2nd Czech-German Business Meeting:
Transforming Industry with Intelligent Production and Energy Solutions

AI-Driven Sensor-Based Robotics for Sustainable and Flexible Manufacturing

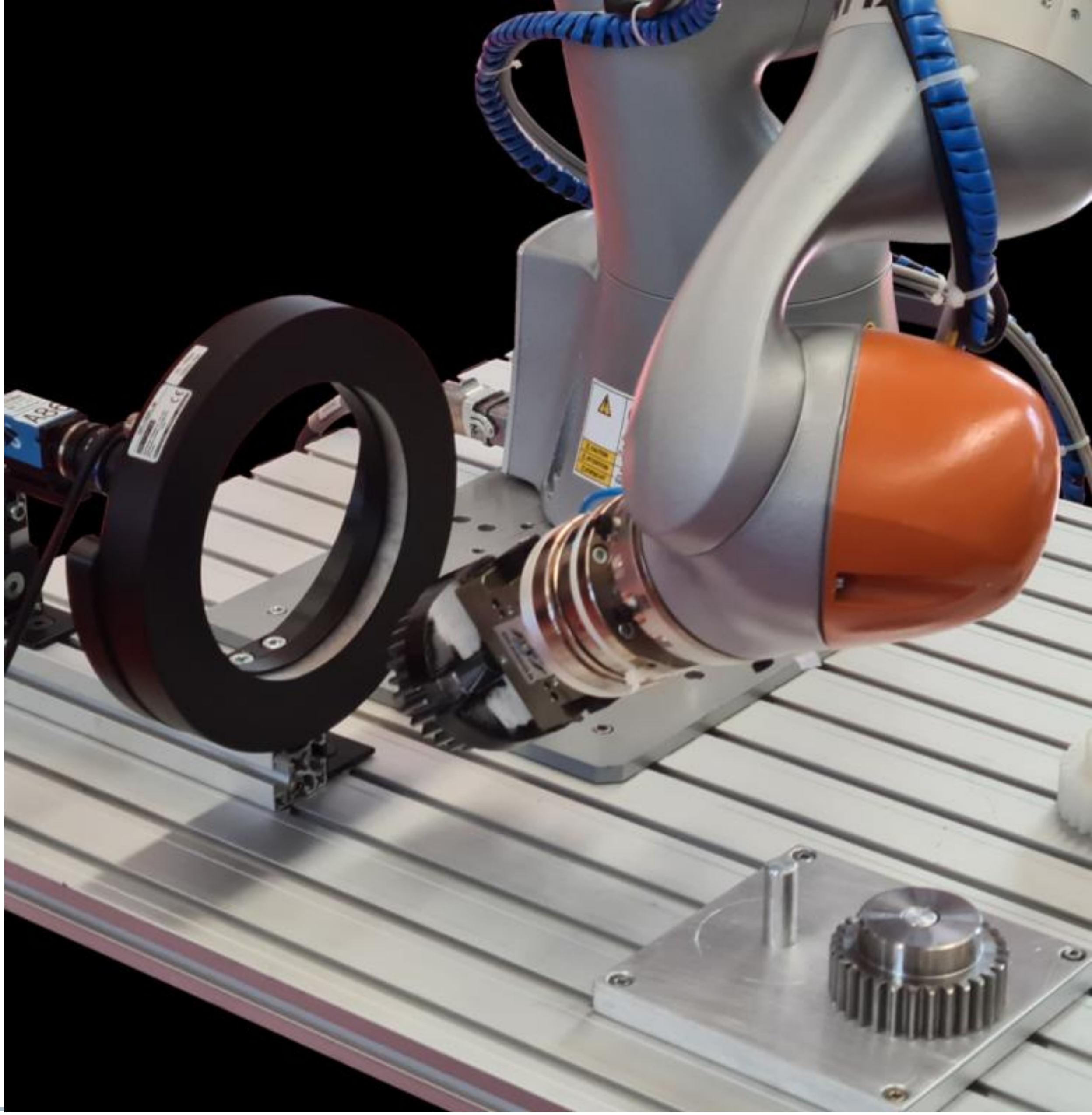
Prof. Ruth Otto [a], Rico Löser [b]

[a] University of Applied Sciences Munich, Lothstr. 34, 80335 Munich, Germany

[b] Fraunhofer Institute for Machine Tools and Forming Technology IWU, 09126 Chemnitz, Germany

Agenda

- Introduction
- Methodology and Preliminary Results
- Final Setup
- Outlook and Next Steps



DLR Projektträger HM Hochschule München University of Applied Sciences Fraunhofer IWU

GreenBotAI

Frugal and adaptive AI for flexible industrial Robotics

GreenBotAI

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE

Liberté Égalité Fraternité

Project Partners

active

1. Fraunhofer IWU
2. HM Hochschule München University of Applied Sciences
3. inbolt
4. Arts et Métiers Sciences et Technologies / lispen

inactive

I. GML

II. edixia – we ensure your quality

Associated Partners

A. EPF École d'ingénieur-e-s

B. KUKA

C. ERM Automatismes – Didactique | Robotique | Fab&Test | Energies

D. EvoBus

E. STELLANTIS

1. **Ensuring continuous production in Europe during pandemics**
2. **Guaranteeing European sovereignty in terms of production automation**
3. **Reducing the energy consumption of robotic applications by 50 %**

GreenBotAI
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag
MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE
Liberté Égalité Fraternité

GreenBotAI

Motivation - Green, Sustainable and Resource Efficient Manufacturing

Challenges in European manufacturing:

- Shift from mass to production on demand
- Complex, flexible production lines
- Global competition, pandemic risks
- Demand for low defect rates

Conflicting requirements:

- Need for skilled, flexible systems
- Simultaneous demand for autonomous, cost-effective automation

