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Knowledge-Based Digital Twin for Predicting Interactions in Human-Robot Collaboration

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Introduction

Statistics regarding human-robot collaboration (HRC) show the global market's projection from **USD 981 million** in 2020 to USD **7,972 million** in 2026 (41.8% compound annual growth rate (CAGR))

More than **15% growth in the installation of cobots until 2028**.
- Affordability, easy to use and low cost

Future achievements should address **accuracy**, **productivity**, **efficiency**, **performance**, **safety**, and **autonomy**

Classical approach

- Human worker is an isolated co-worker
- Rigid planning

Source: *Factory 51 simulation in Technomatix plant simulation*

Collaborative approach

- **Agile planning, and digitally twinable**
- Assisting the **decision-making.**

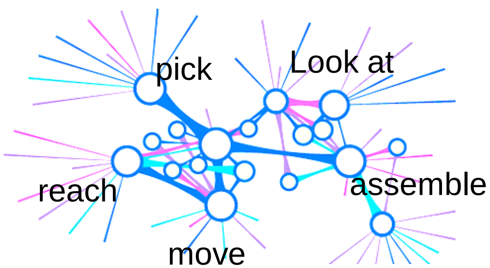
Objective

- In this regard, interpreting and predicting human actions during an assembly task can help to create a **smooth collaboration** (e.g., joint task handling). This may lead to **efficient** and **adaptable robot programming** using a semantic representation of human and robot models.

- In this research, we explore **opportunities** and **challenges** for the semantic representation of human models in the operation phase of cyber-physical production systems (CPPS).

- And, present a concept of **human-robot interaction** in various application domains such as AR/VR, multi-modal interaction, HRC, and big data demonstration.

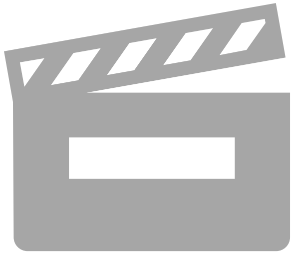
Aspects that determine the effectiveness of predicting human intentions for human-robot interaction, namely are:



a) Ontology

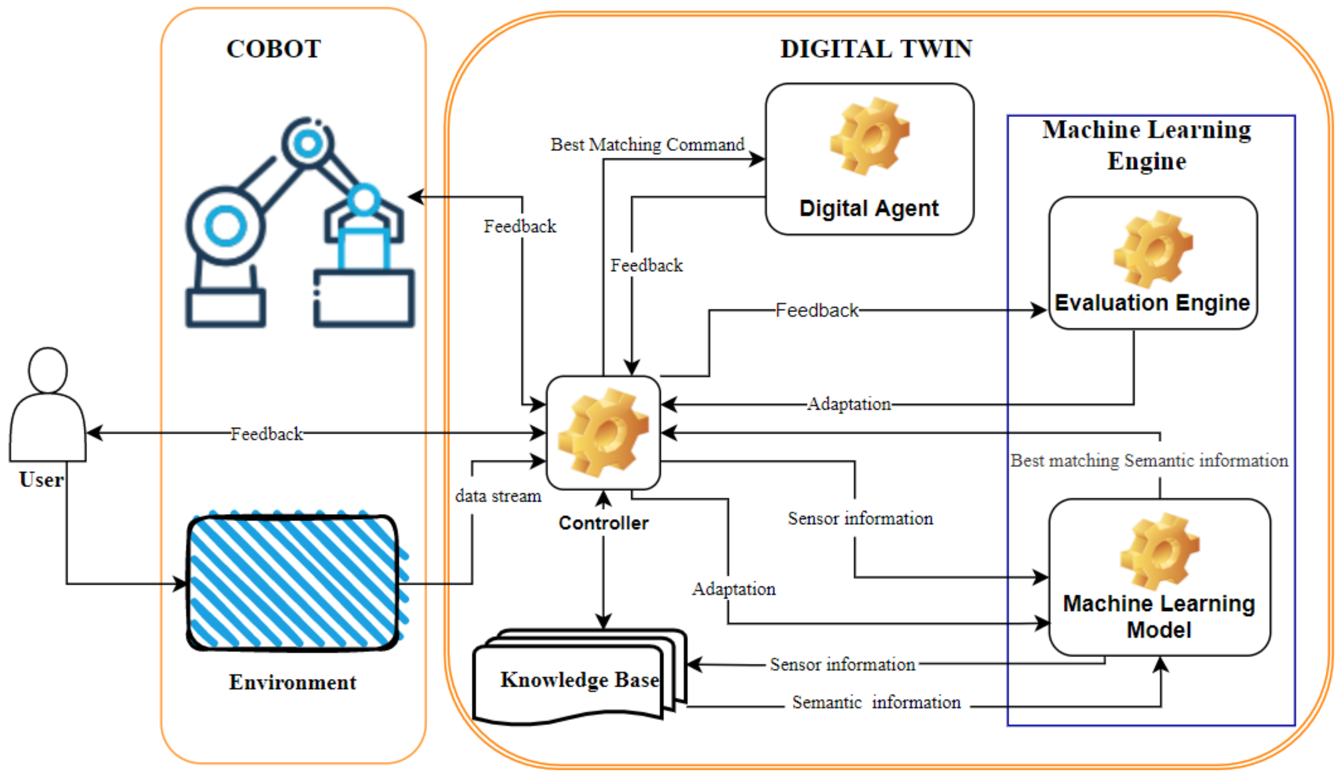
b) Digital twin (FAMS)

