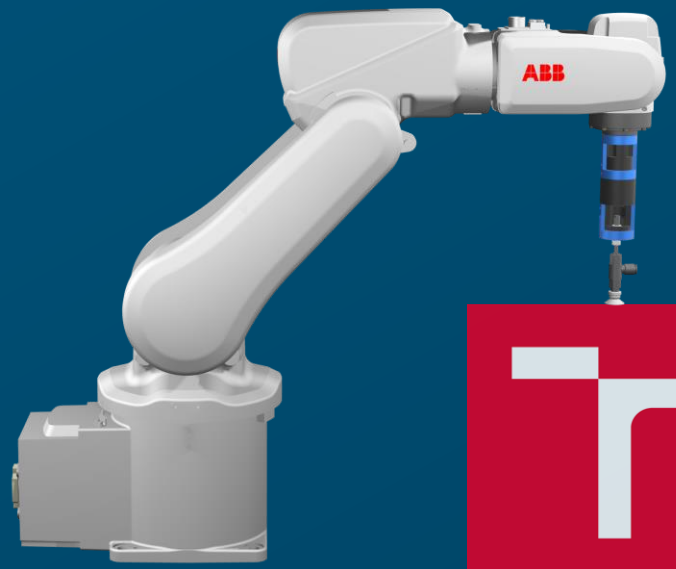
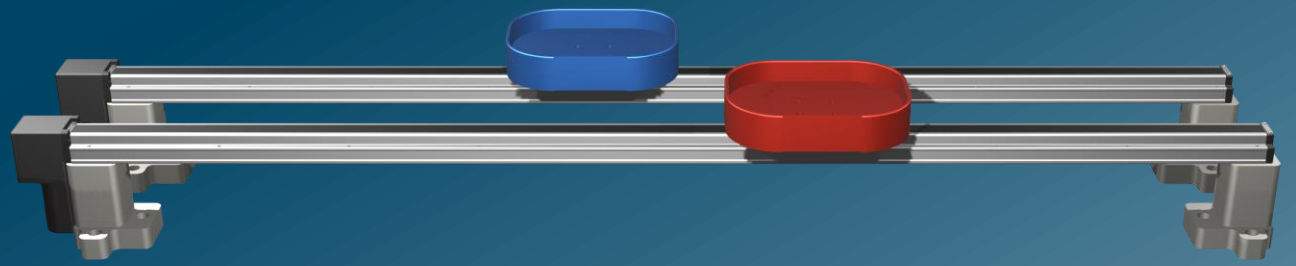
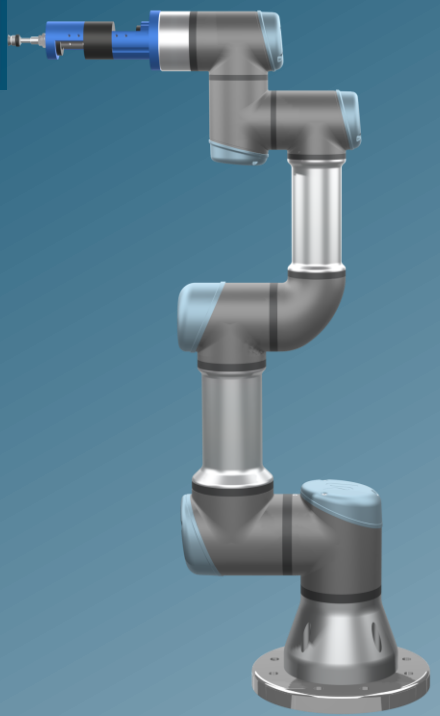
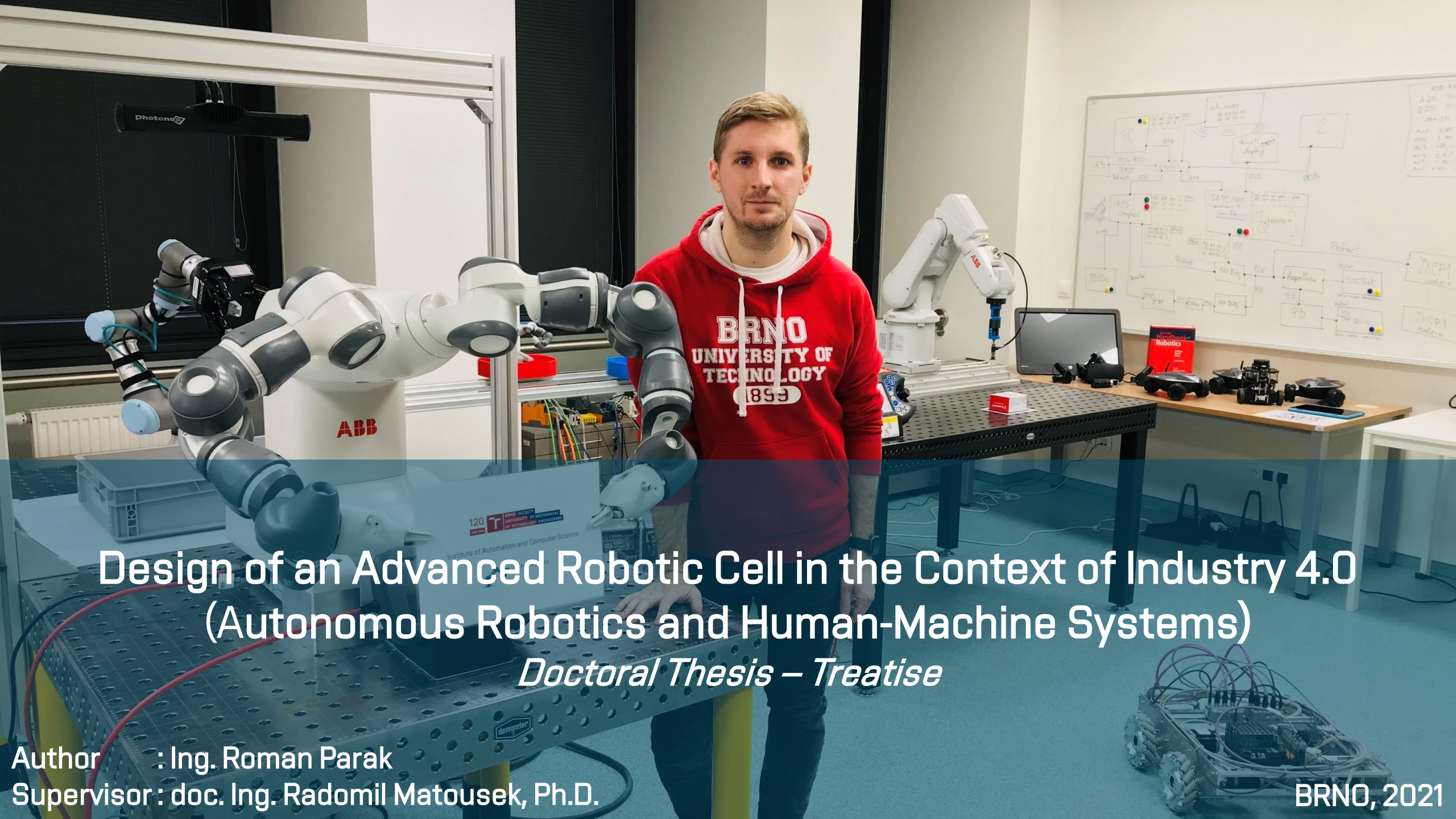


FACULTY OF MECHANICAL ENGINEERING

institute of automation and computer science







Design of an Advanced Robotic Cell in the Context of Industry 4.0 (Autonomous Robotics and Human-Machine Systems)

Doctoral Thesis – Treatise

Author : Ing. Roman Parak
Supervisor : doc. Ing. Radomil Matousek, Ph.D.

BRNO, 2021

Content

Theoretical Part

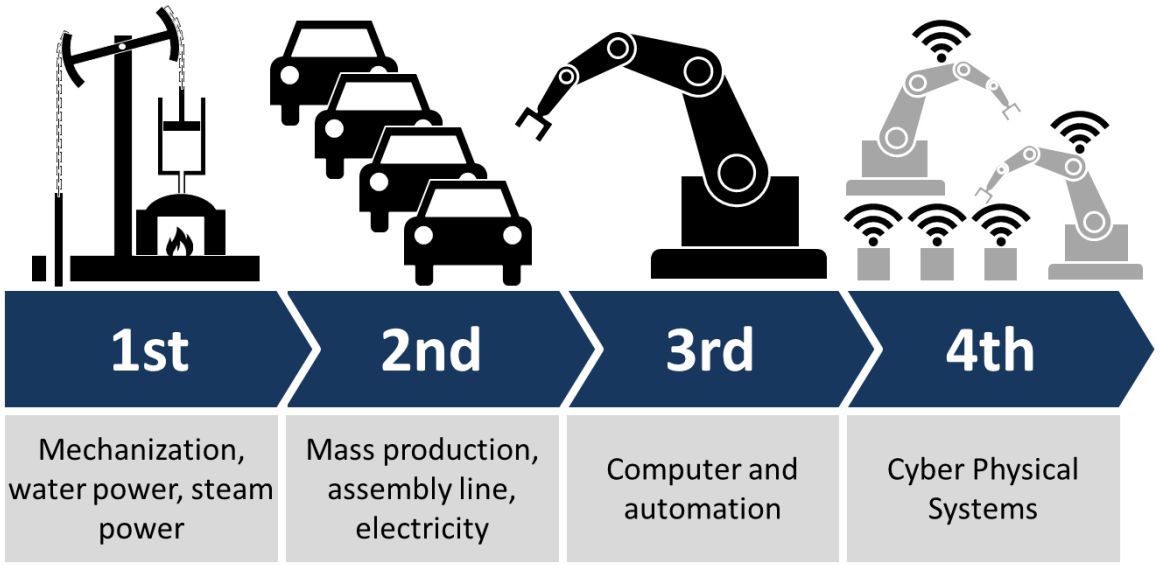
Overview of the current state of Industry 4.0

Kinematics in the field of Industrial robotics

Use of available tools for creating robotic applications

Overview of the current state of Industry 4.0

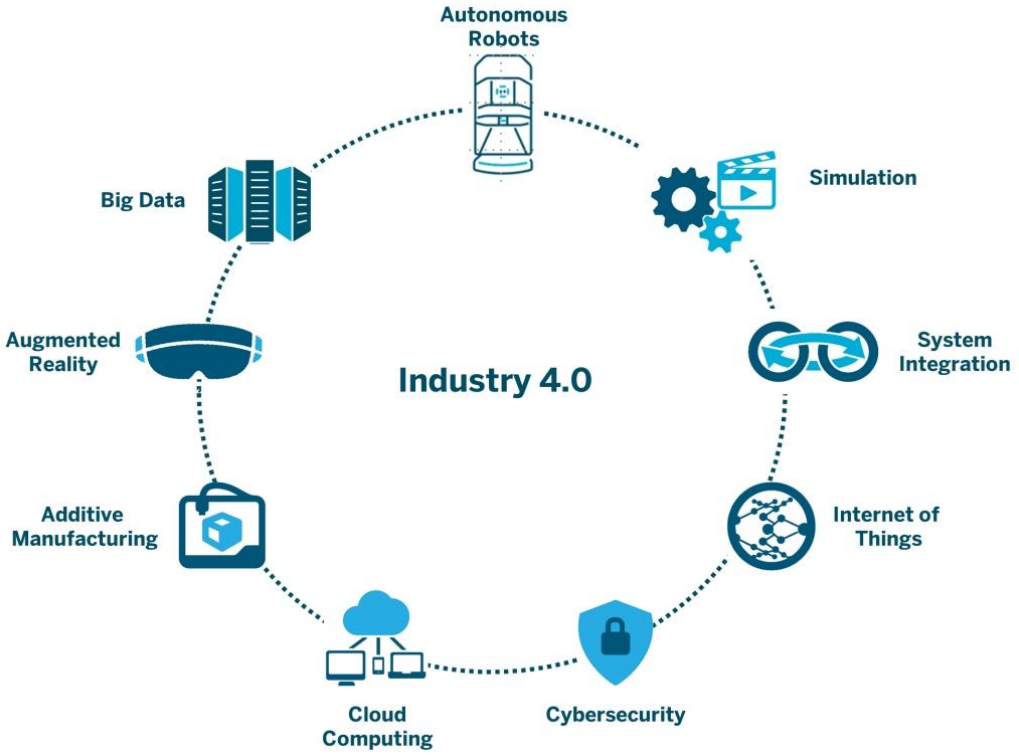
- History of the Industrial Revolution
- The Characteristics of the Fourth Industrial Revolution
- Industrial communication
- The future of industry – I5.0