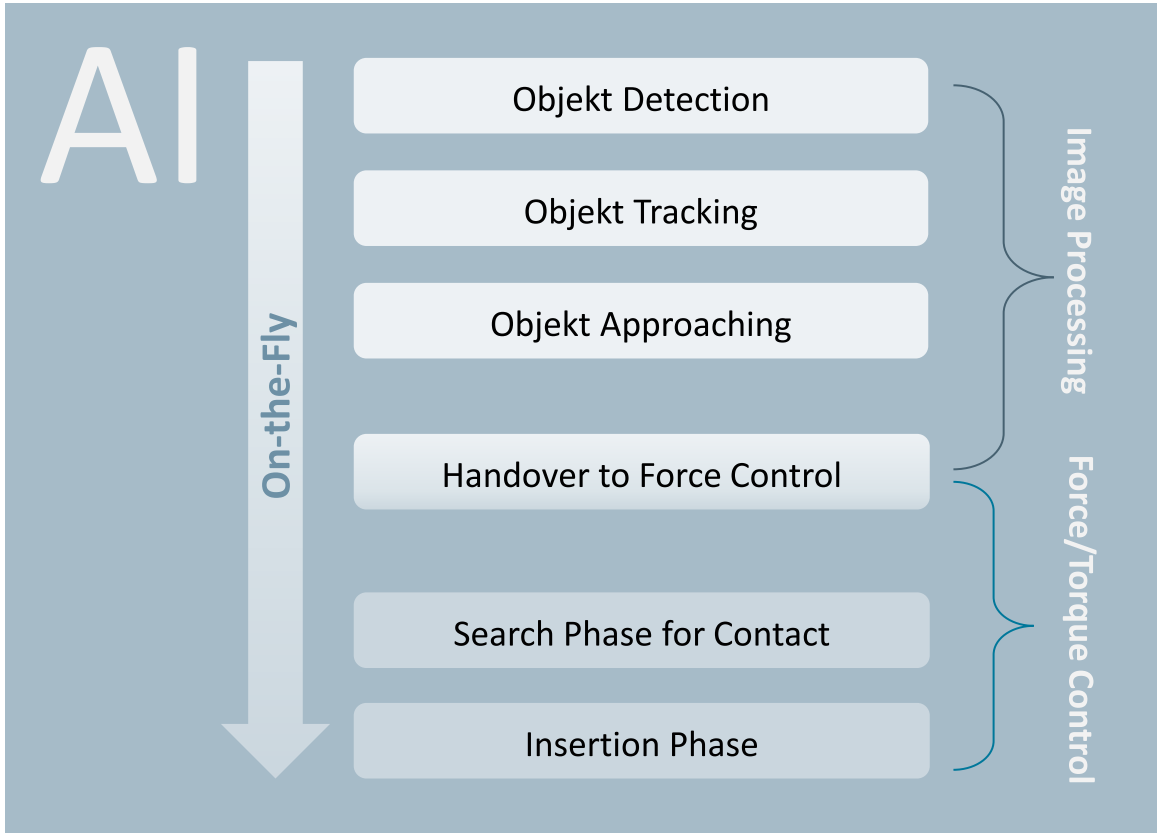
Project goal is an intelligent system to:

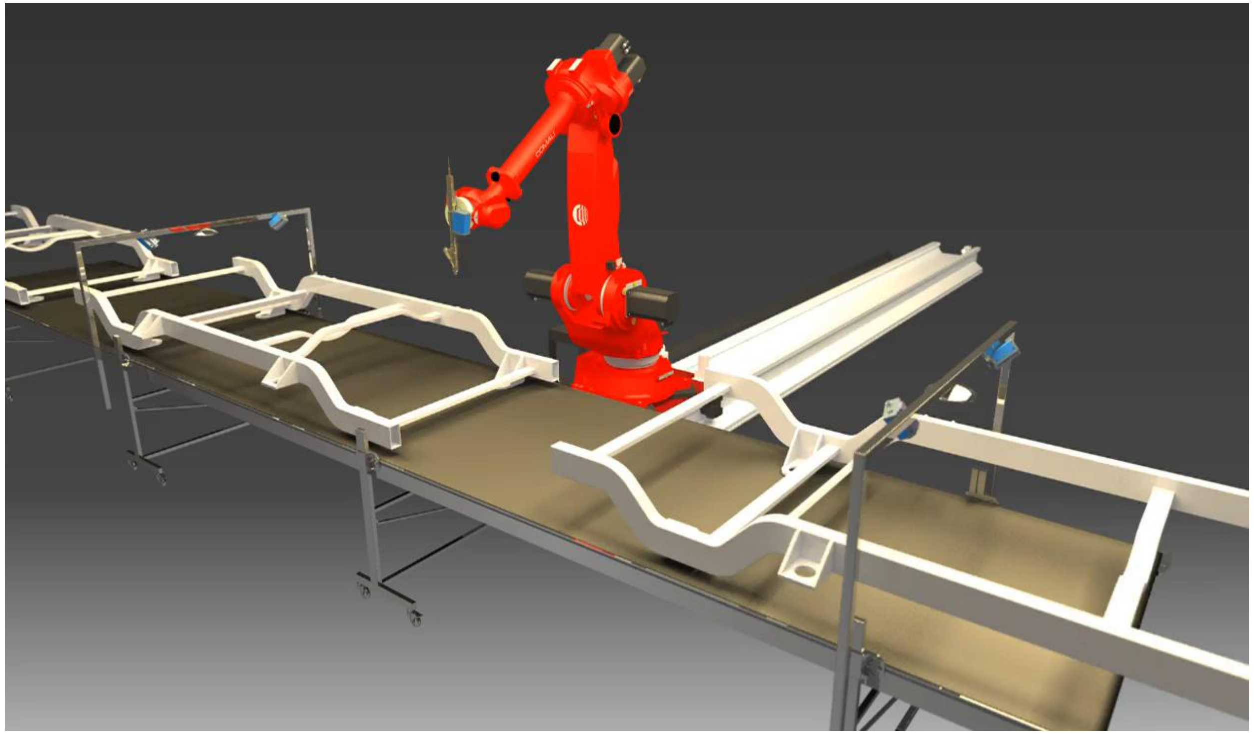
- Enable self-adaptive industrial robots
- Handle complex, labor-intensive tasks
- Perform defect control during handling
- Reduce installation and teach-in time
- Lightweighted AI models / Data reduction in space, time, activation
- Using of low energy consumption hardware

GreenBotAI

Motivation and solution approach

Our Vision for an AI driven, self-learning robot assembly system On-the-Fly





Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag
MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE
Liberté Égalité Fraternité
DLR Projektträger
HM Hochschule München University of Applied Sciences
Fraunhofer IWU