c) Motion Modeling (Manns *et al*. 2018)



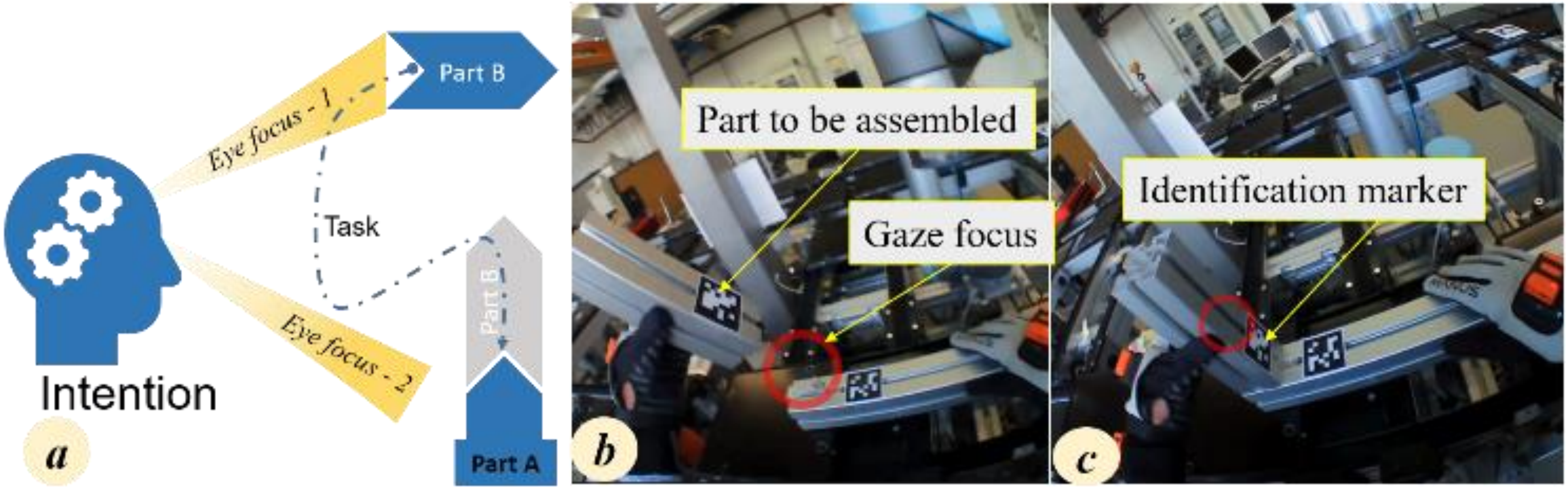
d) Action, attention, and intention

Methods for semantic representation and Intention Prediction in HRC

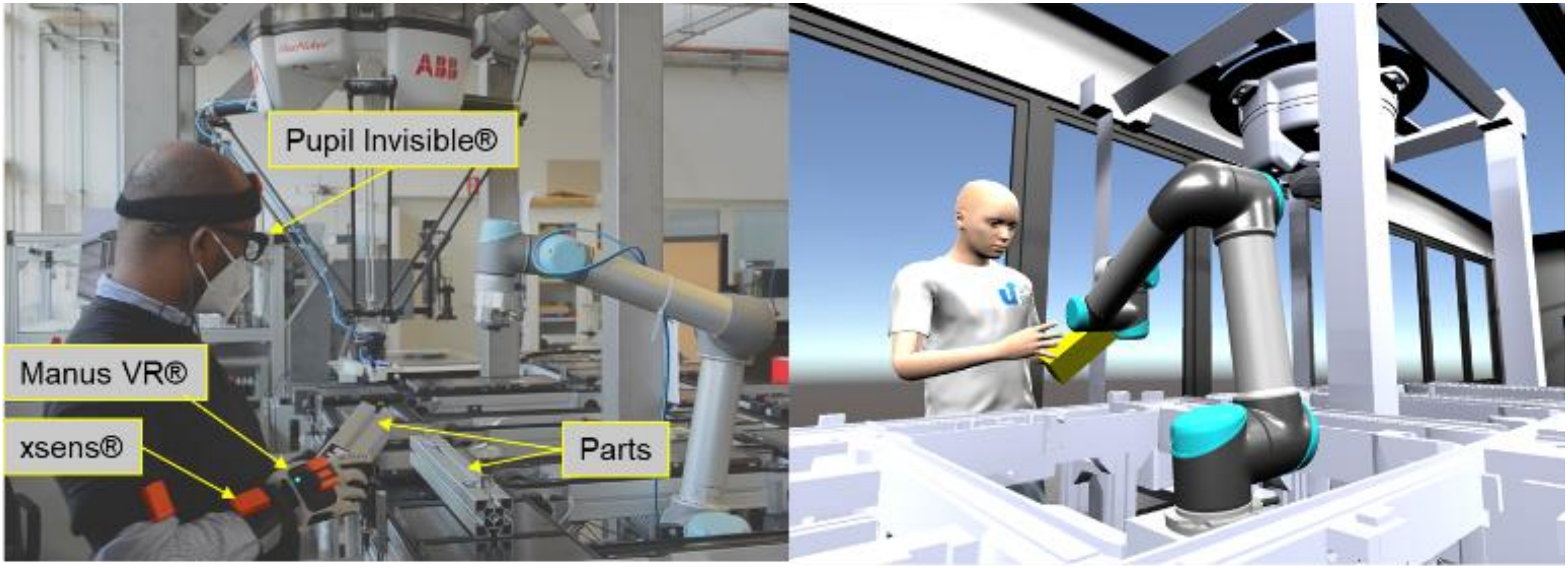


Knowledge-based digital twin concept of the ontological human intention prediction for HRC.

Results



Process illustration for motion capture-based (e.g., gaze) on intention prediction scenario and proof of the concept. In (a), the human looks at part B with *eye focus-1* and then finds the target position by moving into *eye focus 2*. Then decides the assembly position and orientation. Finally, the robot picks the assembled product and places it in mobile storage.



Demonstration of the digital hub for ontological human intention prediction in HRC.

FAMS Fertigungsautomatisierung und Montage

Actual motion

- The worker assembles a frame consisting of aluminum profiles in collaboration with a cobot.
- The movements performed by the worker are: Looking at the object, picking it, moving it, and placing it at the assembly location.
- Only hand and gaze motions are considered to describe human activities in the current investigation.

