Natural and multimodal interfaces for human-machine and human-robot interaction

Francesco De Pace

Computer and Control Engineering

XXXIII cycle

Commitee
Dott. Guido Maiello, Referee, *Justus Liebig Universität Giessen*
Prof. Emanuele Frontoni, Referee, *Università Politecnica delle Marche*
Prof. Jo Lumsden, *Aston University*
Prof. Hoshang Kolivand, *Liverpool John Moores University*
Prof. Bartolomeo Montrucchio, *Politecnico di Torino*

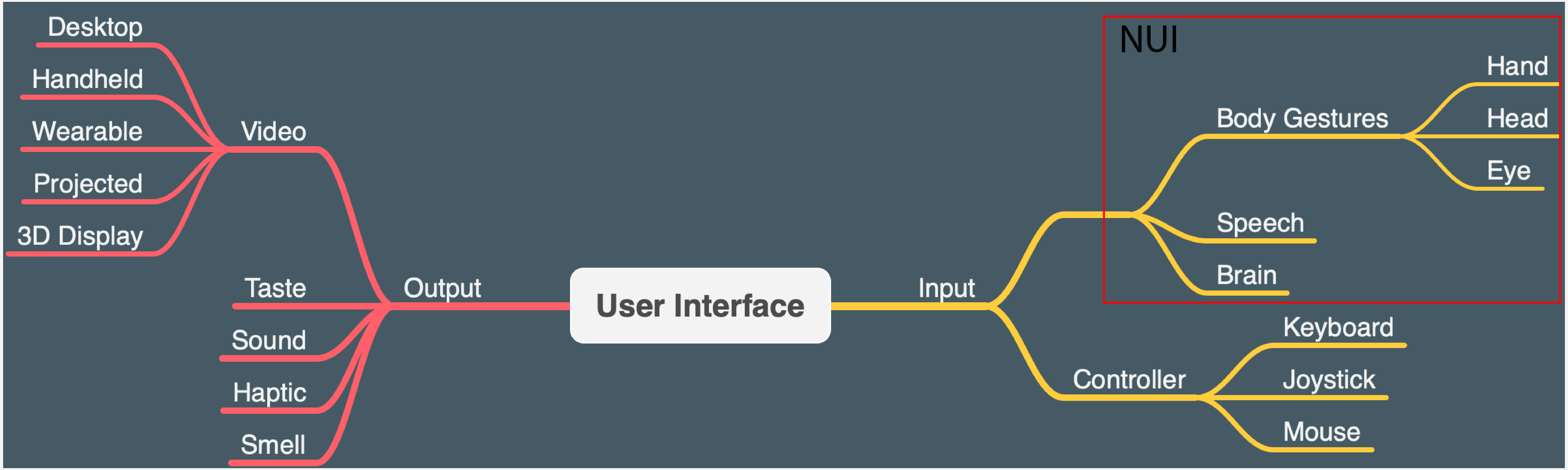
Torino, 12/07/2021

Tutor
Prof. Andrea Sanna, *Politecnico di Torino*

Outline

- The User Interfaces
- Motivations
- Industry 4.0
  - Augmented and Virtual Reality in the Human-Robot Interaction context
- Gaming
  - “Hybrid” games
- Conclusion and Main Limitations
- Main Achievements

The User Interfaces



User Interface (UI)