Fraunhofer IWU

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE

Liberté Égalité Fraternité

GreenBotAI – Methodology

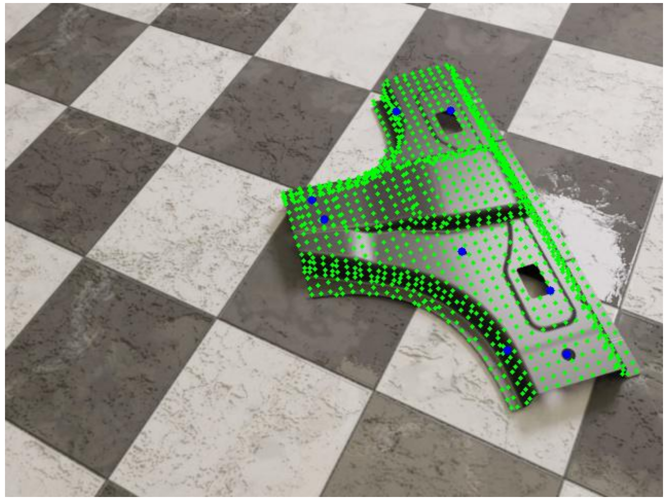
6 DoF pose estimation on the fly / AI training – data acquisition

BlenderProc: Photorealistic Rendering Pipeline

- Create a 5-sided room ("tub")
- Add ceiling area light and point light
- Randomly place object in the room
- Randomly position camera on a sphere around the object
- Align camera to face the object
- Apply random camera translation

Generate required labels based on the known transformation

- Input information: Homogeneous transformation matrix (camera -> object)
- Required output information:
  - Bounding Box
  - Image coordinates of keypoints
- Calculation of the keypoint coordinates in the image:



$$Y = K \cdot RT \cdot [X, 1]^T$$

K – Intrinsic camera parameter

RT – Homogeneous transformation (camera -> object)

X – 3D keypoint coordinates

Y – 2D keypoint coordinates in the image

DLR Projektträger

HM Hochschule München University of Applied Sciences

Fraunhofer IWU

GreenBotAI – Preliminary Results

Tracking of structureless moving parts with NC-robots

GreenBotAI
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag
MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE
Liberté
Égalité
Fraternité

4 DoF pose estimation for robot assembly on-the-fly

- One shot demonstration

→ **15 fps** with accuracy of **< 1 mm** for tracking

→ **10.5 W** of power consumption @ 2.4 GHz

6 DoF pose estimation for robot assembly on-the-fly

- Data acquisition (real and photorealistic) + Training

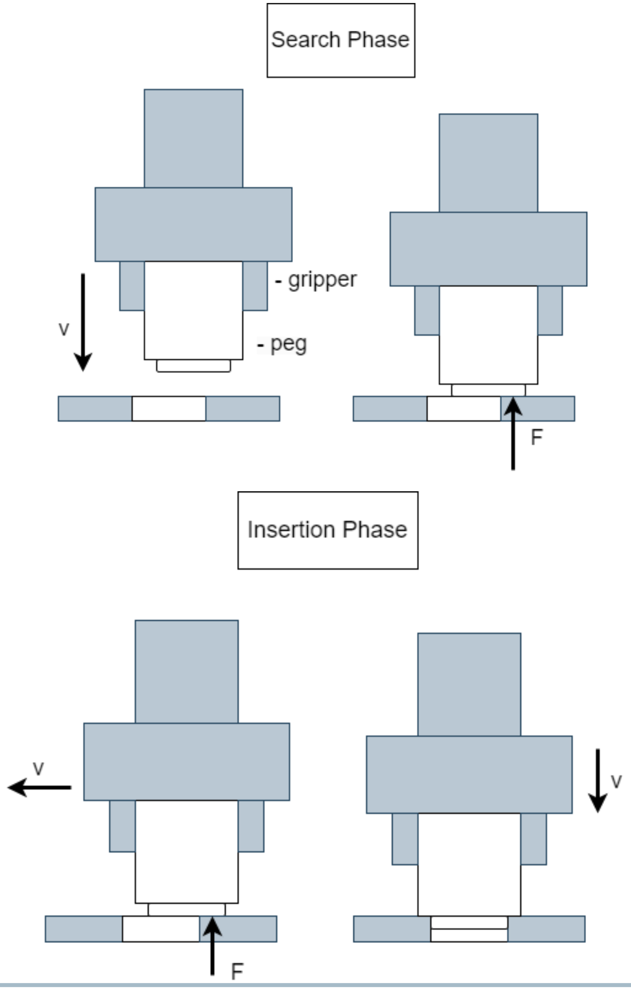
→ Mean L2-error of **< 3.5 mm @13 fps**

→ Max **15 W** of power consumption @1.7 GHz

GreenBotAI – Methodology

Force-torque-controlled Peg-in-Hole Assembly

GreenBotAI
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag
MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE
Liberté Égalité Fraternité



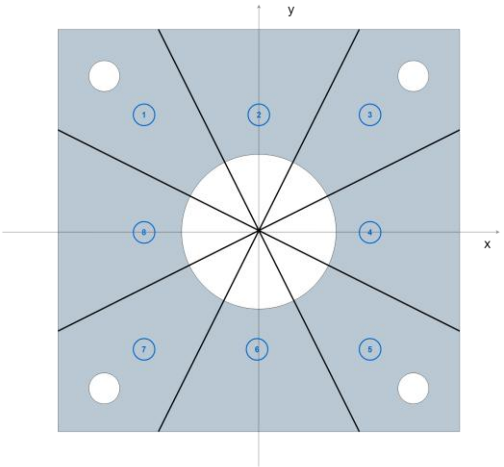
Core Concept: Neural network model to predict gap between current and target position.

$$input = [\tau^{ex}, \tau^{in}, F_x, F_y, F_z, \tau_x, \tau_y, \tau_z]$$

- τ^{ex} external joint torques
- τ^{in} internal joint torques
- F_x, F_y, F_z TCP forces
- τ_x, τ_y, τ_z TCP torques

