for additive manufacturing DVC2: Adaptive 3D printing of systems by a robotic system	2023-2025	250k

Four more project applications are being prepared.

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 workstation was acquired for the needs of the research project Centre for Research on Advanced Mechatronic Systems (CZ.02.1.01/0.0/0.0/16_019/0000867). It is used for functional testing of robot manipulator prototypes designed by the developed algorithms for synthesis of robot kinematic structure. The main components of the workstation are 2 control cabinets for the drive converters of the designed experimental robots and two modular robots with four degrees of freedom. ELVAC, a.s. was the selected supplier of the workplace.

The workstation enables real-time synchronous control of the actuators of two manipulators and can be used to test advanced robot arm control algorithms, including torque control. It consists of a powerful computer with the appropriate communication interface (EtherCAT) and Harmonic Drive motordrivers (three power levels) for controlling the motion units from the same company. The workstation is also equipped with two PLC systems with a number of outputs ready for connecting and testing various robot peripherals.

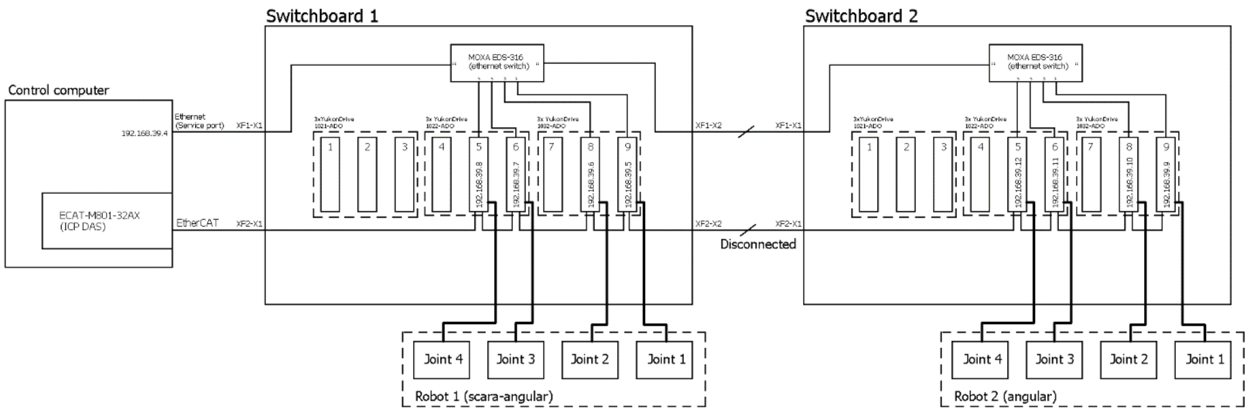


Fig. 6.23: Block diagram of the current test bench configuration

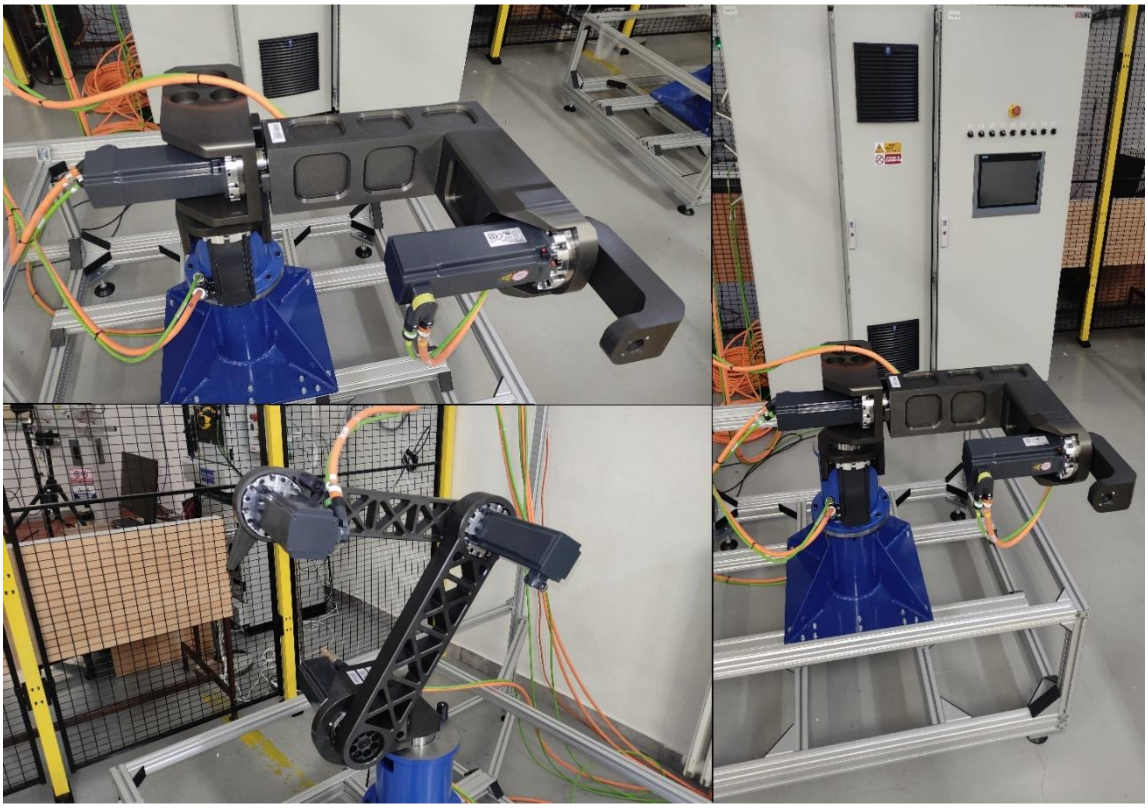


Fig. 6.24: Experimental Robot Test Site

Fig. 6.25: 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 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.
- Robotsystem,
- Elvac,
- ABB robotics,
- IFTSolutions,

7.2. Cooperation with Subjects Abroad

Slovakia

- Technical University of Košice, Slovakia, Mechatronics, internships
- Slovak Technical University of Bratislava - Faculty of Materials Science and Technology,

Poland

- Silesian University of Technology Gliwice, Institute of Fundamentals of Machinery Design – Robotics, Mechatronics, research and educational internships

Austria

- Universitat Innsbruck, Joanneum research – Robotics – internships
- Joanneum research – Institute for Robotics and Mechatronics, Klagenfurt am Wörthersee,
- Carinthia University of Applied Sciences, ADMiRE Centre, Villach

7.3. Abroad stays of teachers, researchers, and students

Workplace	Participants of the stay	Topic	Term