BRIEF OVERVIEW OF THE 4TH INDUSTRIAL REVOLUTION

Overview of the current state of Industry 4.0

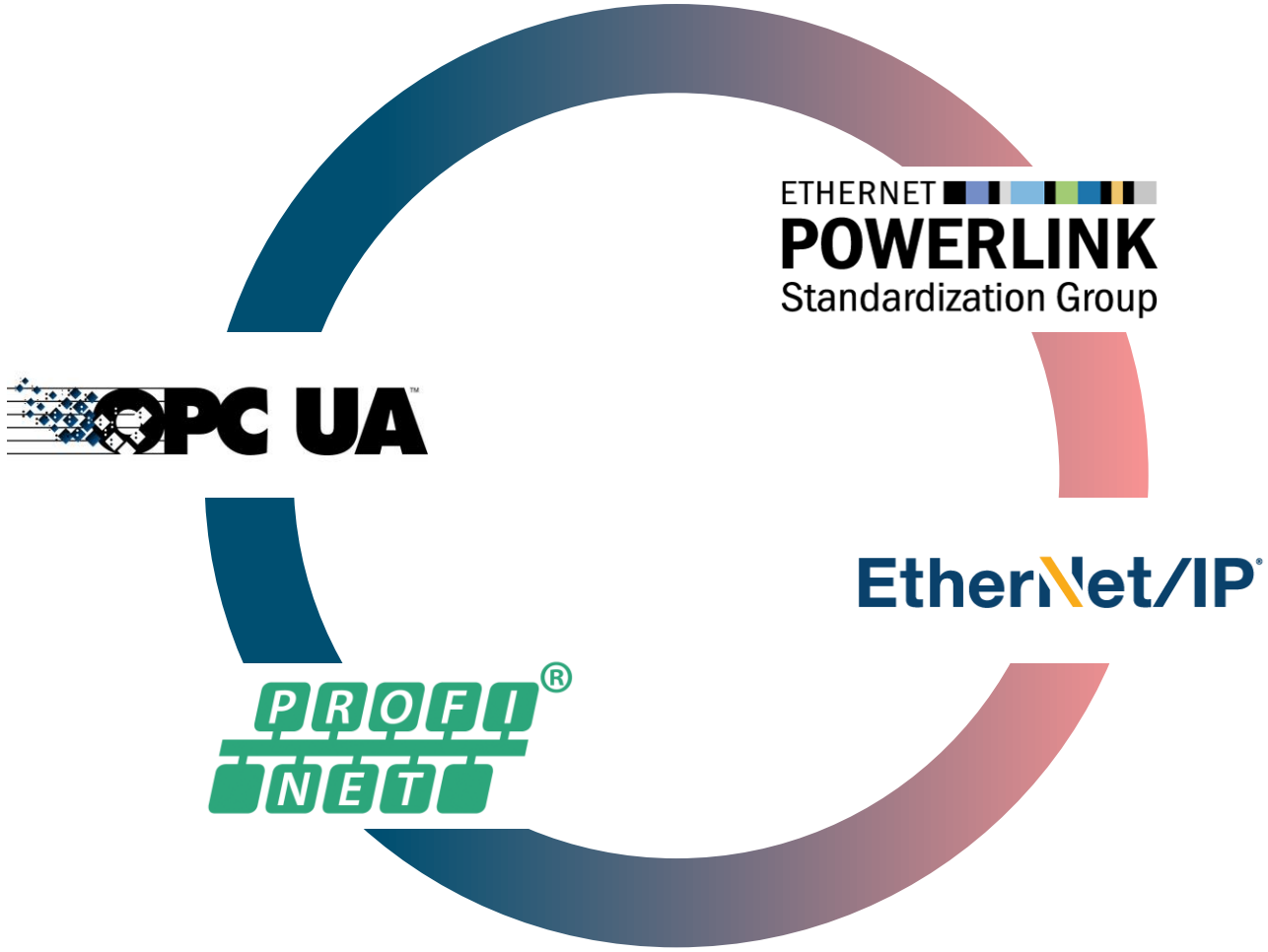
- History of the Industrial Revolution
- The Characteristics of the Fourth Industrial Revolution
- Industrial communication
- The future of industry – I5.0



Main pillars of Industry 4.0

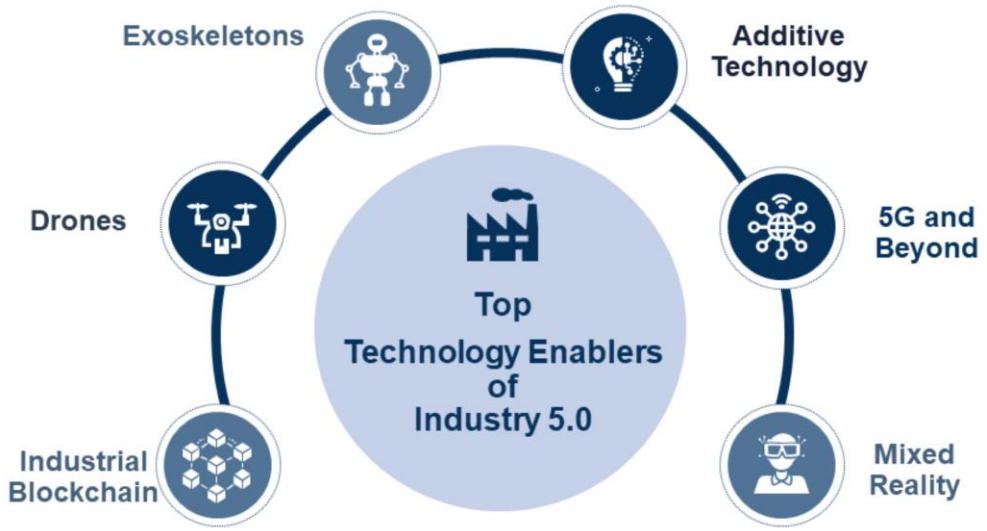
Overview of the current state of Industry 4.0

- History of the Industrial Revolution
- The Characteristics of the Fourth Industrial Revolution
- **Industrial Communication**
- The future of industry – I5.0



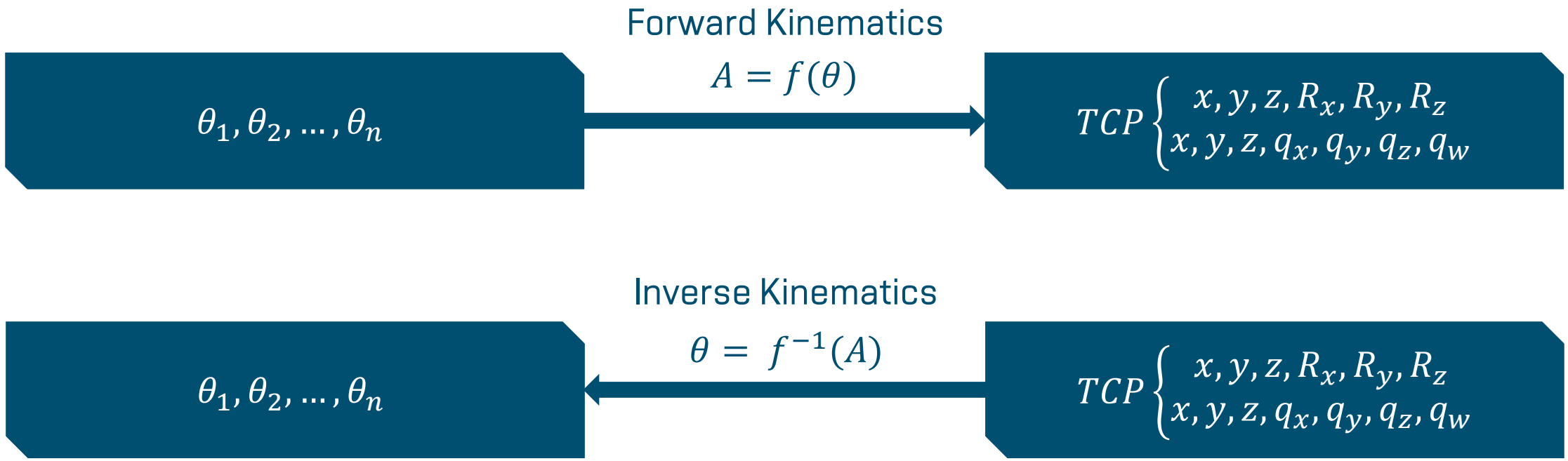
Overview of the current state of Industry 4.0

- History of the Industrial Revolution
- The Characteristics of the Fourth Industrial Revolution
- Industrial communication
- The future of industry – I5.0



Topology Enablers of Industry 5.0

Kinematics in the field of Industrial robotics

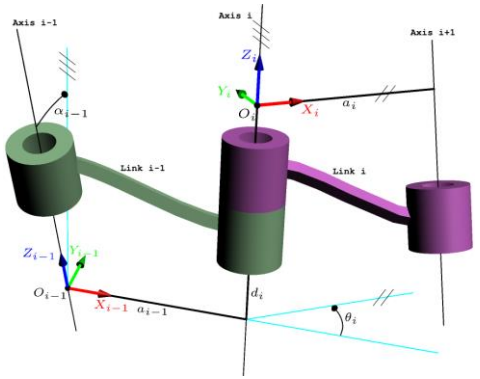


Kinematics in the field of Industrial robotics

Forward Kinematics

$$A = f(\theta)$$

Inverse Kinematics



Denavit – Hartenberger Representation

$$A_i = R_{z,\theta_i} Trans_{z,d_i} Trans_{x,a_i} R_{x,\alpha_i}$$

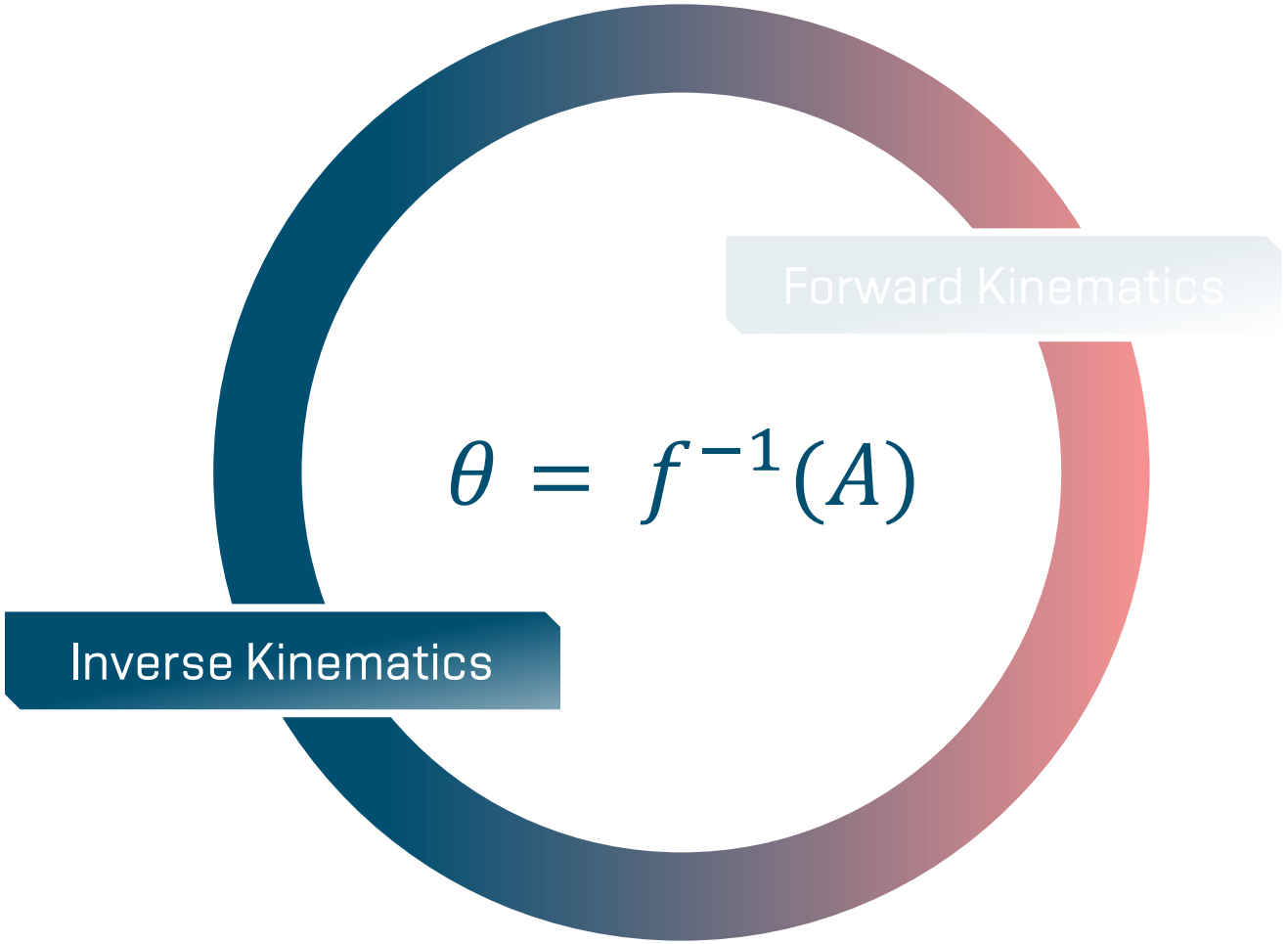
$$= \begin{bmatrix} c\theta_i & -s\theta_i & 0 & 0 \\ s\theta_i & c\theta_i & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_i \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & c\alpha_i & -s\alpha_i & 0 \\ 0 & s\alpha_i & c\alpha_i & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