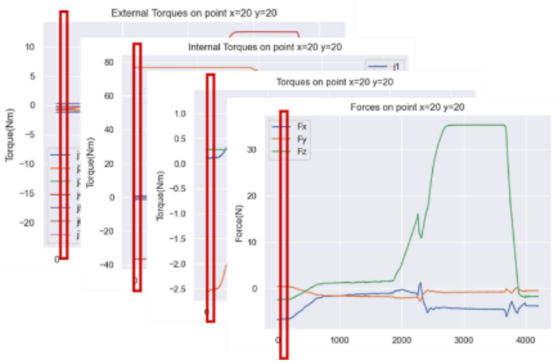
DNN Classification

- 8 error areas



CNN Classification

- Using force and torque values in sequence



DNN Regression

- peg center error position in x and y direction

DLR Projektträger
HM Hochschule München University of Applied Sciences
Fraunhofer IWU

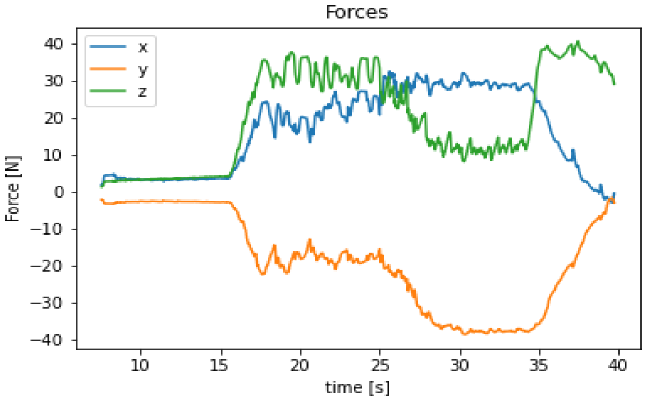
GreenBotAI
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag
MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE
Liberté Égalité Fraternité

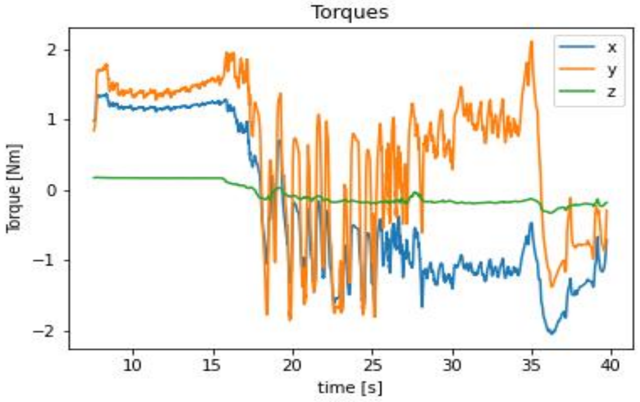
GreenBotAI – Preliminary Results

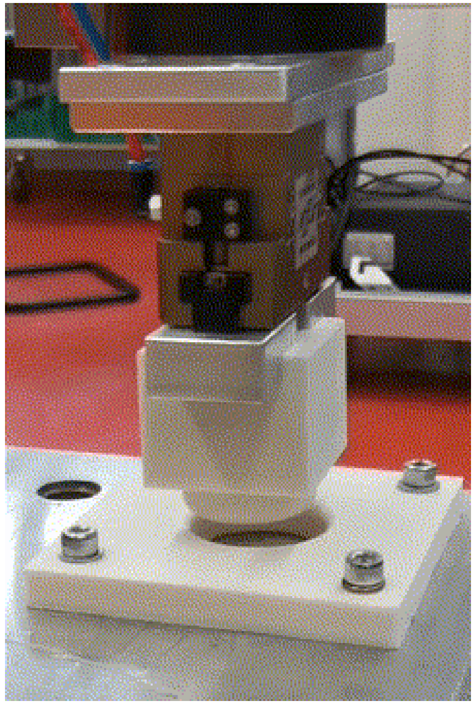
Force-torque-controlled Peg-in-Hole Assembly

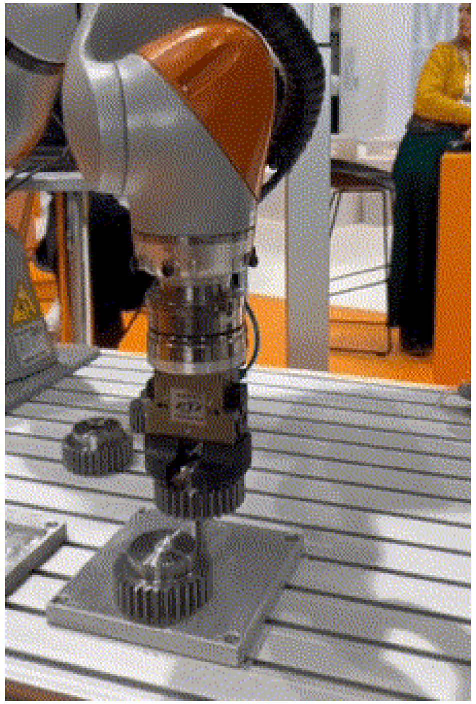
AI-empowered flexible force torque control assembly

- Compensation of uncertainties through AI-driven force-torque control strategies
- Simplification of time-consuming force-torque control programming
- Reduction of force-torque control process time by factor 10
- Minimizing assembly-related collisions to avoid component damage.