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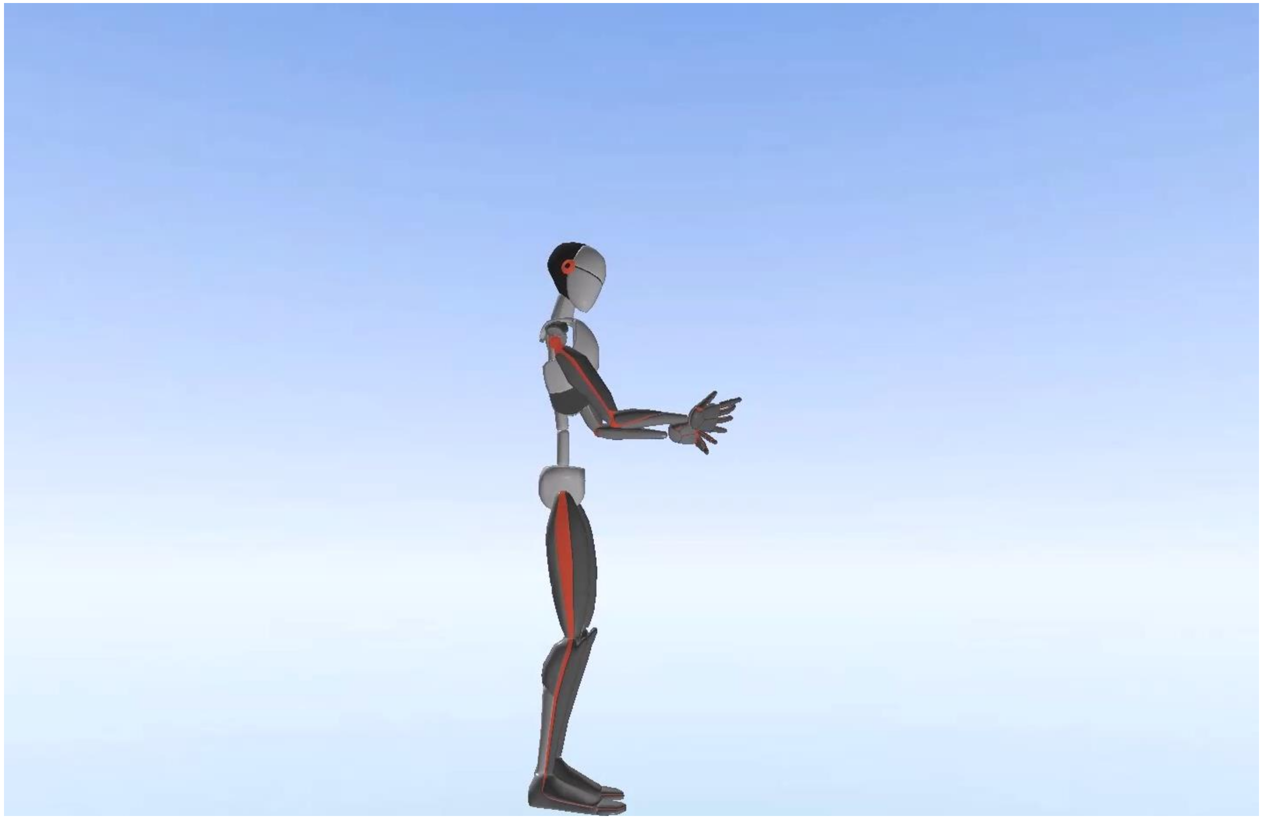
Virtual motion, using MVN env‘t



- Motion data visualization,
- Post processing,
- Online streaming to Unity3D env‘t