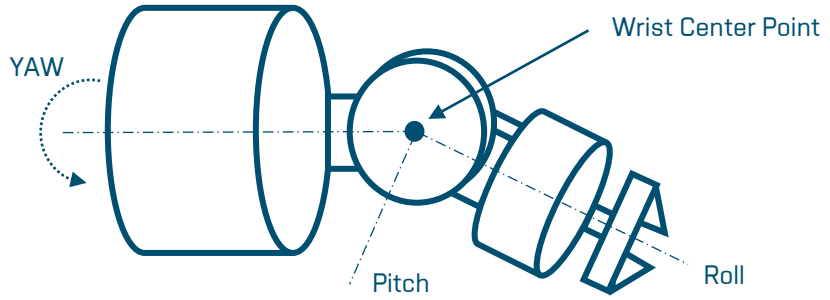
$$= \begin{bmatrix} c\theta_i & -s\theta_i c\alpha_i & s\theta_i s\alpha_i & a_i c\theta_i \\ s\theta_i & c\theta_i c\alpha_i & -c\theta_i s\alpha_i & a_i s\theta_i \\ 0 & s\alpha_i & c\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Translation Part

Rotation Part

Kinematics in the field of Industrial robotics

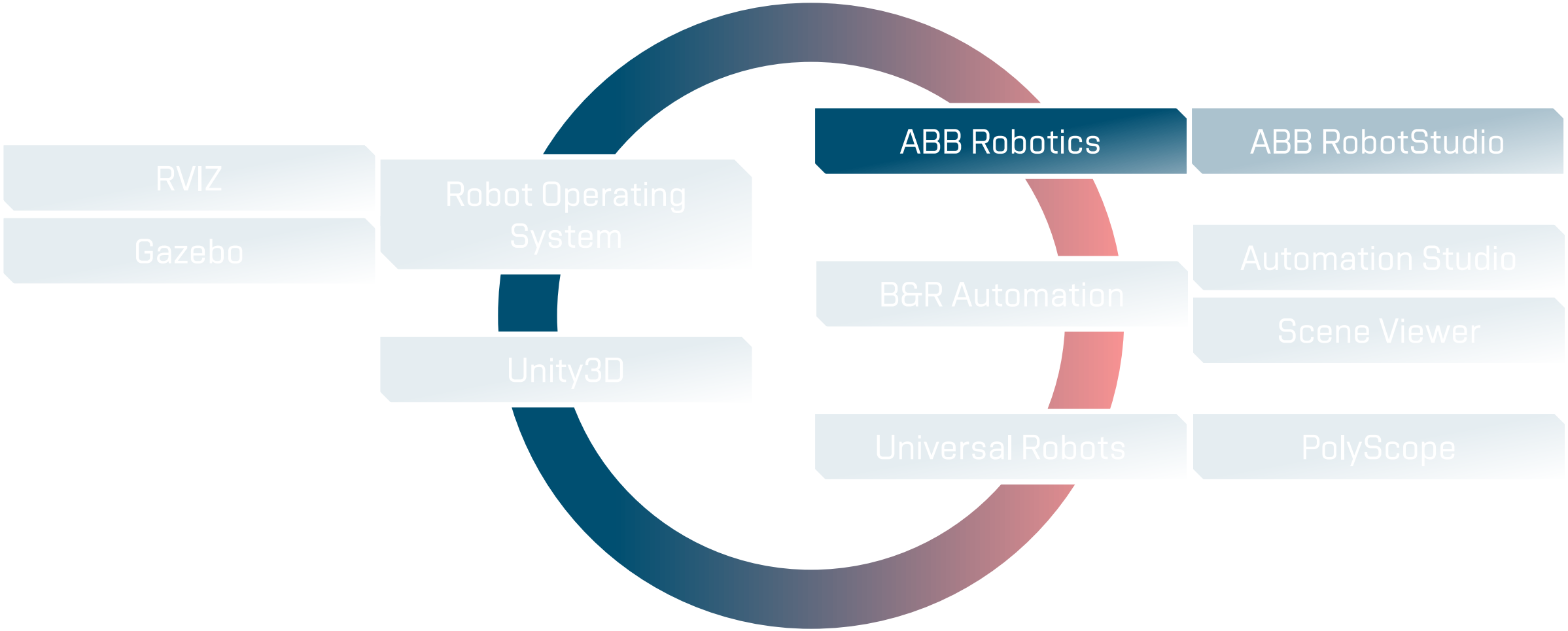




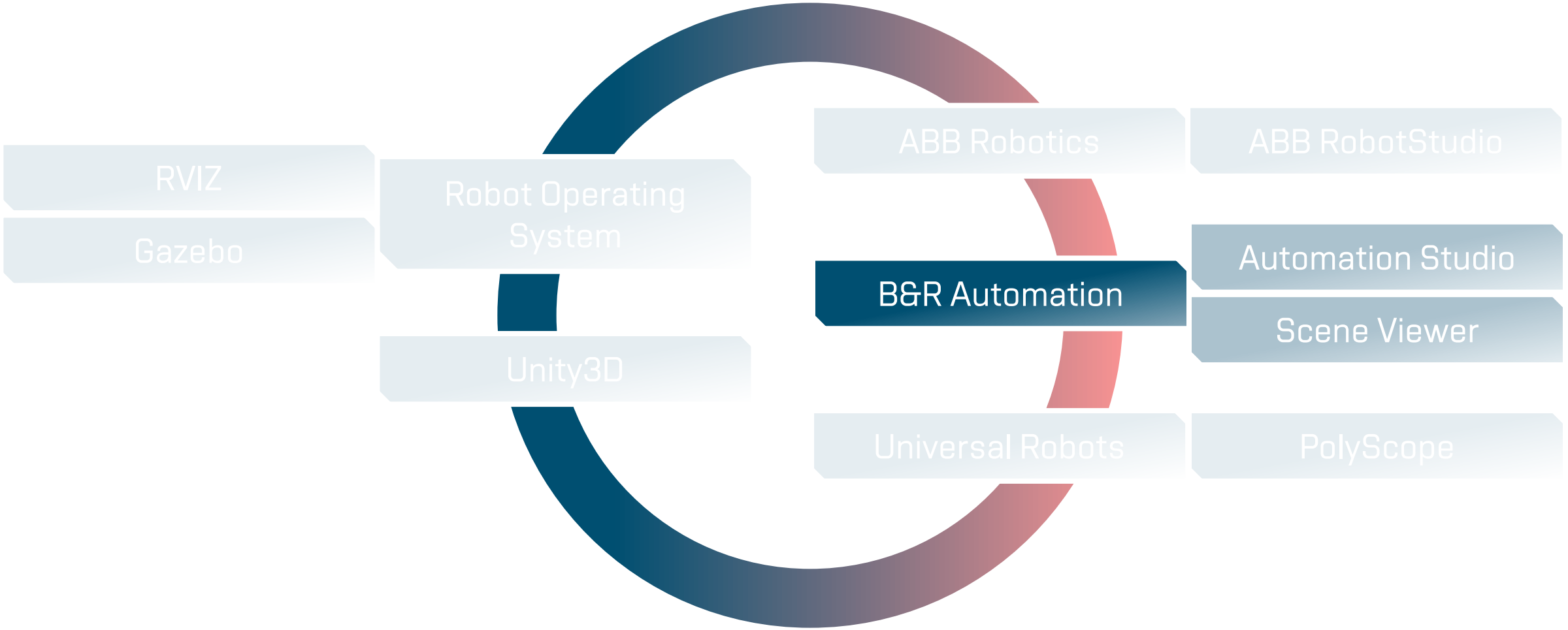
Methods solving the Inverse kinematics Task

- Analytical methods
- Numerical methods

Use of available tools for creating robotic applications



Use of available tools for creating robotic applications



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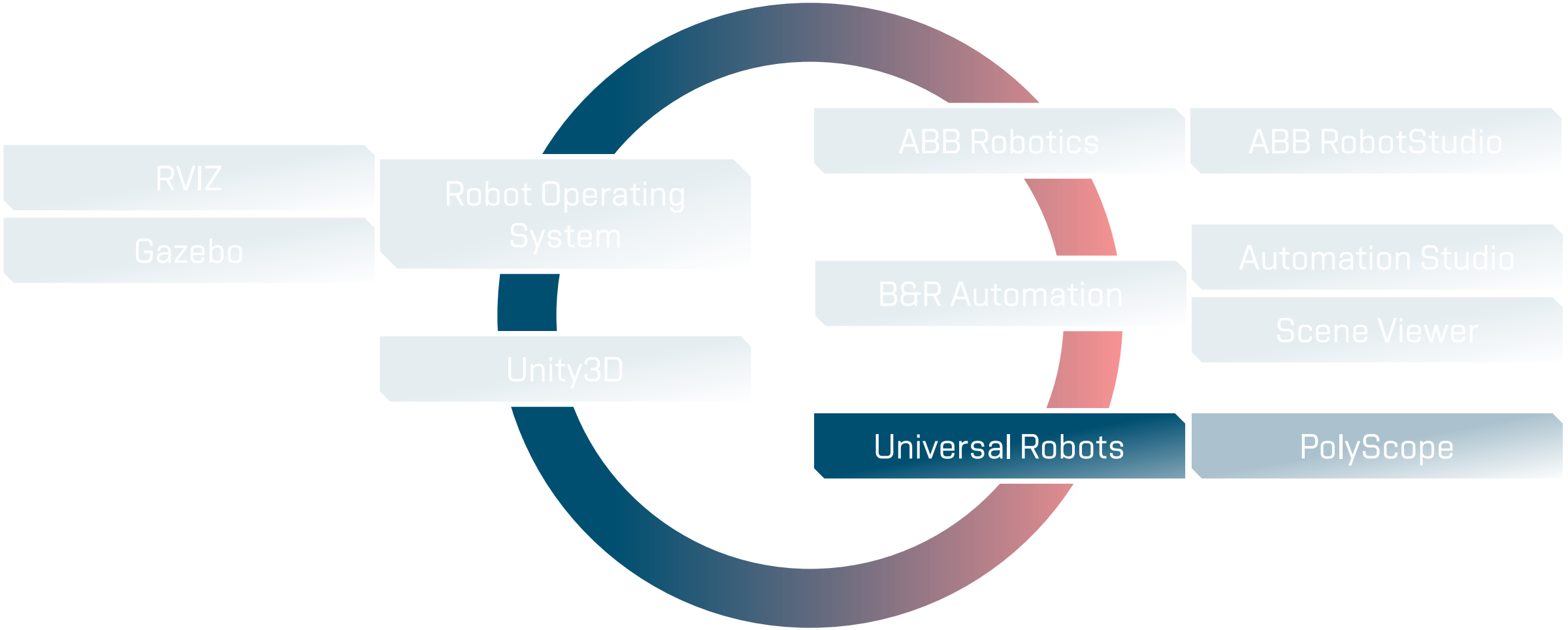
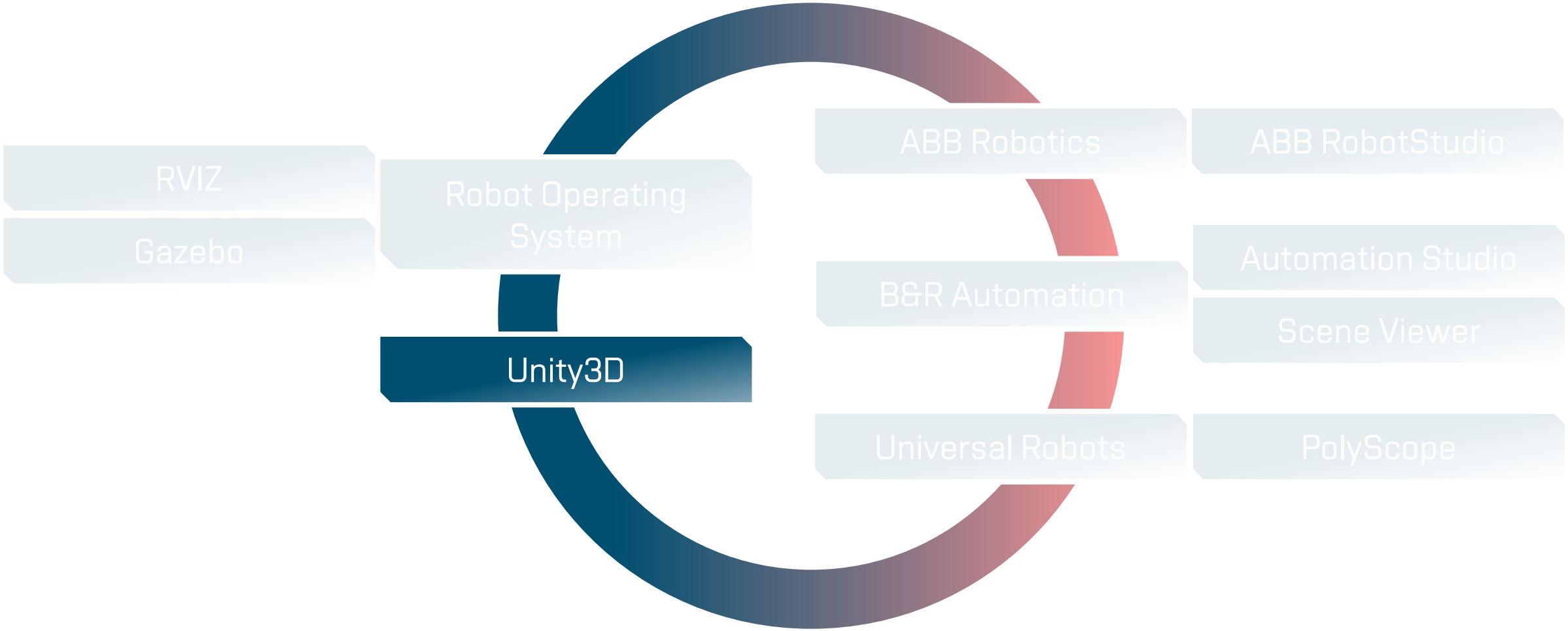
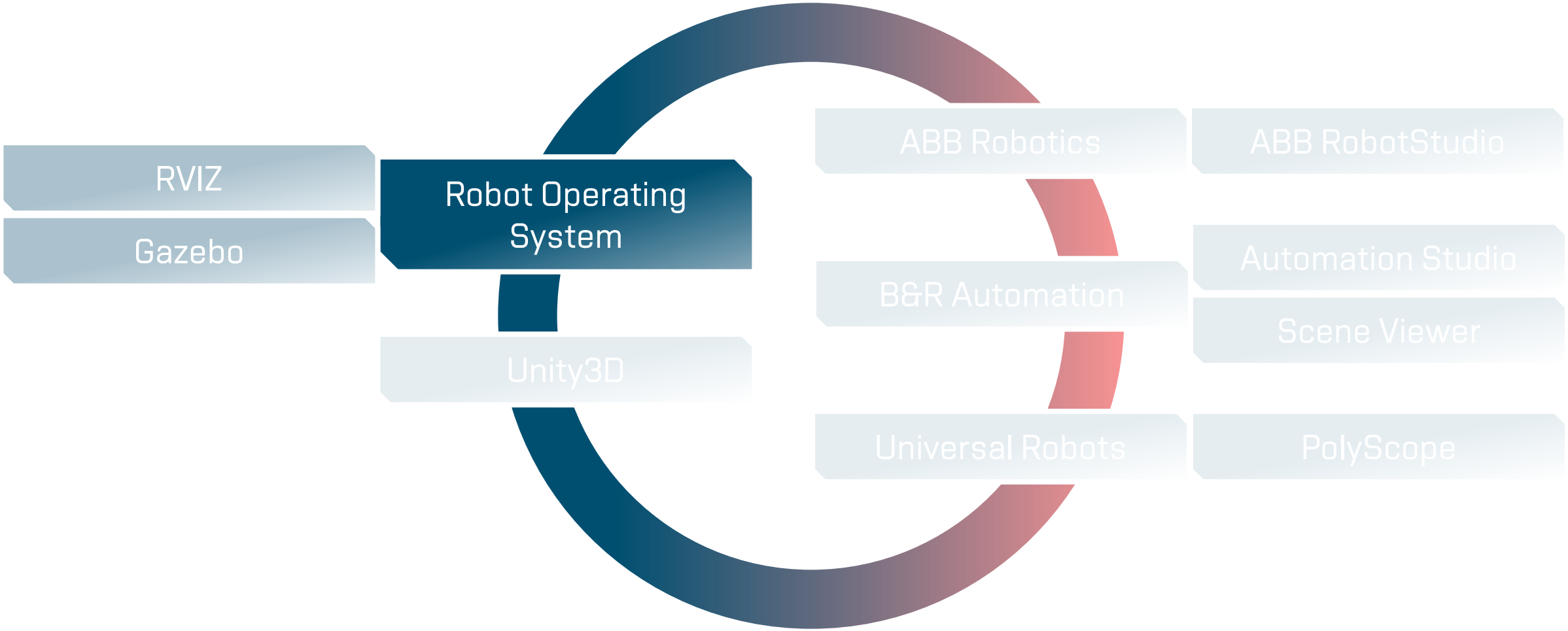