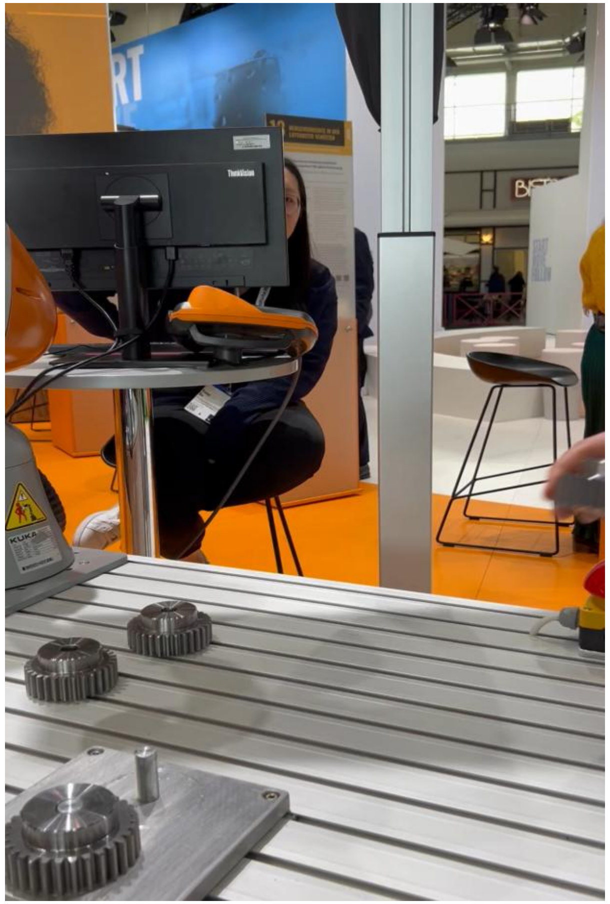


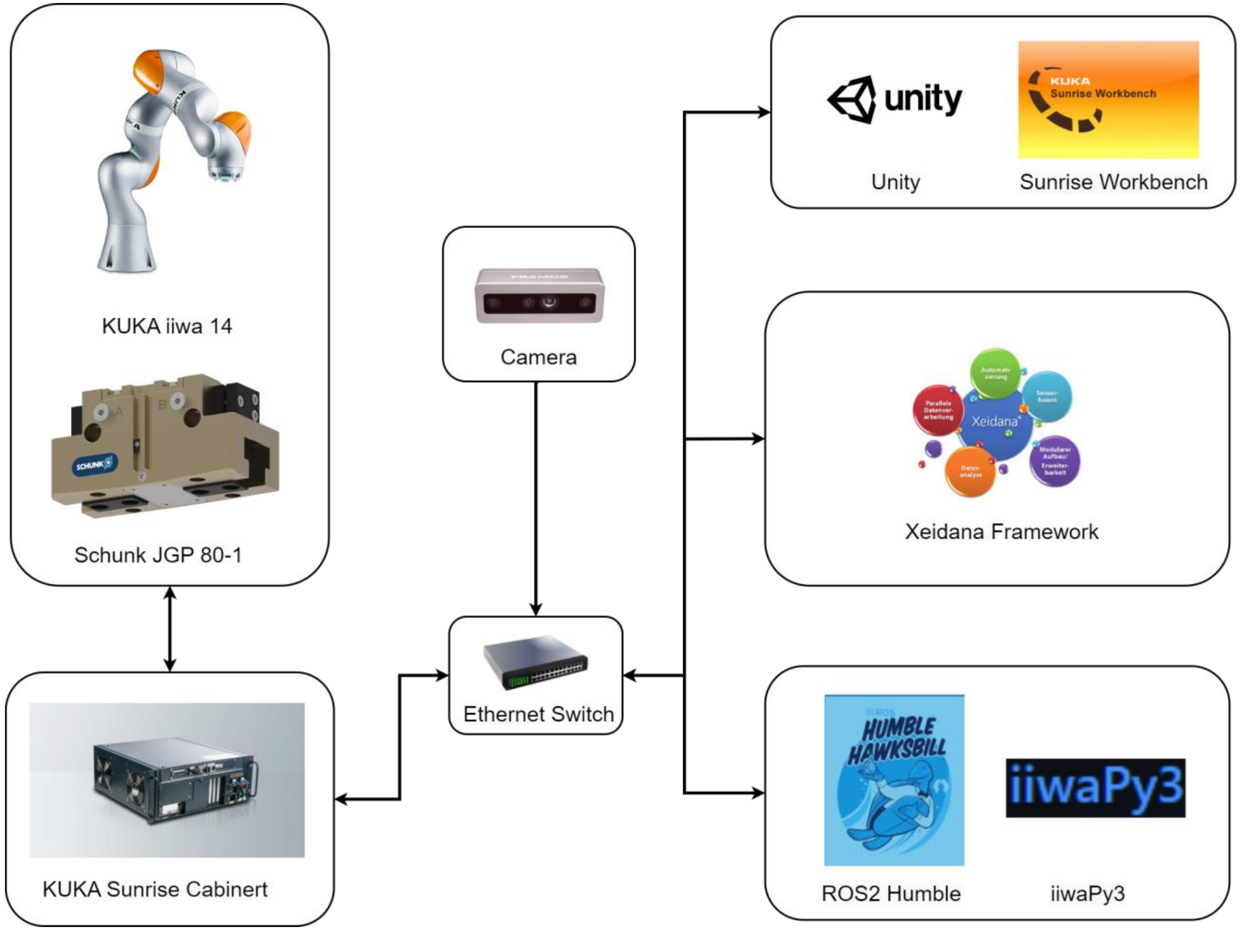


DLR Projektträger
HM Hochschule München University of Applied Sciences
Fraunhofer IWU

GreenBotAI – Preliminary Results

Gear Assembly at Hannover Fair April.2024





GreenBotAI
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag
MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE
Liberté Égalité Fraternité

GreenBotAI – Methodology

On-the-Fly force-torque-controlled Peg-in-Hole Assembly

Search-Phase Overview

The robot applies a downward force along the Z-axis and lateral forces in the X and/or Y directions to locate the hole in the plate. The search phase ends when one of the following conditions is met:

- **Successful Insertion:** The agent receives a reward.
- **Maximum Steps Reached:** The episode restarts.
- **Safety Constraints Triggered:** Predefined limits are exceeded. The agent receives a penalty.

$$States = [T, F_x, F_y, F_z, T_x, T_y, T_z, v]$$

- T: joint torques
- F_x, F_y, F_z TCP forces
- T_x, T_y, T_z TCP torques
- v: velocities of conveyor belt

$$Actions = [f_x, f_y, f_z, \tau_x, \tau_y, \tau_z]$$

- f_x, f_y, f_z force command/search function
- τ_x, τ_y, τ_z torque command

States

T, $F_x, F_y, F_z, T_x, T_y, T_z$

↓

Reinforcement Learning Policy

↓

Actions

$f_x, f_y, f_z, \tau_x, \tau_y, \tau_z$

DLR Projektträger
HM Hochschule München University of Applied Sciences
Fraunhofer IWU