University of Innsbruck, Unit of Geometry and Surveying na University of Innsbruck	Ing. Jiří Suder, Ph.D., Ing. Jakub Mlotek	Boundary deformation region curves of shape-changing links of robotic systems and rod theory methods for boundary deformation region curves.	10. 3. – 22. 3.
Technical University of Sofia	Ing. Adam Boleslavský	Offline programming of robots, deepening knowledge of API in SolidWorks and its use.	24. 5. – 7. 6.
Istanbul Technical University	Ing. Jan Bém, Ing. Adam Boleslavský, Ing. Jakub Chlebek, Ing. Jan Maslowski, Ing. Robert Pastor, Ph.D., Ing. Tomáš Poštulka, Ing. Tomáš Spurný,	Participation in the Anatolian Rover Challenge (ARC) at the Istabul Technical University.	20. 7. - 27. 7.
Lappeenranta University of Technology (LUT), Department of Mechanical Engineering	Ing. Jiří Suder, Ph.D.	Application of nonlinear analysis algorithms of colleagues from Lappeenranta University of Technology to a reconfigurable link manipulator developed by the Department of Robotics.	17. 8. – 15. 9.
Faculty of Materials and Technology, STU, Trnava	Ing. Jan Bém, Ing. Adam Boleslavský, Ing. Jakub Krejčí, Ing. Jakub Mlotek, Ing. Rostislav Wierbica	Deepening knowledge in NX and Tecnomatix software. Creation of a complete robotic workplace.	5. 9. – 9. 9.
Unit of Geometry and Surveying, University of Innsbruck, Austria	Ing. Daniel Huczala, Ph.D.	Development of an algorithm for the synthesis of kinematic structures of robotic manipulators in a collision environment using algebraic methods to accelerate structure optimization.	14. 9. – 18. 10.
Technical University of Košice, Faculty of Mechanical Engineering, Department of Applied Mechanics and Mechanical Engineering	Ing. Jan Bém, Ing. Adam Boleslavský, Ing. Rostislav Wierbica	Simulation models for strength simulations, vibration characterization and dynamic simulations in CAD programs.	3. 10. – 7. 10.
University of Trento, Department of Information Engineering and Computer Science	Ing. Tomáš Spurný	Cooperation development in the field of human-robot interaction.	3. 10. – 14. 10.
Technical University of Košice, Faculty of Mechanical Engineering, Department of Applied Mechanics and Mechanical Engineering	Ing. Jiří Suder, Ph.D.	Analysis of suitable materials for reconfigurable link manipulator. Design of the technological procedure for the application of the most suitable material to obtain the desired properties of the reconfigurable link manipulator.	23. 10. – 1. 11.
University of Montenegro	Ing. Jakub Krejčí	Development of cooperation in the field of IoT devices and wireless communication using the MQTT protocol.	25. 10. – 7. 11.