Use of available tools for creating robotic applications



Use of available tools for creating robotic applications



Practical Part

Current state of the Dissertation thesis
Industry 4.0 Cell (I4C)

The main aims of the Dissertation thesis

Current state of the Dissertation thesis

Augmented Reality

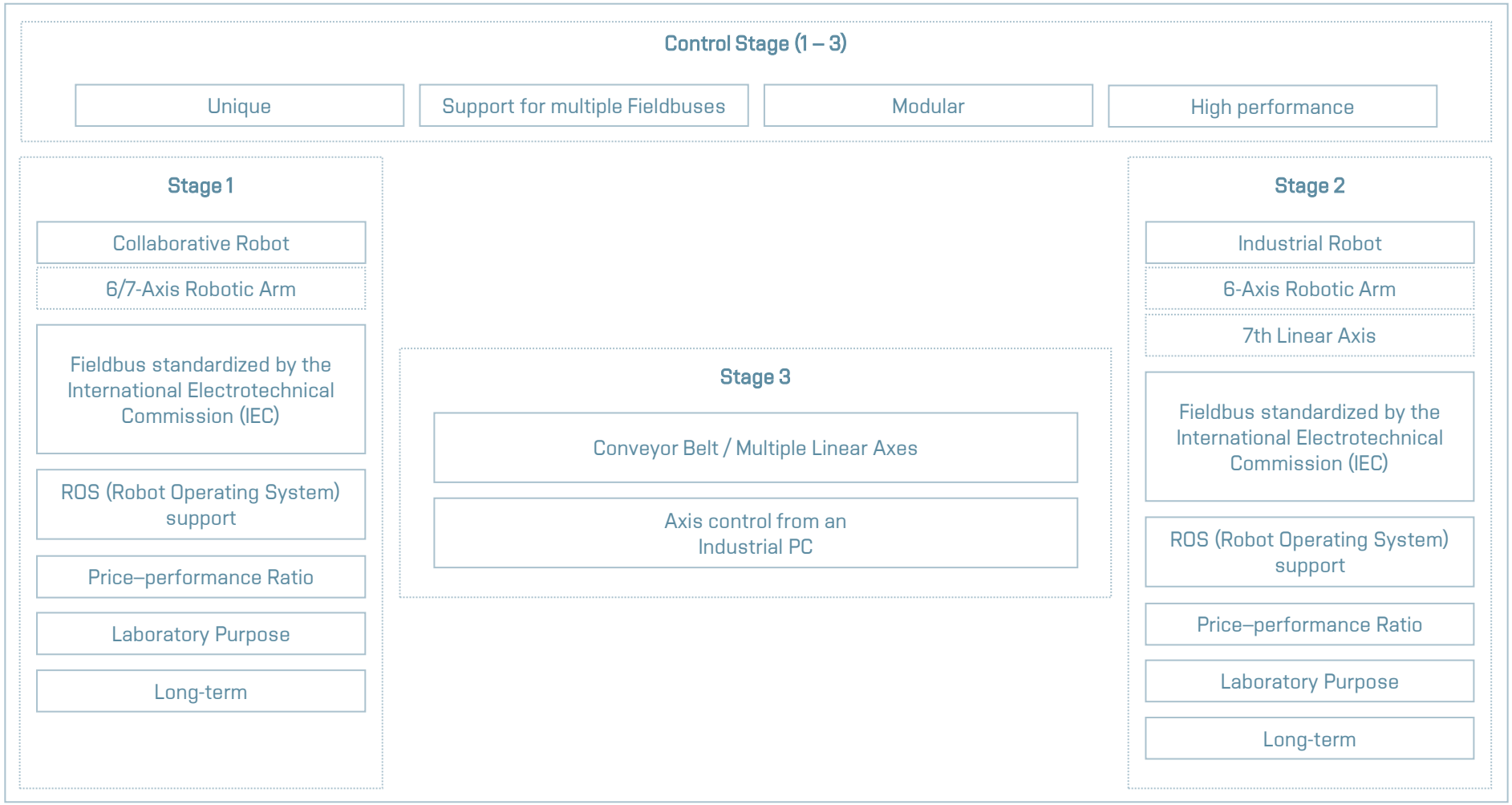
Virtual / Digital Twin

Design and construction of a robotic cell

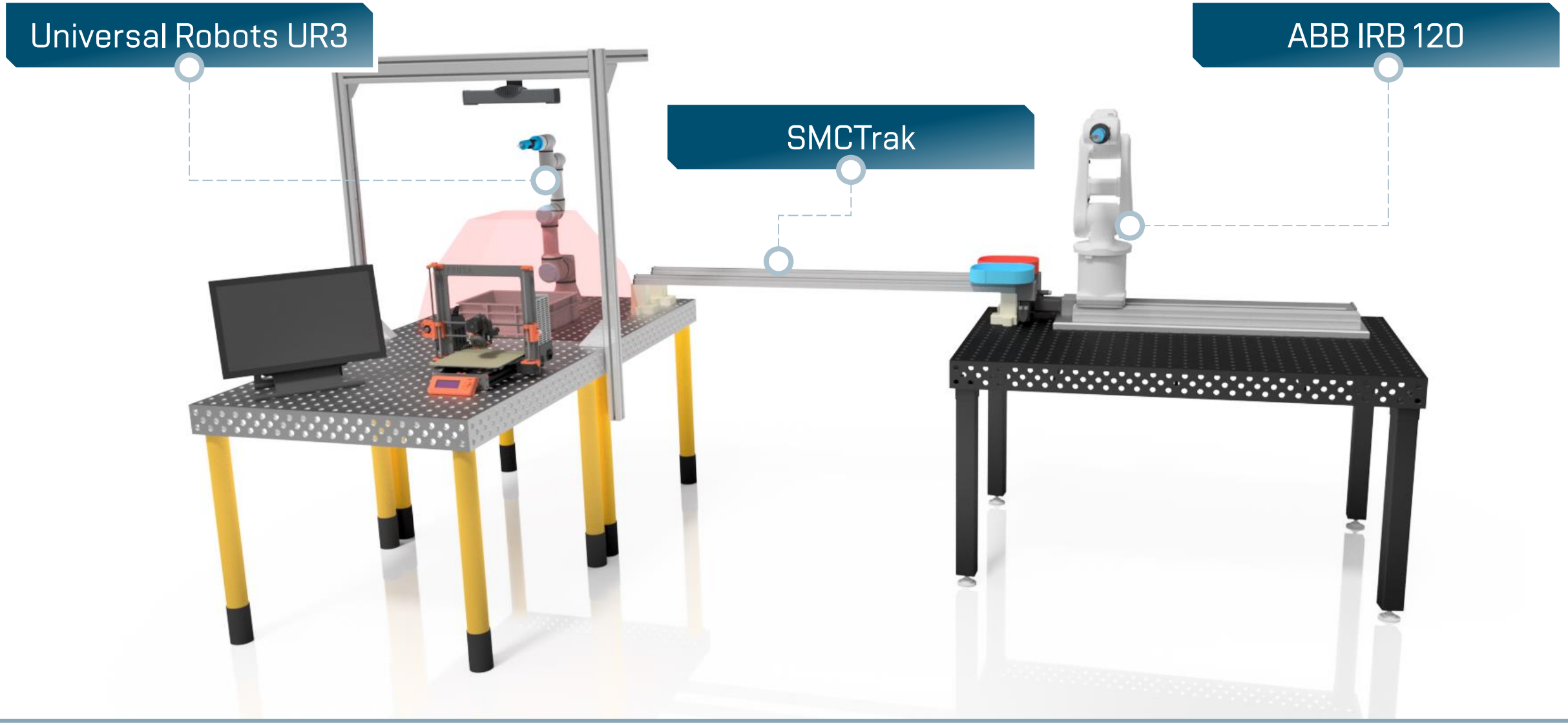
System Integration

Human-Machine Interface

Design and construction of a robotic cell



Design and construction of a robotic cell

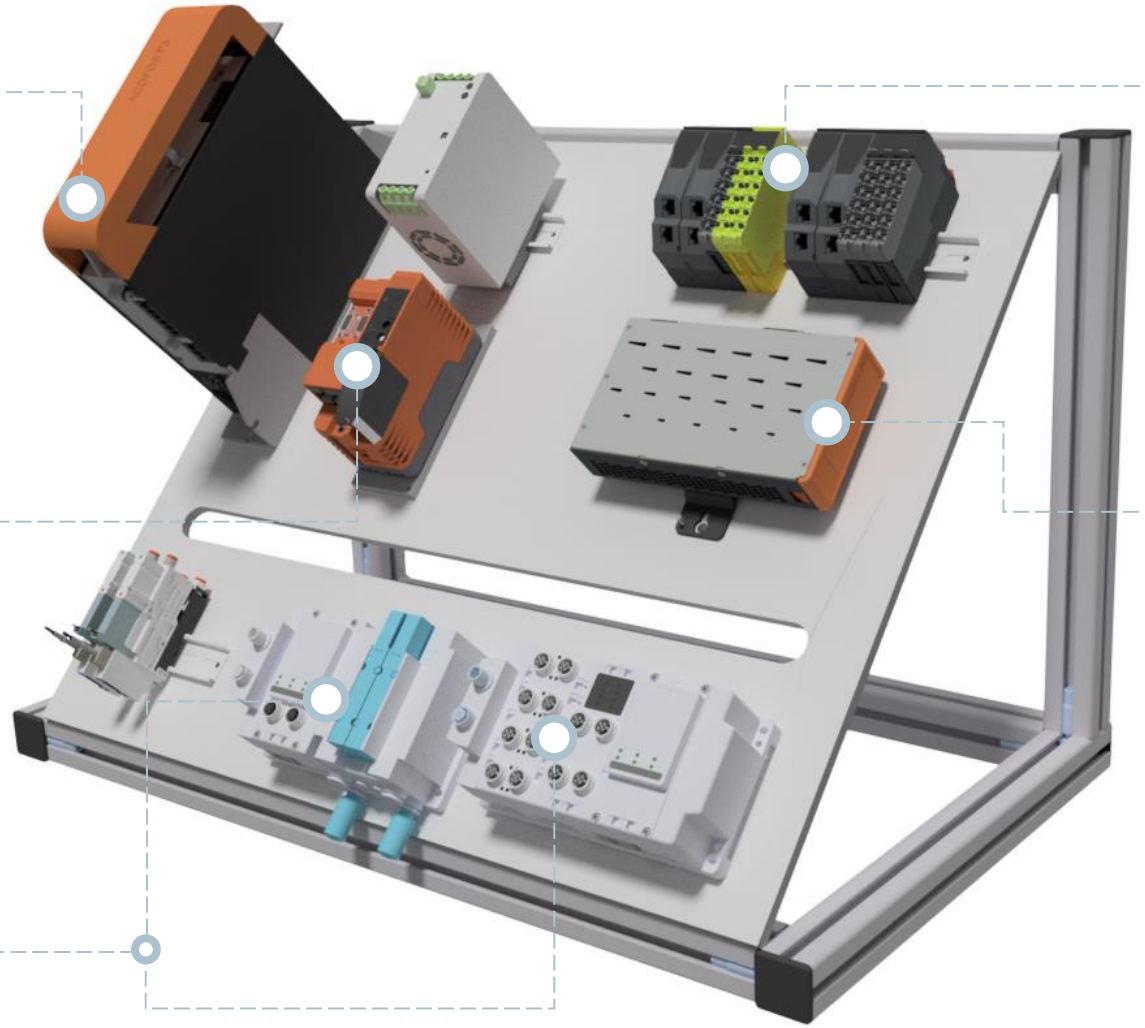


Design and construction of a robotic cell

ACOPOS P3

ACOPOS Micro

EX600 – Wireless



System X20

Industrial PC

Timeline of i4C construction

2018 (Q4)