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

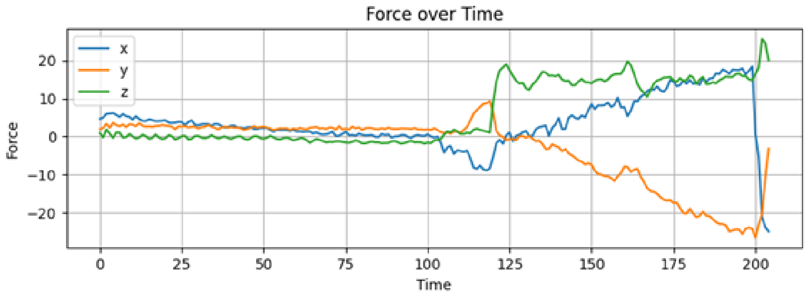
MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE
Liberté Égalité Fraternité

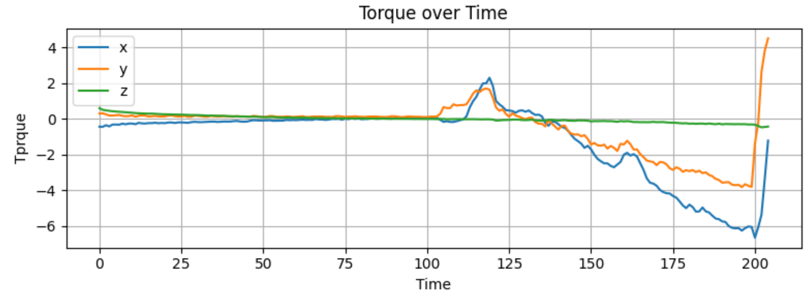
GreenBotAI – Preliminary Results

On-the-Fly force-torque-controlled Peg-in-Hole Assembly

AI-empowered flexible **On-the-Fly** force torque control assembly

- Synchronization between robot and moving part
- Reduction of additional hardware to track the part during assembly process
- Minimization of Commissioning Times and Downtimes





DLR Projektträger · HM Hochschule München University of Applied Sciences · Fraunhofer IWU

GreenBotAI – Preliminary Results

Digital Twin

GreenBotAI

Supported by:

Federal Ministry for Economic Affairs and Climate Action

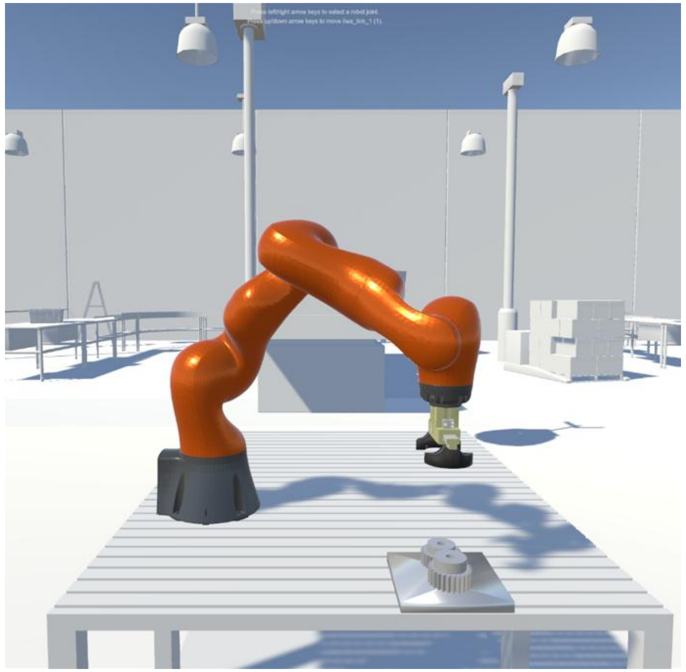
on the basis of a decision by the German Bundestag

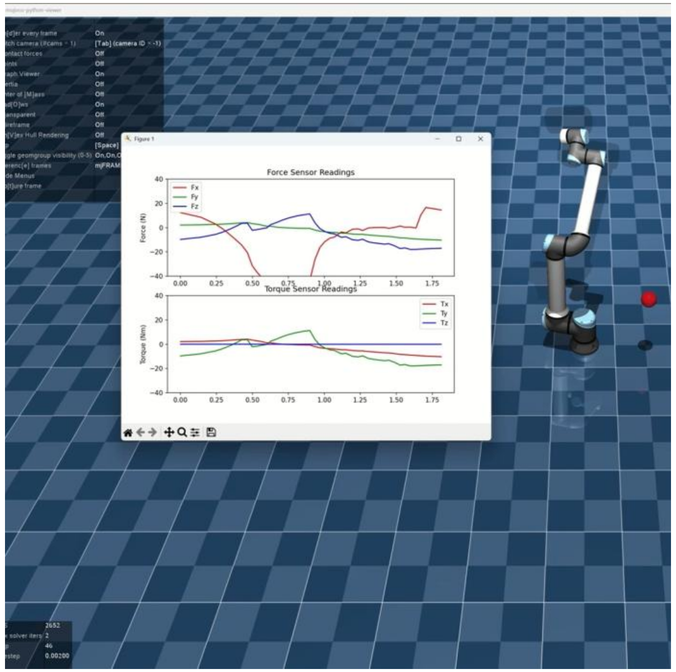
MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE

Liberté
Égalité
Fraternité

Vision and Force torque enabled digital twin

- Real-time virtual scenario reproduction
- Synthetic data to extend the dataset for AI
- Optimization of setup configuration and reducing setup time by simulation of realistic data