Technical University of Košice, Faculty of Mechanical Engineering, Department of Manufacturing Technology and Robotics	Ing. Jan Bém, Ing. Adam Boleslavský	Solving the problem of models for strength simulations in SolidWorks and connection with Microsoft Visual Studio.	31. 10. – 4. 11.
Technical University of Košice, Department of Applied Mechanics and Mechanical Engineering	assoc. prof. Ing. Zdenko Bobovský, PhD., Ing. Václav Krys, Ph.D.	Analysis and analysis of results from the measurement of industrial robot parameters using the digital image correlation method and the measurement of service robot parameters using the Pulze system.	31. 10. – 1. 11.
Carinthia University of Applied Sciences, ADMiRE, Villach	Ing. Michal Vocetka, Ph.D., Ing. Jakub Mlotek, Ing. Adam Boleslavský, Ing. Wierbica	Development of cooperation in the field of shape-changing robot links for robotic systems.	21. 11. – 24. 11.
University of Udine Polytechnic Department of Engineering and Architecture	Ing. Aleš Vysocký, Ph.D., Ing. Stefan Grushko, Ph.D., Ing. Robert Pastor, Ph.D.	Presentation of our research. Presentation from the UNIUD on adaptive machine control with tool feedback and structural analysis using neural network.	23. 11. – 24. 11.

7.4. Foreign guests

Workplace	Participants of the stay	Topic	Term
Technical University of Košice	Ing. Varga	Design of redundant link for a shape changing robotic arm	1. 6. – 30. 6.
Technical University of Košice	assoc. prof. Ing. Virgala, PhD.,	The control system of the pneumatic module of the cascade redundant robot	2. 6. – 3. 6.
Slovak Technical University of Bratislava	assoc. prof. Ing. Ružarovský, PhD., assoc. prof. Ing. Sobrino, PhD., Ing. Bočák, Ing. Skýpala,	Digitization of the design of robotic workplaces	23. 6. – 24. 6.
Technical University of Košice	assoc. prof. Ing. Huňady, PhD., assoc. prof. Ing. Hagara, PhD.	Measurement of industrial robot parameters using the digital image correlation method and measurement of service robot parameters using the Pulze system	27. 6. – 1. 7.
Technical University of Košice	assoc. prof. Ing. Gajdoš, PhD.	Use of industrial robots for 3D printing	27. 6. – 28. 6.
Technical University of Košice, Faculty of Mechanical Engineering, Department of Manufacturing Technology and Robotics	Ing. Ondočko	Analysis of the workspace of a non-standard modular robotic arm consisting of unique rotation modules	4. 7. – 22. 7.
Technical University of Košice	Ing. Varga	Redundant manipulators and their design solutions	11. 7.