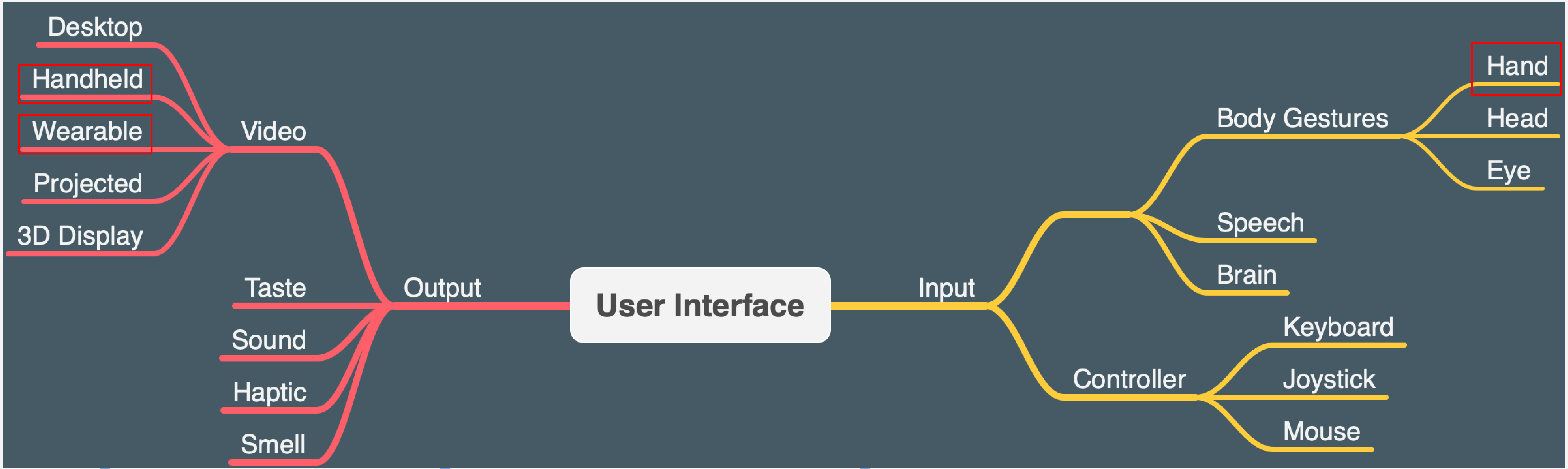
“The medium through which the communication between users and computers takes place ([1])”

Natural User Interface (NUI)

Interfaces that allow the users to interact with the machines without the necessity to learn the underlying interface mechanism (open discussion)

[1] Hix D, Hartson HR. Developing user interfaces: Ensuring usability through product and process. Wiley; 1993.

Selected Interfaces



Input

- Body Gestures
  - Mainly Hand Gesture Recognition System

Natural User Interface (NUI)

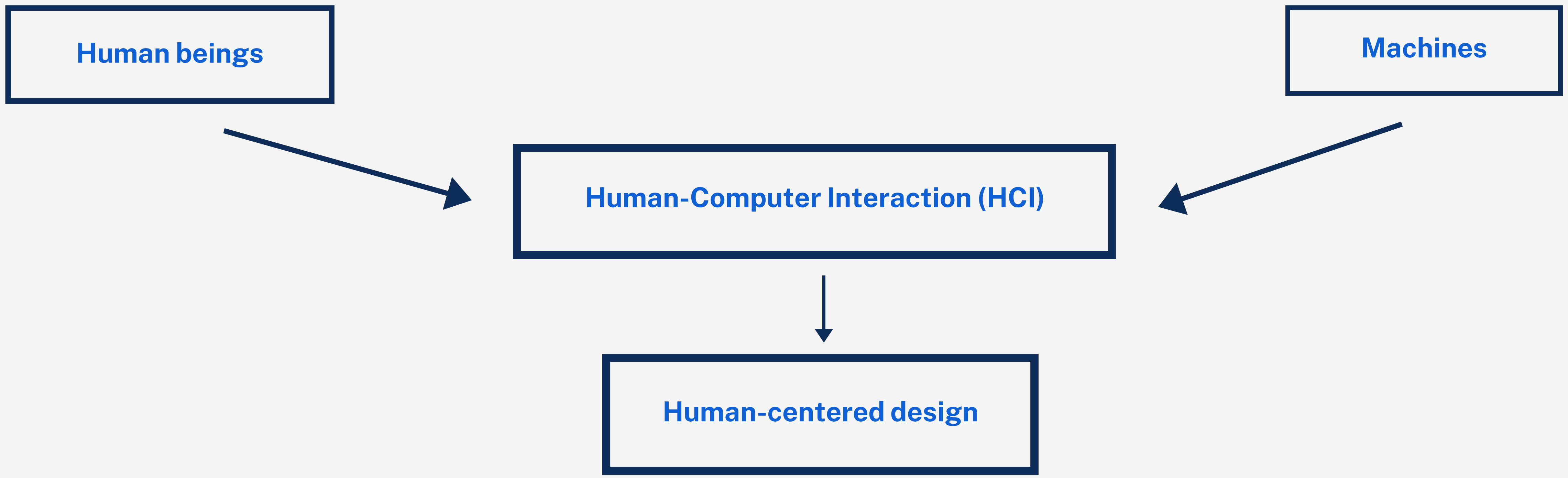
- Video interfaces
  - Handheld and Wearable for the Virtual and Augmented Reality (VR/AR) interfaces