2019 (Q3)

2020 (Q2)

2021 (Q2)

Current state of the Dissertation thesis

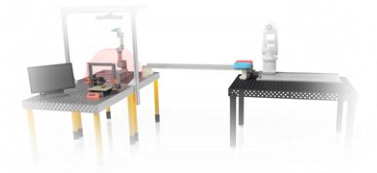
Augmented Reality

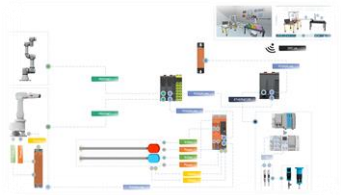
Virtual / Digital Twin

Design and construction of a robotic cell

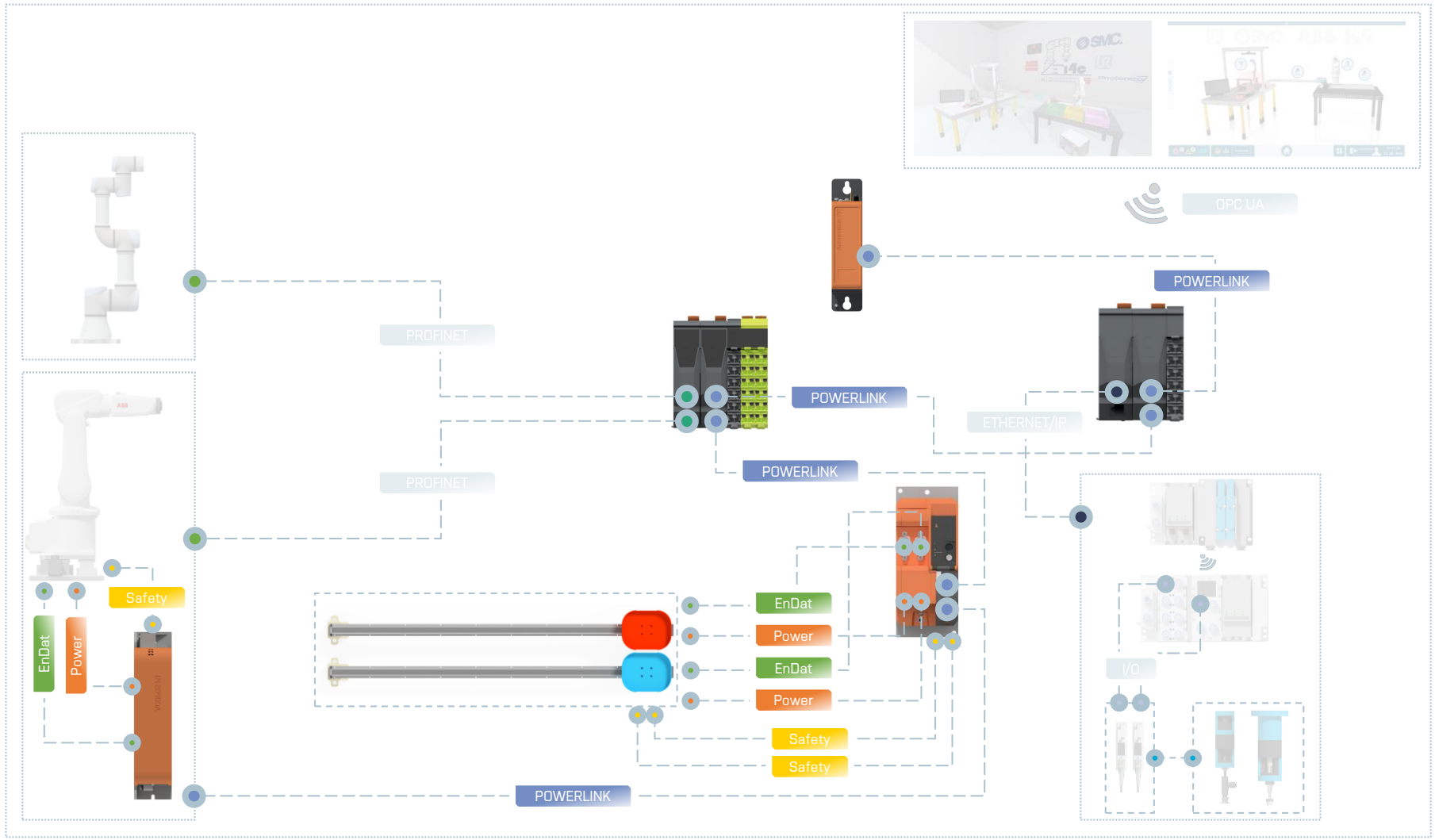
System Integration

Human-Machine Interface



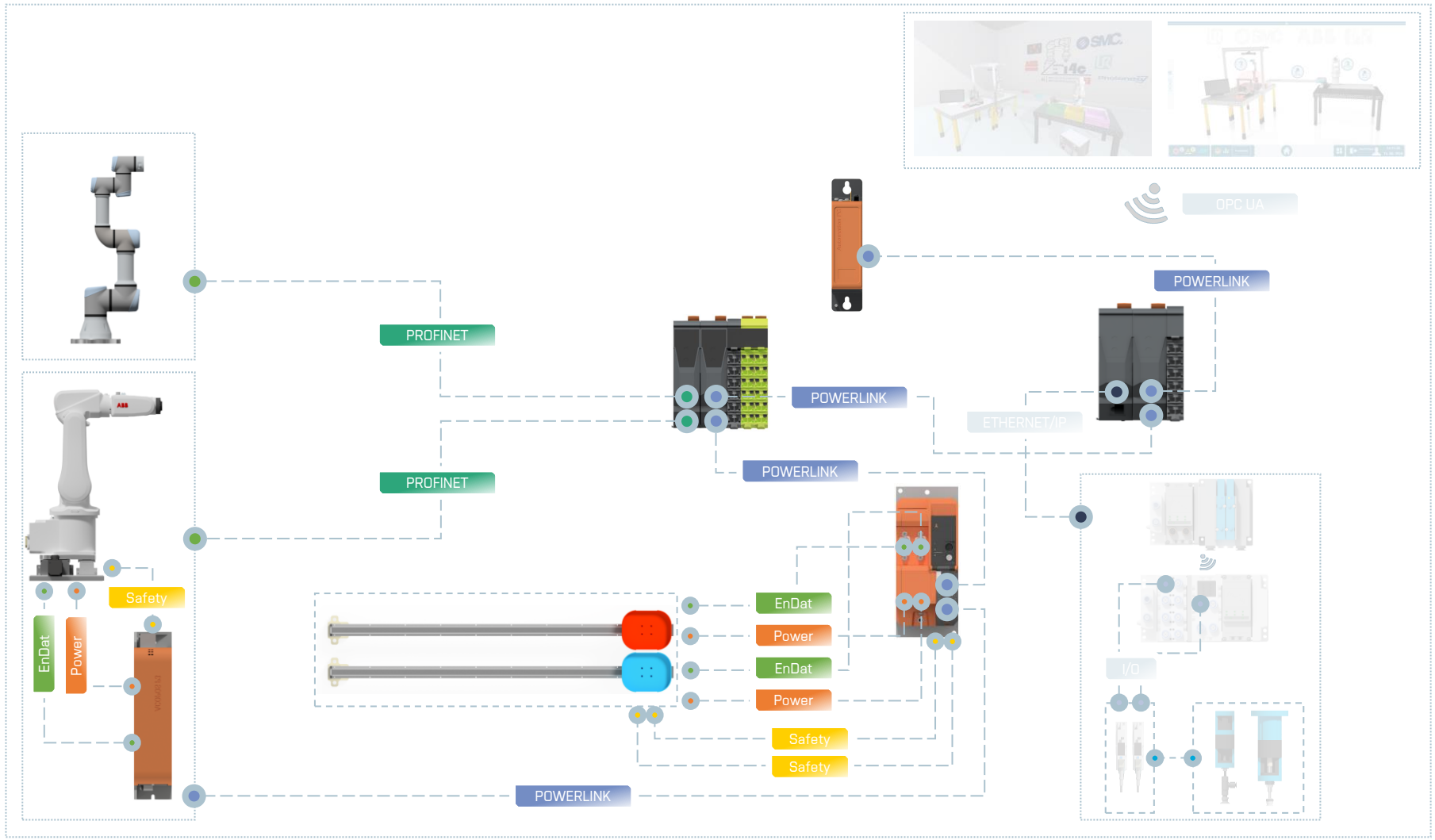


System Integration



- POWERLINK
- PROFINET
- ETHERNET/IP
- Digital/Analog I/O
- OPC UA

System Integration



POWERLINK

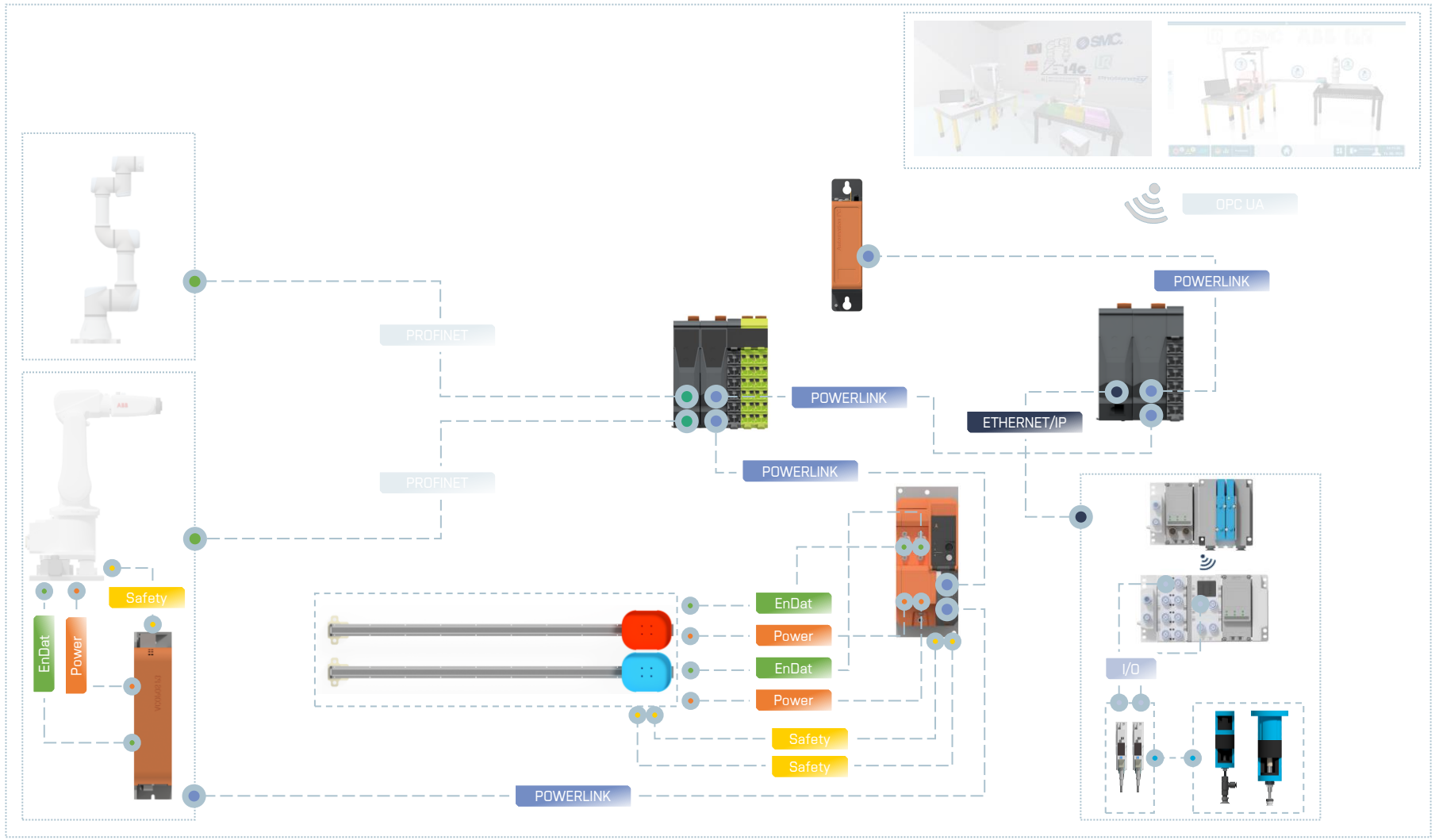
PROFINET

ETHERNET/IP

Digital/Analog I/O

OPC UA

System Integration



POWERLINK

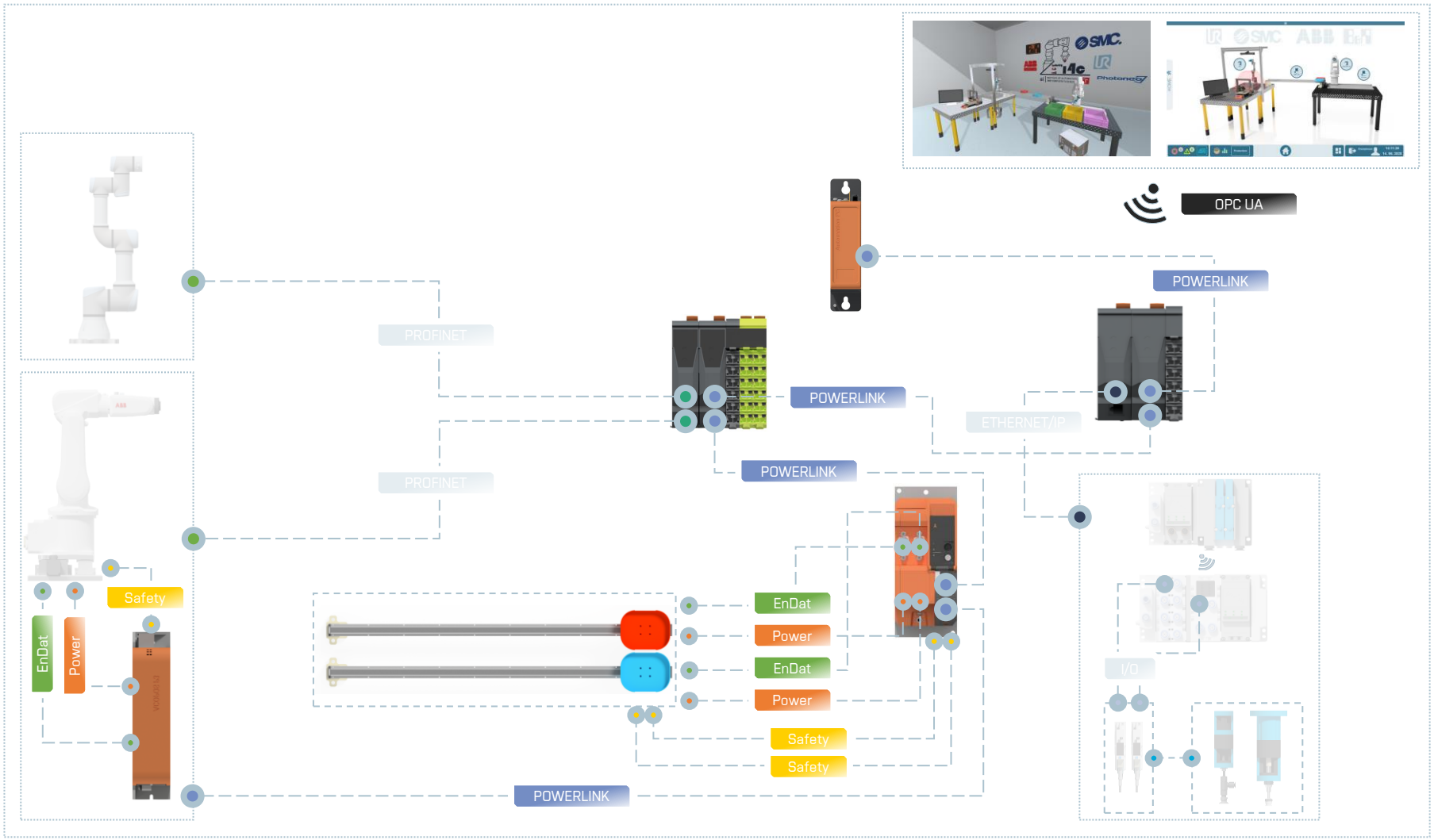
PROFINET

ETHERNET/IP

Digital/Analog I/O

OPC UA

System Integration



POWERLINK

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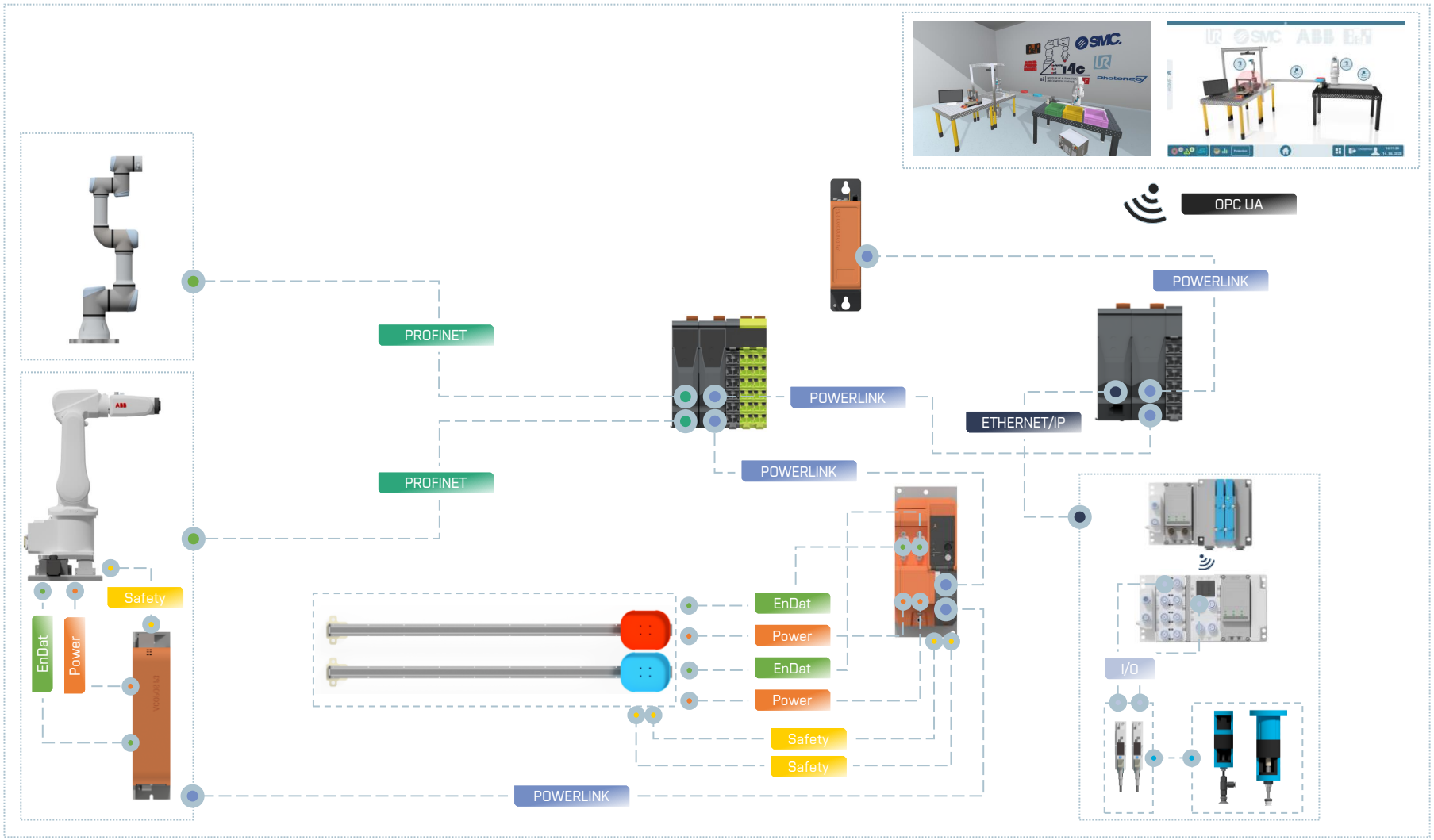
ETHERNET/IP

Digital/Analog I/O

OPC UA

System Integration



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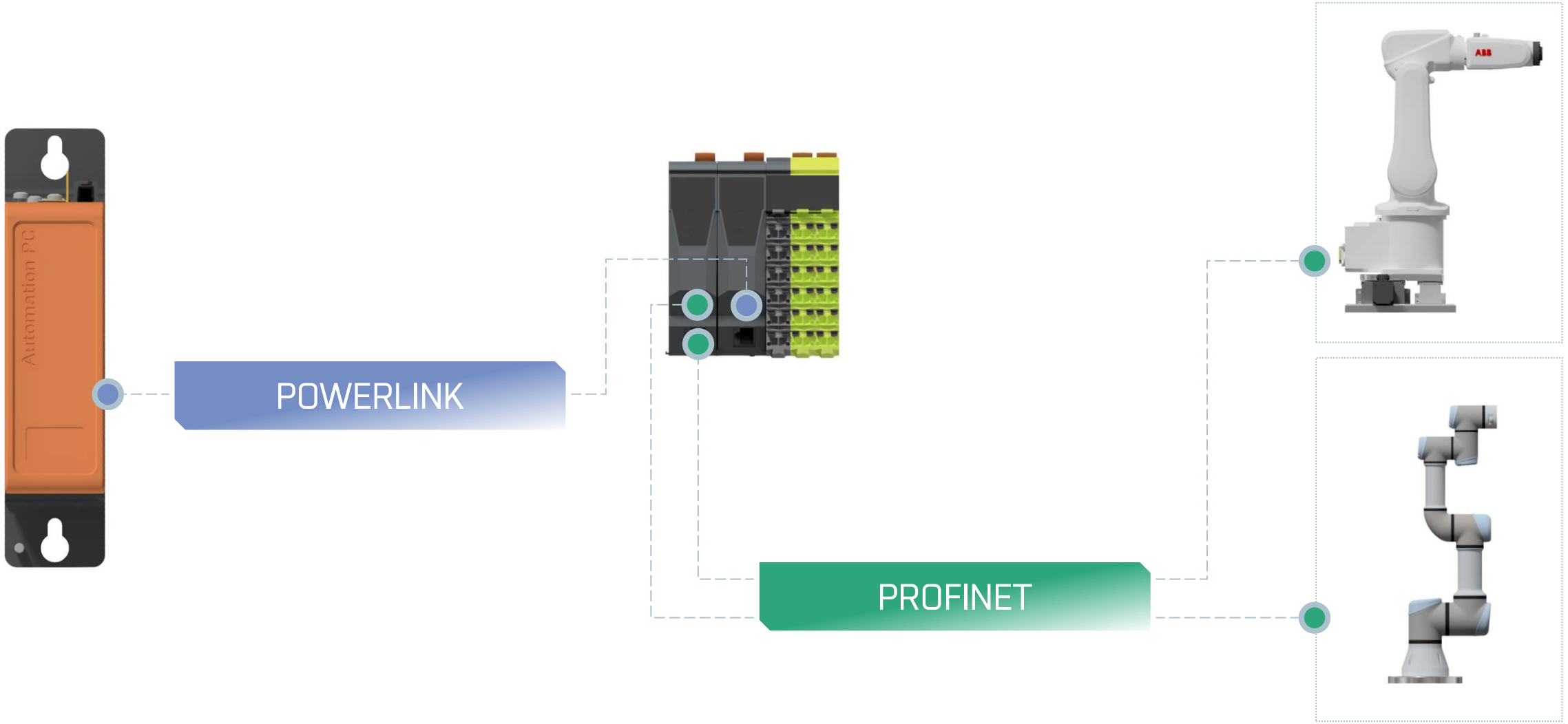


System Integration

OPC UA

Third-party App.