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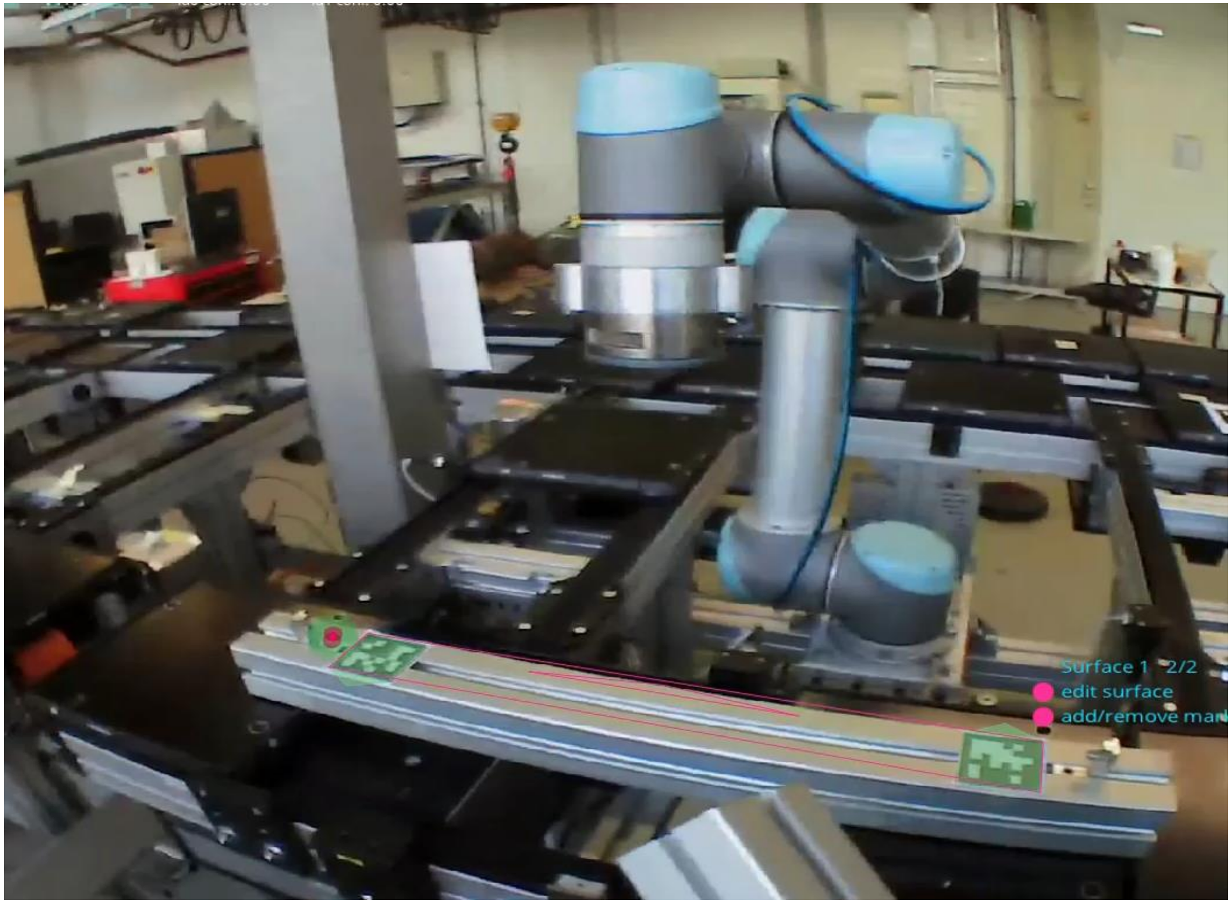
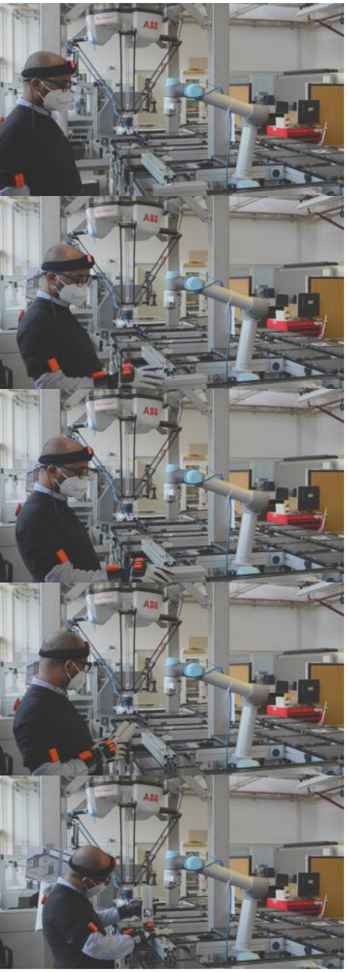
Gaze and object tracking