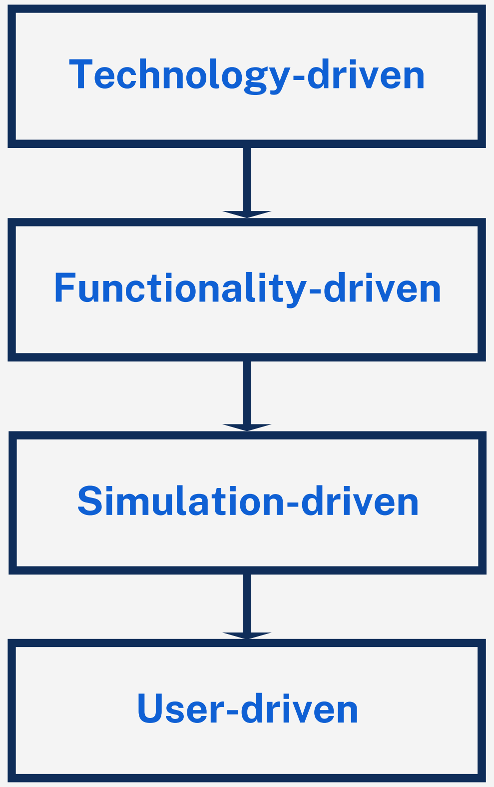
Virtual interfaces used in several domains

- Medical
- Entertainment
- Industry
- Gaming

The domains considered in my Ph.D. dissertation

Motivations





[2]

“[. . .] usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques” [1]

- The techniques and methodologies employed to assess the systems from a user-centered perspective can be easily moved from one context to another without loosing efficacy

- The Industry 4.0 and Gaming domains have several characteristics in common:
  - High levels of interaction and accuracy
  - Reliable systems in terms of usability and workload
  - Collaborative and multiuser environments
  - ...

[1] ISO 9241-210:2019 Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems.
[2] Grasset R, Dunser A, Billinghurst M. Human-centered development of an ar handheld display. In 2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality 2007 Nov 13 (pp. 177-180). IEEE.