DLR Projektträger

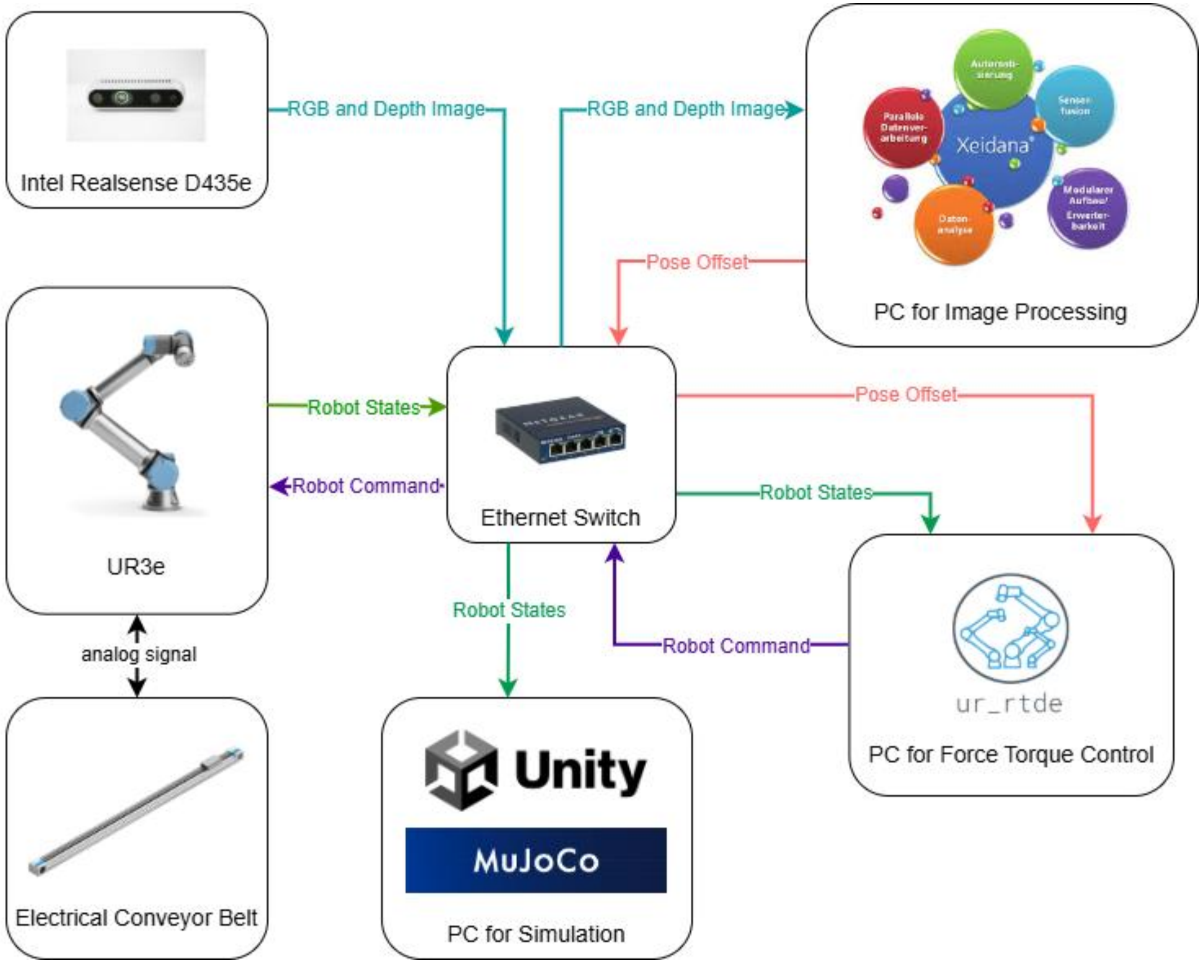
HM Hochschule München University of Applied Sciences

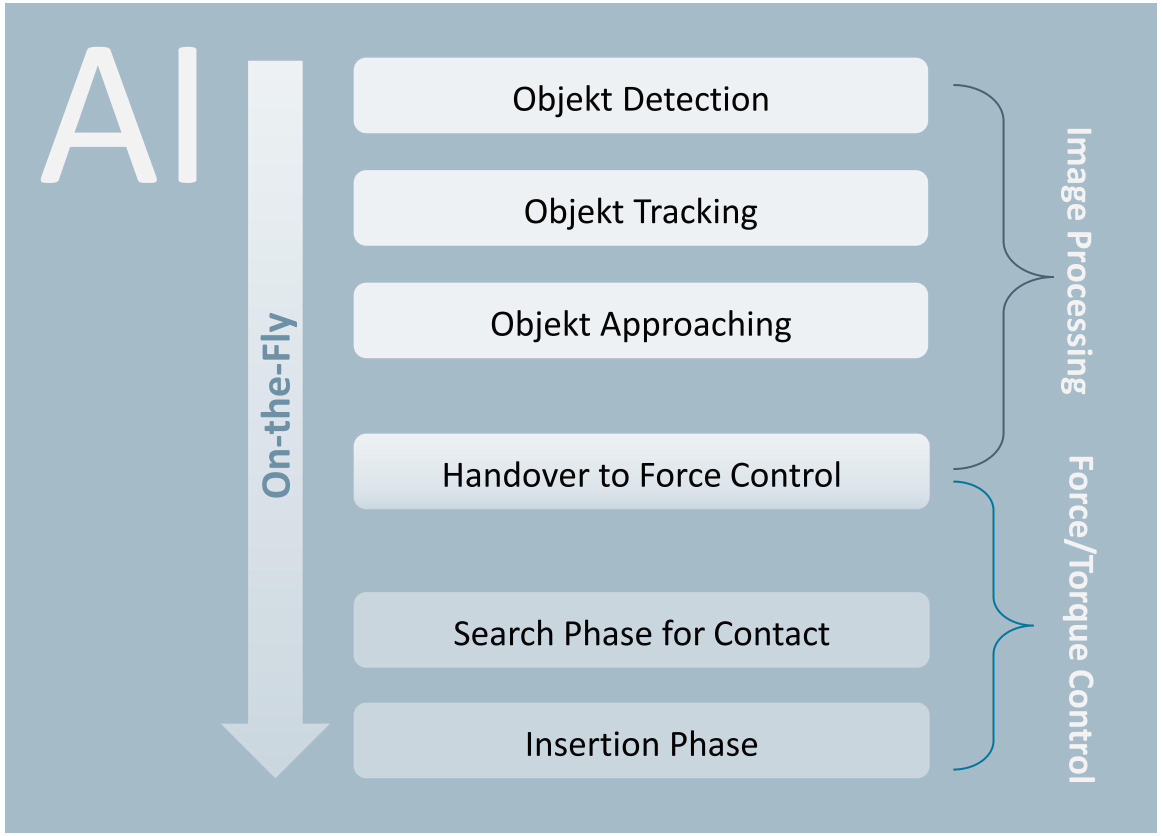
Fraunhofer IWU

GreenBotAI – Automatica 2025, June 24th-27th

Setup: **On-the-Fly** Vision and Force-Torque-controlled Peg-in-Hole Assembly

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag
MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE
Liberté
Égalité
Fraternité