Technical University of Košice	assoc. prof. Ing. Huňady, PhD., assoc. prof. Ing. Hagara, PhD.	Measurement of industrial robot parameters using the digital image correlation method and measurement of service robot parameters using the Pulze system	19. 9. – 23. 9.
Carinthia University of Applied Sciences	Dr. Brandstötter	Establishment of research cooperation between VŠB-TUO and Carinthia University of Applied Sciences in the field of 3D printing for the design of mechatronic systems.	3. 11. – 4. 11.
Technical University of Košice	Ing. Jadlovská, PhD.	Approaches to modelling and control of under-actuated mechanical systems	7. 11. – 8. 11.
Polytechnic Department of Engineering and Architecture	Prof. Gasparetto, Dr. Scalera	Establishment of research cooperation between VŠB-TUO and Polytechnic Department of Engineering and Architecture in the field of human-robot cooperation	15. 11. – 16. 11.
Silesian University of Technology, Gliwice - Institute of Fundamentals of Machinery Design	Prof. Przystałka, Dr. Panfil	Advanced robots in automotive production applications	21. 11. – 22. 11.
Technical University of Košice	assoc. prof. Ing. Jánoš, PhD., assoc. prof. Ing. Semjon, PhD.,	Use of industrial robotic systems at universities	23. 11. – 24. 11.
Technical University of Košice	assoc. prof. Ing. Huňady, PhD., assoc. prof. Ing. Hagara, PhD.	Measurement of parameters of industrial and service robots using the Pulze system	23. 11 – 25. 11.
Technical University of Košice	assoc. prof. Ing. Miková, PhD.	Unconventional methods of modelling mechatronic systems	23. 11. – 25. 11.
Technical University of Košice	assoc. prof. Gajdoš, PhD., Ing. Štefčák,	Preprocessing in 3D printing with industrial robots - case studies.	28. 11. – 29. 11

8. PUBLISHING ACTIVITIES

8.1. Articles in International Journals

MIKOVÁ, Ľubica, PRADA, Erik, KELEMEN, Michal, KRYS, Václav, MYKHAILYSHYN, Roman, SINČÁK, Peter Ján, MERVA, Tomáš and LEŠTACH, Lukáš. Upgrade of Biaxial Mechatronic Testing Machine for Cruciform Specimens and Verification by FEM Analysis. *Machines*. 2022. 10(10), 916. Scopus, WoS, **Q2**

KOT, Tomáš, WIERBICA, Rostislav, OŠČÁDAL, Petr, SPURNÝ, Tomáš and BOBOVSKÝ, Zdenko. Using Elastic Bands for Collision Avoidance in Collaborative Robotics. *IEEE Access*. 2022. vol 10, pp. 106972-106987. ISSN 2169-3536. Scopus, WoS, **Q2**

VYSOCKÝ, Aleš, GRUSHKO, Stefan, SPURNÝ, Tomáš, PASTOR, Robert and KOT, Tomáš. Generating Synthetic Depth Image Dataset for Industrial Applications of Hand Localisation. *IEEE Access*. 2022, vol. 10, pp. 99734-99744. ISSN 2169-3536. Scopus, WoS, **Q2**

HUCZALA, Daniel, KOT, Tomáš, PFURNER, Martin, KRYS, Václav and BOBOVSKÝ, Zdenko. Multirepresentations and Multiconstraints Approach to the Numerical Synthesis of Serial Kinematic Structures of Manipulators. *IEEE Access*. 2022, vol. 10, pp. 68937-68951. Scopus, WoS, **Q2**

OŠČÁDAL, Petr, SPURNÝ, Tomáš, KOT, Tomáš, GRUSHKO, Stefan, SUDER, Jiří, HECZKO, Dominik, NOVÁK, Petr and BOBOVSKÝ, Zdenko. Distributed Camera Subsystem for Obstacle Detection. *Sensors*. 2022, 22(12), 4588. Scopus, WoS, **Q2**

PASTOR, Robert, MIHOLA, Milan, ZEMAN, Zdeněk and BOLESLAVSKÝ, Adam. Knowledge-Based Automated Mechanical Design of a Robot Manipulator. *Applied Sciences*. 2022, 12(12), 5897. Scopus, WoS, **Q3**