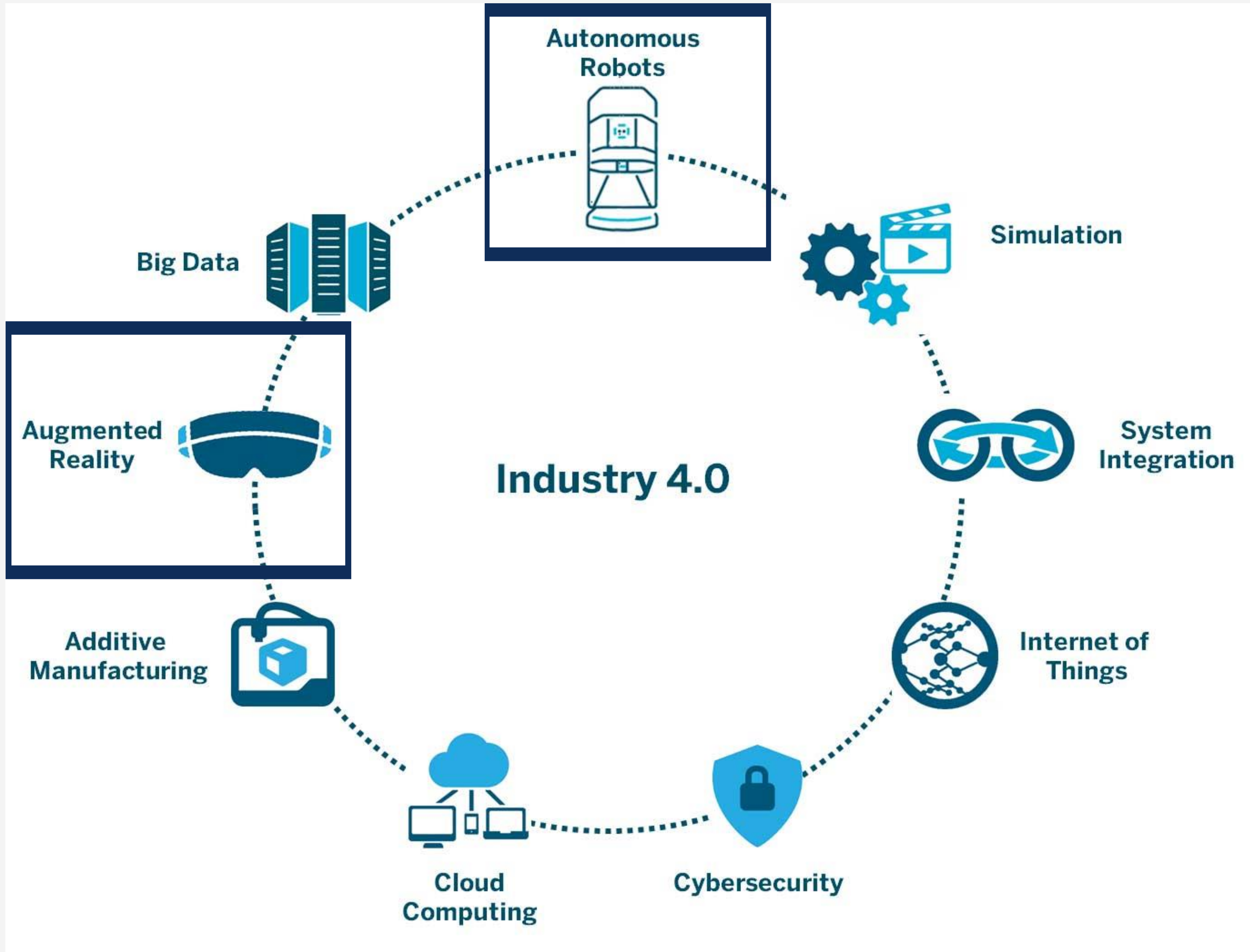
Industry 4.0

Industry 4.0

Industry 4.0: high-tech strategy for future manufacturing industries [1]

- **Autonomous Robot**
  They are expected to work side-by-side with humans
- **Augmented Reality**
  It provides innovative interfaces to interact with robots

Although VR is not «properly» included in the pillars, it is heavily used to interact and/or control industrial robots