- OPC UA CLIENT
- EGM (Externally Guided Motion)
- Joint/Cartesian
- SDK (Software Development Kit)
- Joint/Cartesian
- Robot Web Services

Multi-Threading

UDP (User Datagram Protocol)

Third-party App.

- OPC UA CLIENT
- Real-Time Data Exchange (RTDE)
- Joint/Cartesian
- Real-time Interface
- e-Series/CB-Series

Multi-Threading

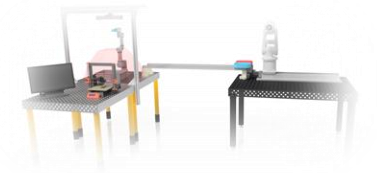
TCP/IP Transmission Control Protocol (TCP) Internet Protocol (IP)

Current state of the Dissertation thesis

Augmented Reality

Virtual / Digital Twin

Design and construction of a robotic cell



System Integration

Human-Machine Interface

Human-Machine Interface

...

OPC Unified Architecture (UA)

Platform Independence

Intuitive Operation

Multi-client / Multi-user

mapp View

Current state of the Dissertation thesis

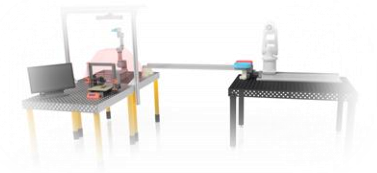
Augmented Reality

Virtual / Digital Twin

Design and construction of a robotic cell

System Integration

Human-Machine Interface



Virtual / Digital Twin

Universal Robots
PolyScope

?