- Gaze tracking
- Object detection and tracking



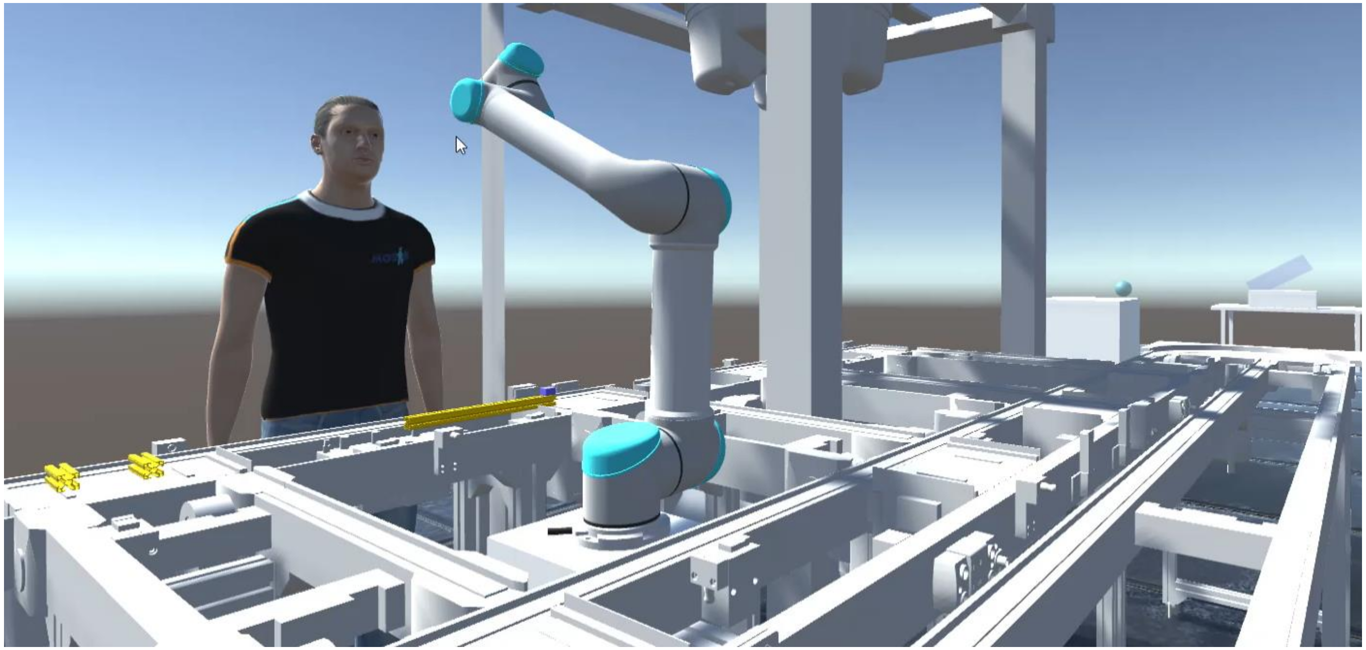
Look at

Reach

Pick

Move

Assemble



Proof of concept using MOSIM environment

FAMS Fertigungsautomatisierung und Montage

Table 3 Performance evaluation

Activities	Measured time[ms]	Simulation time [ms]
Look at	550	166
Reach	1284	633
Decision of part type	2550	360
Move to assemble	4183	267
Move to home	1283	66

- For example, **looking at** an object is 30.18%, and **reaching** an object is 49.29% faster than the actual motion.

- The discrepancy is especially apparent for the **decision activity**.

Conclusion and Outlook

- This paper provides an **AI-enhanced approach and knowledge-based DT**, which explores the interaction of human users with robots in a collaborative production environment so that the actions are derived from human attention predicted from attention captured via sensors and their associated information that is mined from semantic ontologies.
- The future research in HRC using DT involves more indicators such as **effectiveness**, **decision time**, and **action time** analytically.

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- Future work needs a focus on human **understandability** and **explainability** to enable the evolution of the knowledge base and comply with the EU guidelines on trustworthy AI.
- In subsequent development steps, the methodology, in particular the knowledge base, should be expanded to include a **possibility for humans and machines for reciprocal learning** in order to learn new tasks on the job.
- The other aspect is the **workforce's mobility**, leading to human experts' operations from **diverse cultural backgrounds** as **attention manifestation differs across cultures**.

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THANK YOU!

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