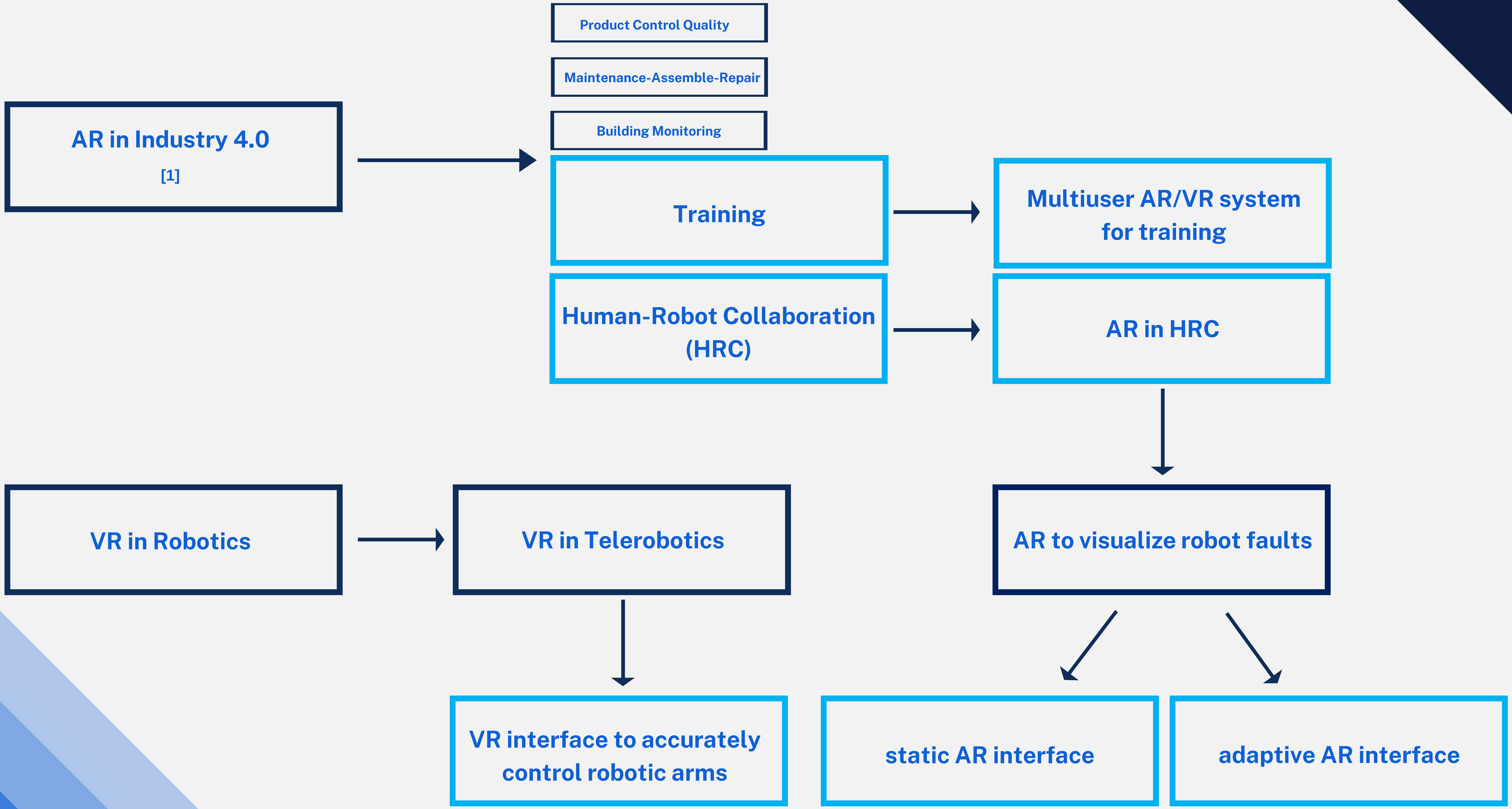


Nine fundamental pillars [2]

[1] ISO 9241-210:2019 Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems

[2] Erboz G. How to define industry 4.0: main pillars of industry 4.0. Managerial trends in the development of enterprises in globalization era. 2017 Jun 1:761-7.