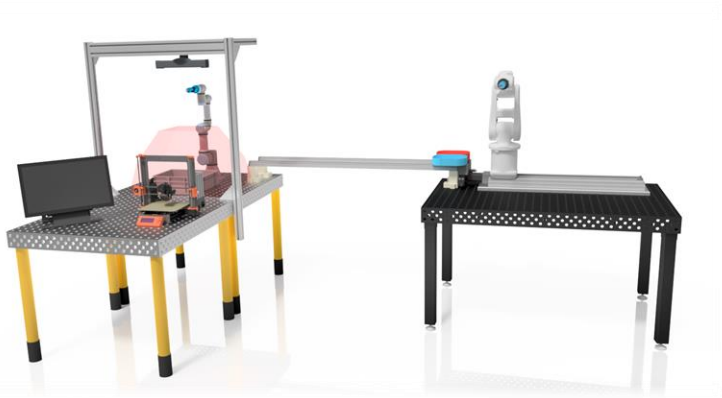
ABB Robotics
RobotStudio

B&R Automation
Scene Viewer

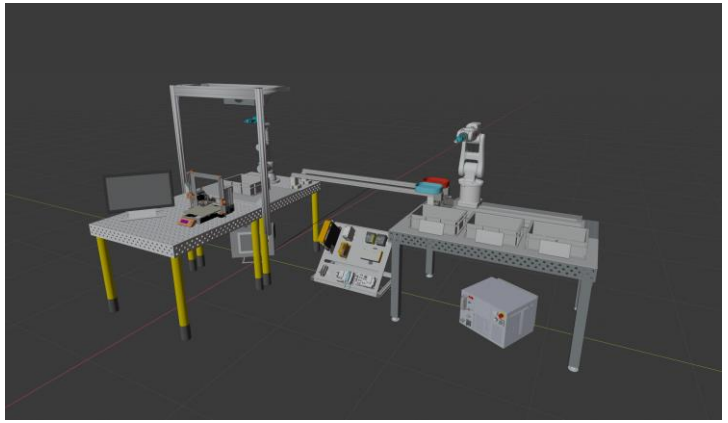
Virtual / Digital Twin

Export → .obj

Autodesk Inventor

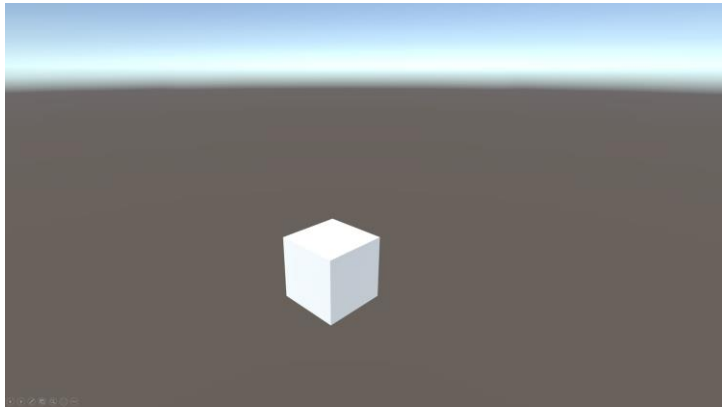


Blender



Export → .blend

Unity3D Virtual / Digital Twin application



Virtual / Digital Twin

Industrial Robot ABB
- Data Collection
- Real / Simulation
- Robot Web Services (RWS)
- XML, JSON

Joint / Cartesian

Industrial PC B&R
- Data Collection
- Real / Simulation
- OPC UA

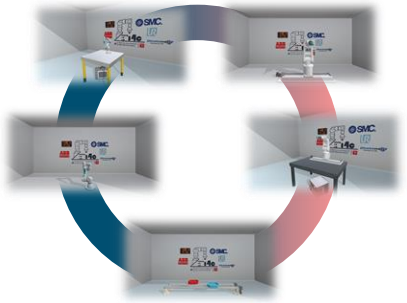
Axis Position

Digital / Analog I / O

Collaborative Robot UR
- Data Collection
- Real / Simulation
- TCP/IP

Joint / Cartesian

Unity3D Virtual / Digital Twin application



- UDP (User Datagram Protocol)
- TCP/IP
  Transmission Control Protocol (TCP)
  Internet Protocol (IP)
- OPC Unified Architecture (UA)

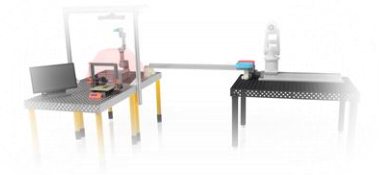
- Platform Independence
- Intuitive Operation
- Multi-Threading
- NVIDIA PhysX

Easy compilation into Augmented reality (AR)

Current state of the Dissertation thesis

Augmented Reality

Design and construction of a robotic cell



System Integration

Virtual / Digital Twin

Human-Machine Interface

Augmented Reality

QR ↔ Augmented Reality 3D Model

- UDP (User Datagram Protocol)
- OPC Unified Architecture (UA)
- Platform Independence
- Intuitive Operation
- TCP/IP Transmission Control Protocol (TCP) Internet Protocol (IP)
- Multi-Threading

Augmented Reality

Test Application

The main aims of the Dissertation thesis

The main aims of the Dissertation thesis

Forward Kinematics

$A = f(\theta)$

Inverse Kinematics

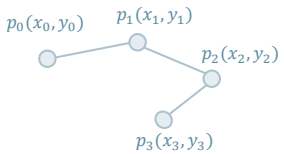
$\theta = f^{-1}(A)$

Method 1

Default Approach

Simple trajectory generation from multiple points.

$$p(t) = (1-t)p_0 + tp_1, t \in [0,1]$$

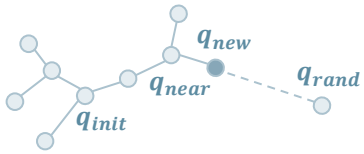


Method 2

Sampling Approach

RRT (Rapidly-Exploring Random Tree)
RRT-Connect
Bidirectional-RRT
PRM (Probabilistic Roadmap)
...

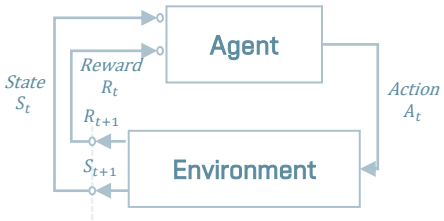
$EXTEND\ (T, q_{rand})$



Method 3

Deep Reinforcement Learning

Deep Q-Network (DQN)
Double Deep Q-Network (DDQN)
Deep Deterministic Policy Gradient (DDPG)
...

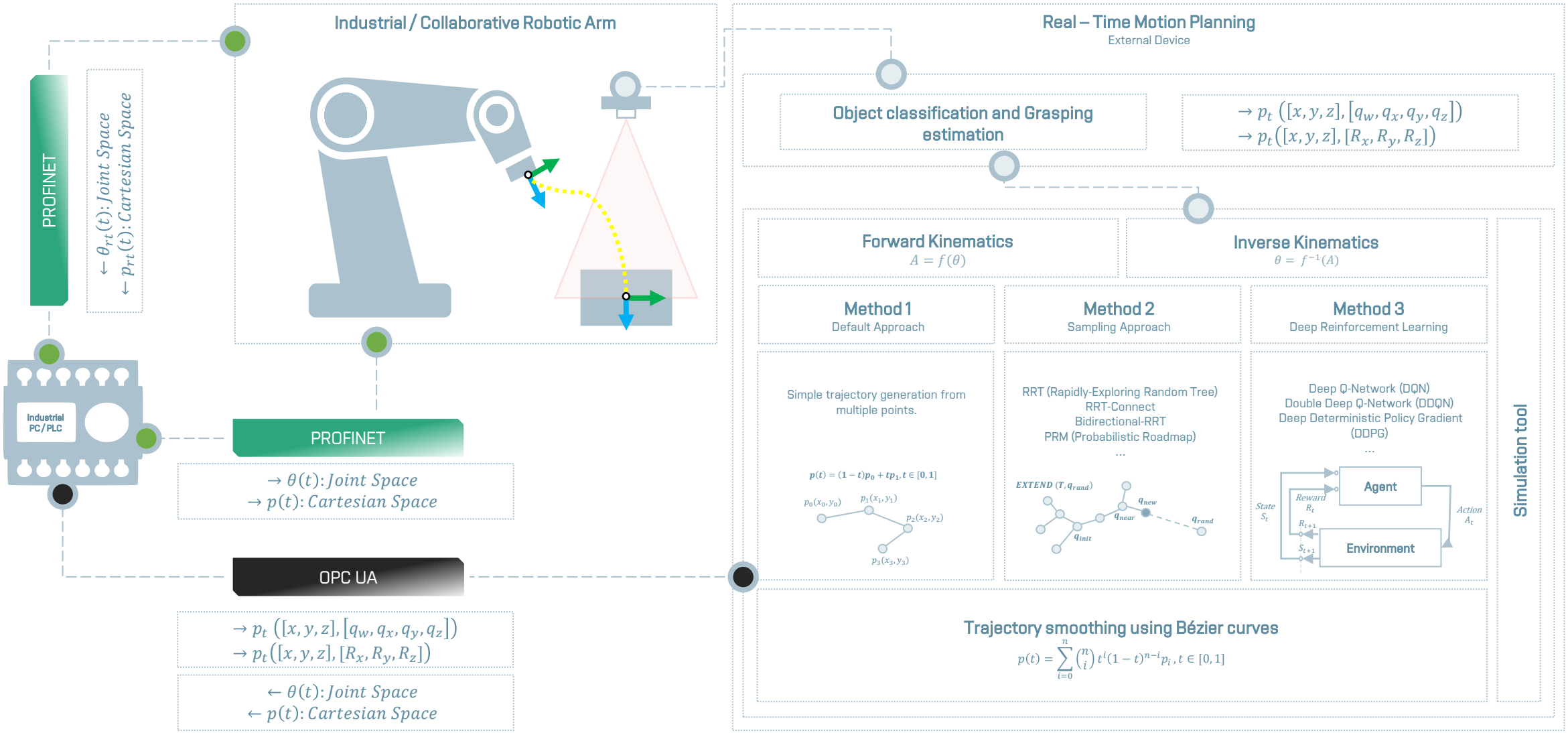


Simulation tool

Trajectory smoothing using Bézier curves

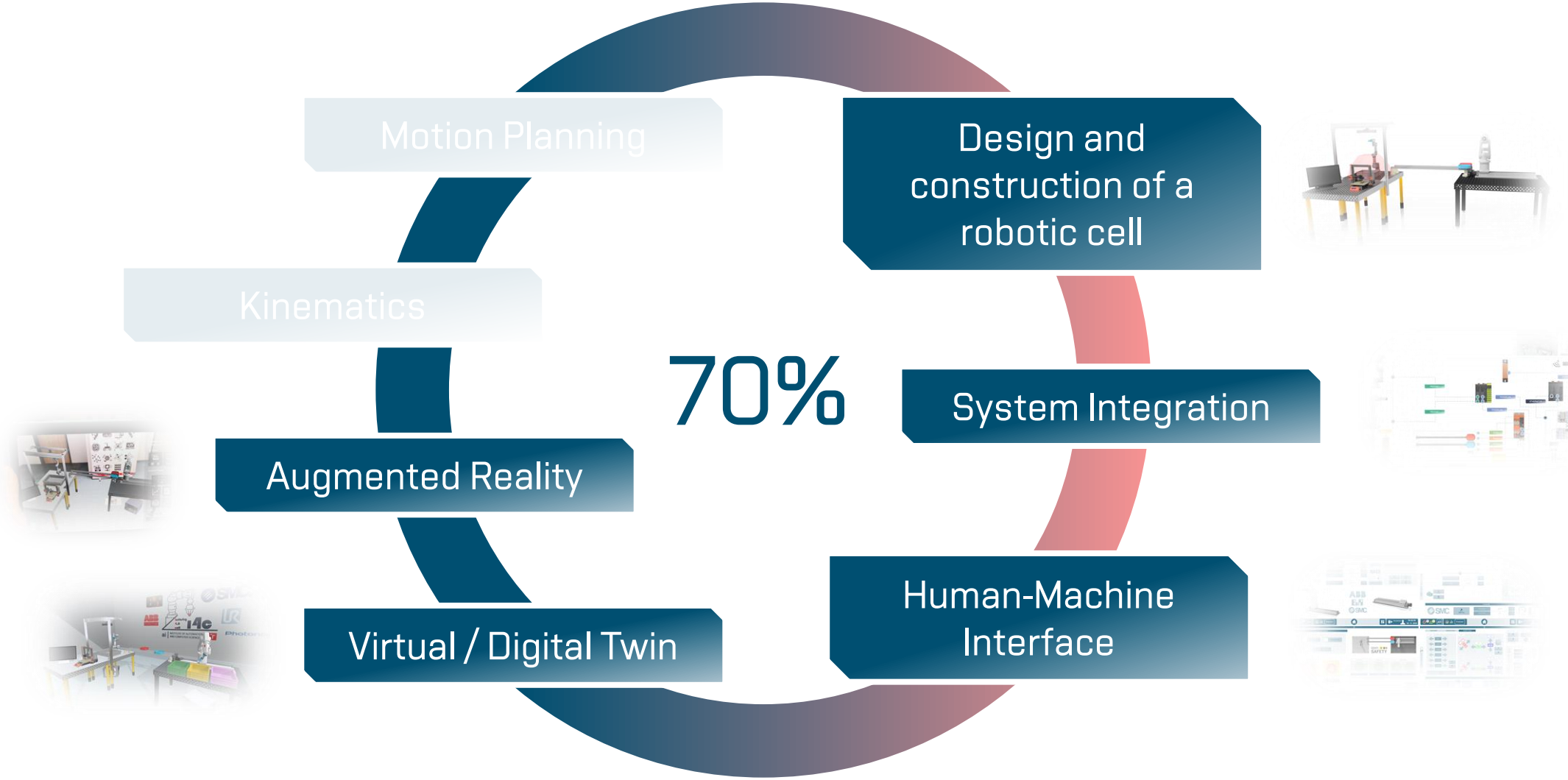
$$p(t) = \sum_{i=0}^{n} \binom{n}{i} t^i (1-t)^{n-i} p_i, t \in [0,1]$$