DLR Projektträger
HM Hochschule München University of Applied Sciences
Fraunhofer IWU

GreenBotAI
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag
MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE
Liberté Égalité Fraternité

Outlook and Next Steps

AI-Driven Robotic Disassembly and Inspection Platform

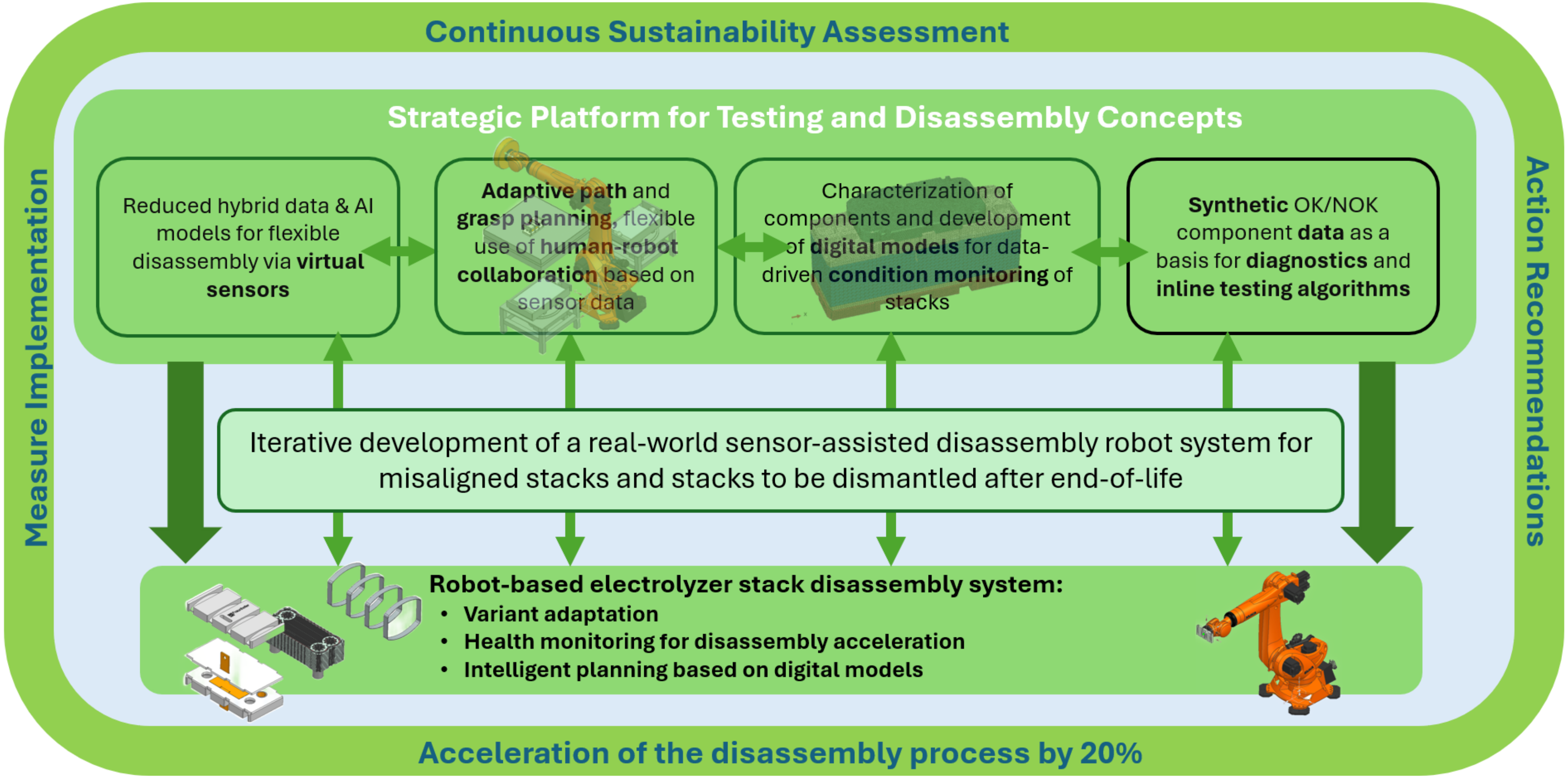
The planned follow-up project builds directly on the results of GreenBotAI, transferring validated methods to new application scenarios.

Vision and Key innovations:

- AI-based system for identifying faulty components, e.g. in PEM electrolyzers
- Robotic platform enables automated inspection and disassembly
- Uses abnormal behavior data to detect defects early
- Virtual Commissioning accelerates development and testing
- Mixed Reality supports intuitive operation and system interaction
- Digital Twin and synthetic data reduce false detection rates by up to 50%
- Goal: 20% faster disassembly and 25% lower costs through intelligent automation

DLR Projektträger
HM Hochschule München University of Applied Sciences
Fraunhofer IWU

Outlook and Next Steps



GreenBotAI
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag
MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE
Liberté Égalité Fraternité
DLR Projektträger
HM Hochschule München University of Applied Sciences
Fraunhofer IWU

GreenBotAI

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag
MINISTÈRE DE L'ÉCONOMIE, DES FINANCES ET DE LA RELANCE
Liberté Égalité Fraternité

Thank you for your attention!

Contact

Prof. Ruth Otto
rotto@hm.edu
Professor for Robotics and Industrial Automation
Munich University of Applied Sciences

Contact

M. Eng. / Diplôme d'Ingénieur Rico Löser
Rico.Loeser@iwu.fraunhofer.de
Consortium Management
Fraunhofer IWU

GreenBotAI Webseite

Acknowledgements

The work is part of the France-German project GreenBotAI - Frugal and adaptive AI for flexible industrial Robotics which is supported by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) on the basis of a decision by the German Bundestag under the contract Grant 01MJ22001.

DLR Projektträger
HM Hochschule München University of Applied Sciences
Fraunhofer IWU