HECZKO, Dominik, OŠČÁDAL, Petr, KOT, Tomáš, BOLESLAVSKÝ, Adam, KRYS, Václav, BÉM, Jan, VIRGALA, Ivan and BOBOVSKÝ, Zdenko. Finding the Optimal Pose of 2D LLT Sensors to Improve Object Pose Estimation. *Sensors*. 2022, 22(4), 1536. ISSN 1424-8220. Scopus, WoS, **Q2**

8.2. Articles in Czech Journals

Suder, J., Kot, T., Panec, A., Vocetka, M. MIHOLA, Milan, ZEMAN, Zdeněk, BOLESLAVSKÝ, Adam, BÉM, Jan, PASTOR, Robert and FOJTÍK, David. Automation of Design of Robotic Arm. *MM Science Journal*. 2022, issue October, pp. 5876-5882. ISSN 1803-3126. Scopus, WoS

BOLESLAVSKÝ, Adam, MIHOLA, Milan, WIERBICA, Rostislav, BÉM, Jan and SPURNÝ, Tomáš. Research and Development of a Software Tool for Parametric Modeling of Robotized Workplaces. *MM Science Journal*. 2022, issue June, pp. 5675-5683. ISSN 1803-3126. Scopus, WoS

ZEMAN, Zdeněk, MIHOLA, Milan, SUDER, Jiří and BOLESLAVSKÝ, Adam. Automation of Partial Tasks in the Design of Robotic Arms. *MM Science Journal*. 2022, issue March, pp. 5513-5521. ISSN 1803-3126. Scopus, WoS

8.3. Contributions in International Conferences

MLOTEK, Jakub, BOBOVSKÝ, Zdenko, SUDER, Jiří, OŠČÁDAL, Petr, VOCETKA, Michal and KRYS, Václav. Shape-Changing Manipulator Possibilities and the Effect of the Deformable Segment on the Size of the Working Area. In *Mechanisms and Machine Science*. 2022. pp. 272-280. ISBN 9783031048692. ISSN 2211-1098. e-ISSN 2211-1099. Scopus

VYSOCKÝ, Aleš, GRUSHKO, Stefan, PASTOR, Robert and NOVÁK, Petr. Simulation Environment for Neural Network Dataset Generation. In *International Conference on Modelling and Simulation for Autonomous Systems (MESAS)*. 2022. ISBN 978-3-030-98260-7. Scopus, WoS

HUCZALA, Daniel, KOT, Tomáš, MLOTEK, Jakub, SUDER, Jiří and PFURNER, Martin. An Automated Conversion Between Selected Robot Kinematic Representations. In *10th International Conference on Control, Mechatronics and Automation (ICCMA, Luxembourg)*. 2022.

8.4. Applied Outputs

8.4.1. Prototype, Functional Sample

HECZKO, Dominik, BOBOVSKÝ, Zdenko and OŠČÁDAL, Petr. Robotic precision inspection of 3D printed and welded objects. 2022.

HECZKO, Dominik, OŠČÁDAL, Petr and BOBOVSKÝ, Zdenko. System for 3D shape inspection of a part. 2022.

HECZKO, Dominik, OŠČÁDAL, Petr and BOBOVSKÝ, Zdenko. System for determining the position of the object in the gripper. 2022.

OŠČÁDAL, Petr, KOT, Tomáš and HECZKO, Dominik. Sensor for object proximity evaluation. 2022.

KOT, Tomáš and OŠČÁDAL, Petr. Automatic trajectory correction system implemented in the robot control system. 2022.

GRUSHKO, Stefan and VYSOCKÝ, Aleš. Workspace control system with collision handling. 2022.

OŠČÁDAL, Petr, HECZKO, Dominik and KOT, Tomáš. Calibration gridboard for determining the position and orientation of cameras in space. 2022.

GRUSHKO, Stefan and VYSOCKÝ, Aleš. Human-machine interface (HMI) to improve robot-human collaboration in shared workspace conditions. 2022.

8.4.2. Patent, Utility Model, Registered Design

GRUSHKO, Stefan and STREJČEK, Radim. Joint with two degrees of freedom for use in exoskeletons and rehabilitation devices. 2022.

8.4.3. Software

KOT, Tomáš and BOBOVSKÝ, Zdenko. Software for optimizing the robot location relative to the trajectory. 2022.

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

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