The main aims of the Dissertation thesis



Conclusion

Conclusion


Motion Planning
Design and construction of a robotic cell
Kinematics
70%
System Integration
Augmented Reality
Human-Machine Interface
Virtual / Digital Twin

Doctoral Activities

Doctoral Activities

- Pedagogical practice
- Projects
- Overview of supervised master's / bachelor's theses
- Publications
- Cooperation with industrial companies
- Other

Computer Science

Control Theory I & II

Automation

Industry 4.0

Machine Vision

Programming for robots and manipulators

Programmable Logic Controllers

Doctoral Activities

- Pedagogical practice
- Projects
- Overview of supervised master's / bachelor's theses
- Publications
- Cooperation with industrial companies
- Other

Research in the field of Digital twins for the production of electrical switchboards. Cooperation with ABB Group.
Duration: 01.12.2018 – 31.05.2020

Use of augmented reality for product presentation. Cooperation with SMC Industrial Automation.
Duration: 01.12.2019 – 29.02.2020

Industry 4.0 and Artificial Intelligence methods.
Duration: 01.03.2020 – 28.02.2023

Robotic workplace for the analysis of test samples. Cooperation with University Hospital Brno and CEITEC.

Program Czech Rise Up 2.0 – Research against COVID-19.
Duration: 01.06.2021 – 30.04.2022

TEST EXCHANGE. Network of Testbeds for Industry 4.0 in Czech-Austrian cooperation.
Duration: 1. 10. 2021 – 31. 12. 2022

Doctoral Activities

- Pedagogical practice
- Projects
- Overview of supervised Master's / Bachelor's theses
- Publications
- Cooperation with industrial companies
- Other

Master's Thesis	1 student
Bachelor's Thesis	11 students
Opponent	11 students
Consultant	10+ students
Awarded	3 students

- Pedagogical practice
- Projects
- Overview of supervised master's / bachelor's theses
- **Publications**
- Cooperation with industrial companies
- Other

PARAK, R.; MATOUSEK, R; LACKO, B. I4C - Robotic cell according to the Industry 4.0 concept. Automa, 2021, vol. 27, no. 1, p. 10 – 12. ISSN: 1210-9592.

PARAK, R.; MATOUSEK, R. Comparison of multiple Reinforcement Learning and Deep Reinforcement Learning methods for the task aimed at achieving the goal. Mendel Journal series, 2021, vol. 27 (2021), no. 1, p. 1 – 8. ISSN: 1803-3814

Czech Institute of Informatics, Robotics and Cybernetics (CIIRC CTU) and Industry 4.0 Cluster:
I4C - Robotic Cell of Industry 4.0 at IACS FME BUT in Brno

- Pedagogical practice
- Projects
- Overview of supervised master's / bachelor's theses
- Publications
- Cooperation with industrial companies
- Other

Doctoral Activities

- Pedagogical practice
- Projects
- Overview of supervised master's / bachelor's theses
- Publications
- Cooperation with industrial companies
- Other

Organizer / co-organizer

International Conference on Soft Computing MENDEL, Principia Cybernetica, Open Days, Night of Scientists

Speaker

Science enjoys us, Trade Media International - Conference on robotics (2020, 2021), Industry 4.0 Cluster (2021)

Collaborator

University Course – master's studies (Programming for robots and manipulators) / bachelor's studies (Industry 4.0), Teaching materials for bachelor's / master's studies, Laboratory improvement / development

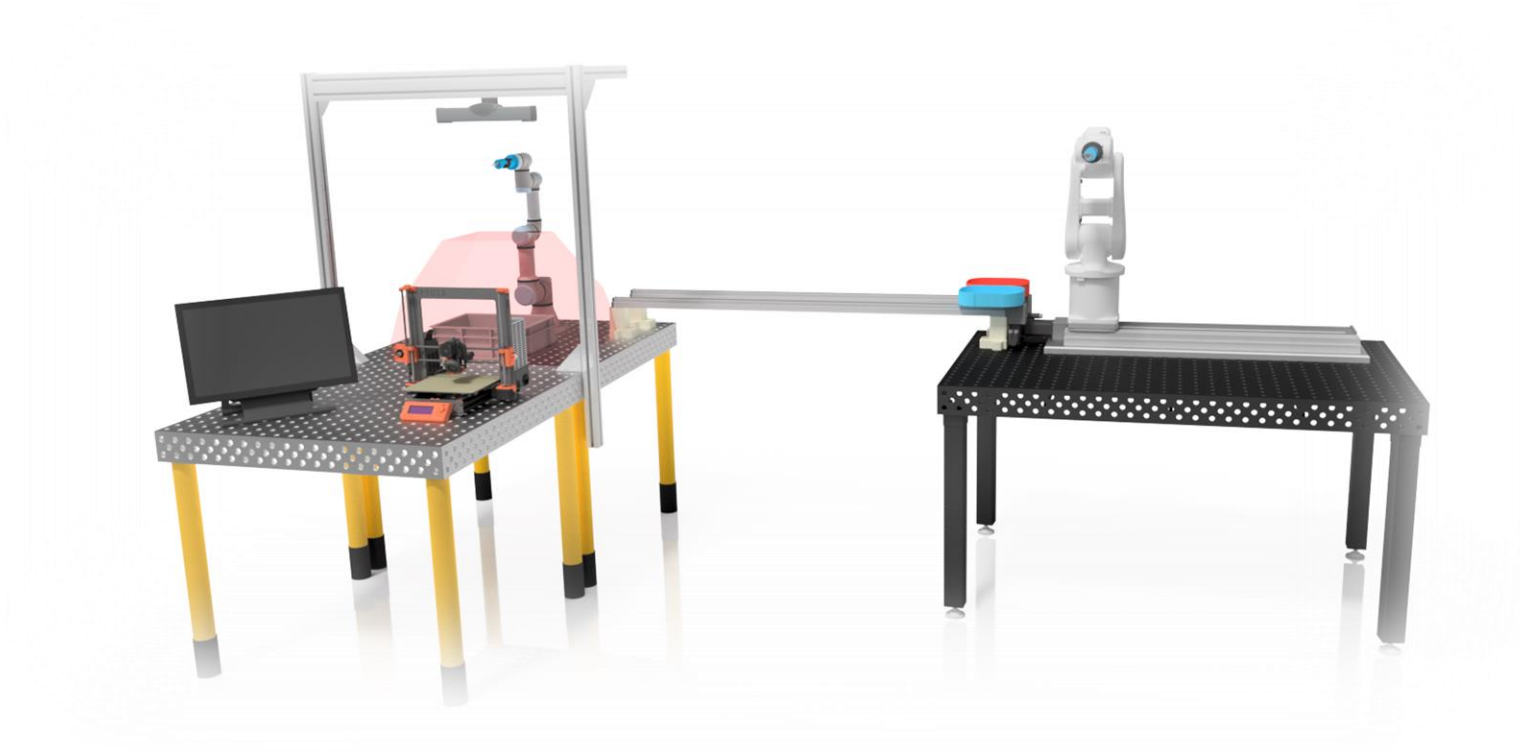
Member of the Commission - State Examination

Secretary

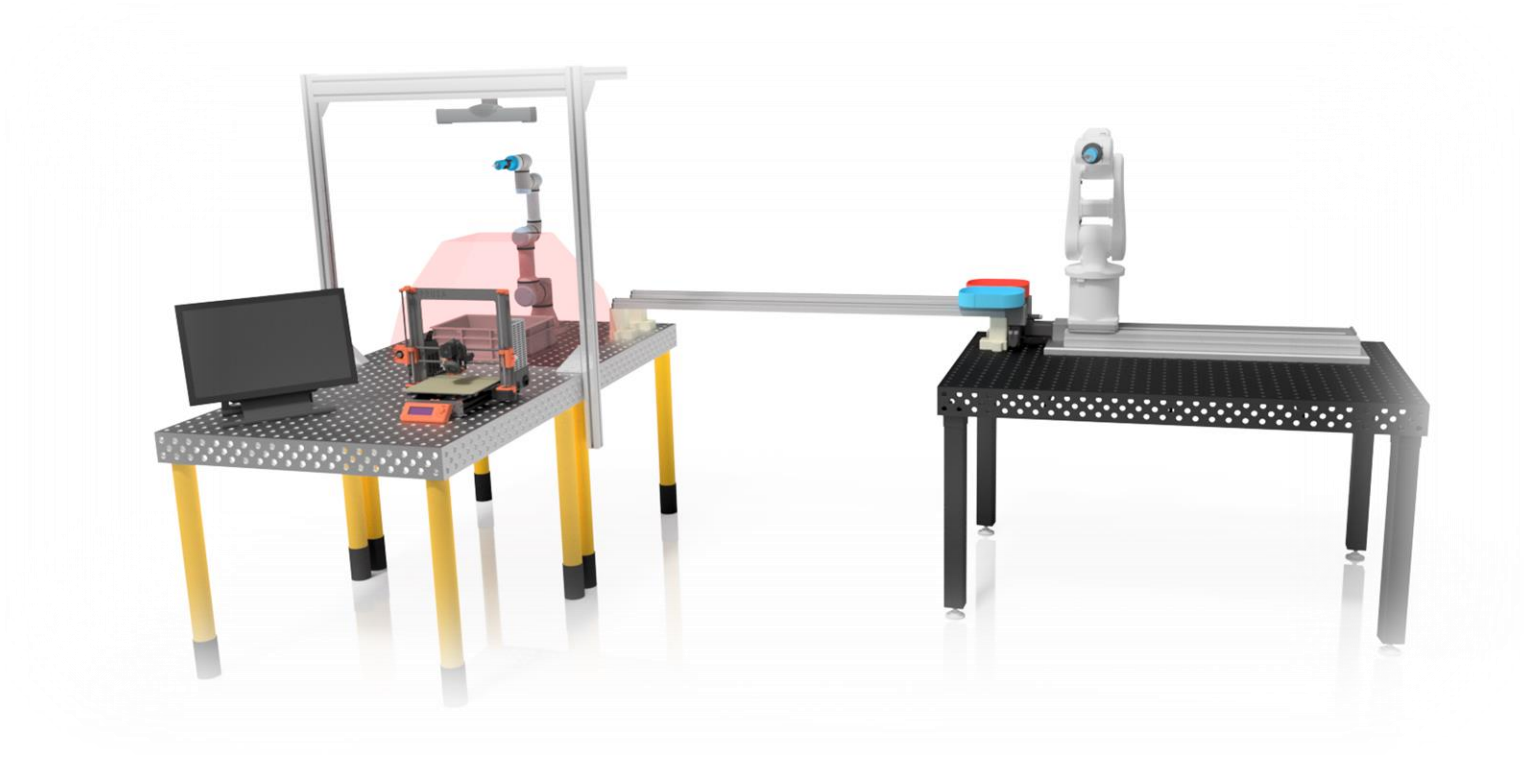
Honors & Awards:

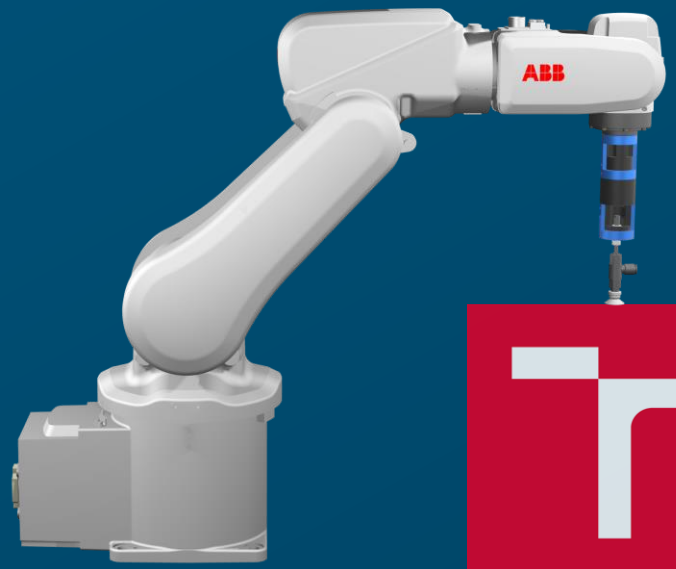
Rector's Award for Ph.D. students, Silver medal – Team Award

Thank You!



Questions?





FACULTY OF MECHANICAL ENGINEERING

institute of automation and computer science