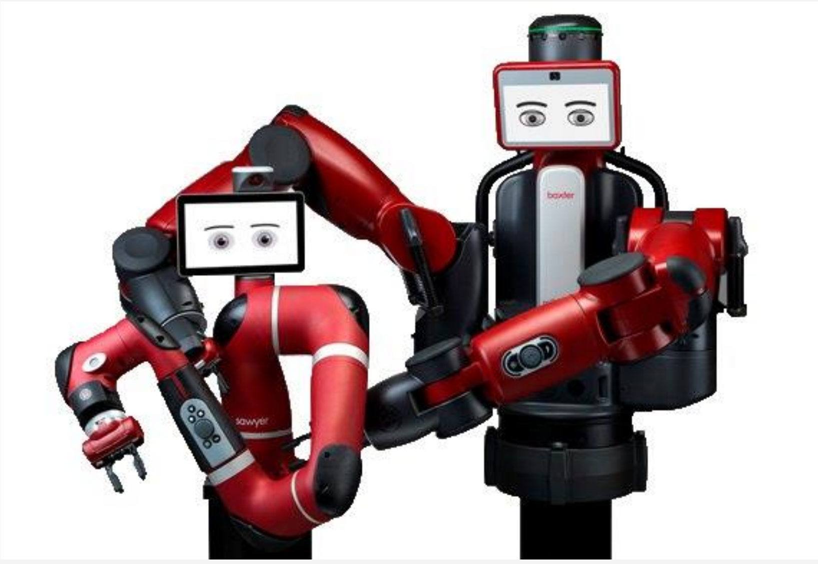
Overview

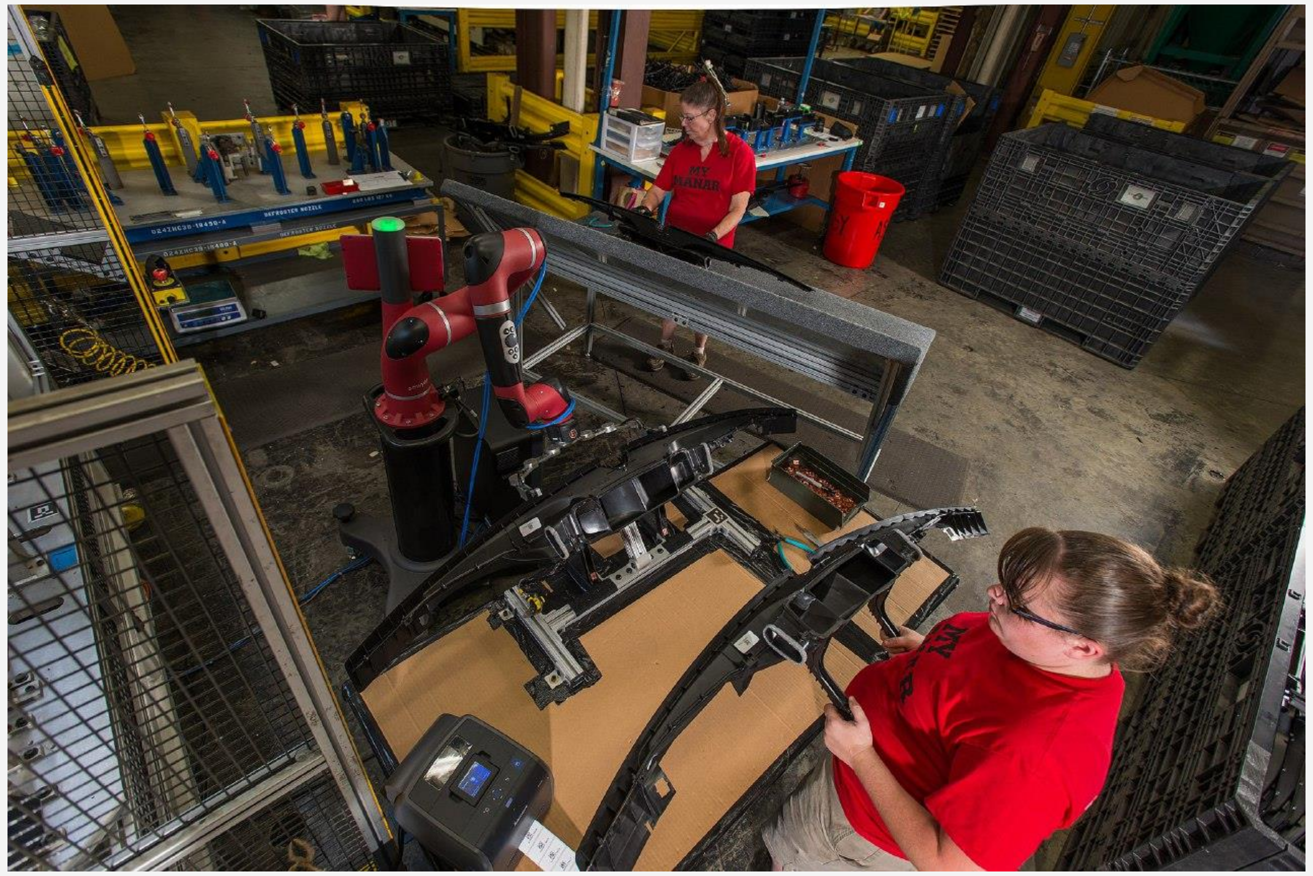


[1] De Pace F, Manuri F, Sanna A. Augmented reality in industry 4.0. American Journal of Computer Science and Information Technology. 2018;6(1):17.

A systematic review of Augmented Reality interfaces for collaborative industrial robots [1]

- Since AR interfaces are becoming quite popular in the HRC domain, it becomes of primary importance to analyze their use in this context
- There is a lack of studies that has evaluated the related state of the art
- There are misconceptions regarding the term "**collaborative**" or, more in general, related to the definition of a "**collaborative robot**"
- **Goals:**
  - To clearly define what a "collaborative robot" is
  - To analyze the effectiveness of AR interfaces in the HRC context by answering to three research questions





[1] De Pace F, Manuri F, Sanna A, Fornaro C. A systematic review of Augmented Reality interfaces for collaborative industrial robots. Computers & Industrial Engineering. 2020 Nov 1;149:106806.

QR1: what are the main uses of AR technologies in the HRC context?

QR2: what are the main strengths and weaknesses of the AR technologies in the HRC context?

QR3: what are the potential future developments of AR technologies in the HRC context?

Cobot and Collaborative Operations

- 2011: ISO 10218, part 1 and part 2 define the guidelines for the use of industrial robots

- 2016: ISO/TS 15066 has been integrated into the ISO 10218 and it defines:
  - "A **collaborative robot** is a robot that can be used in a collaborative operation"
  - "A **collaborative operation** is a state in which purposely designed robots work in direct cooperation with a human within a defined workspace (the **collaborative workspace** CWS)"

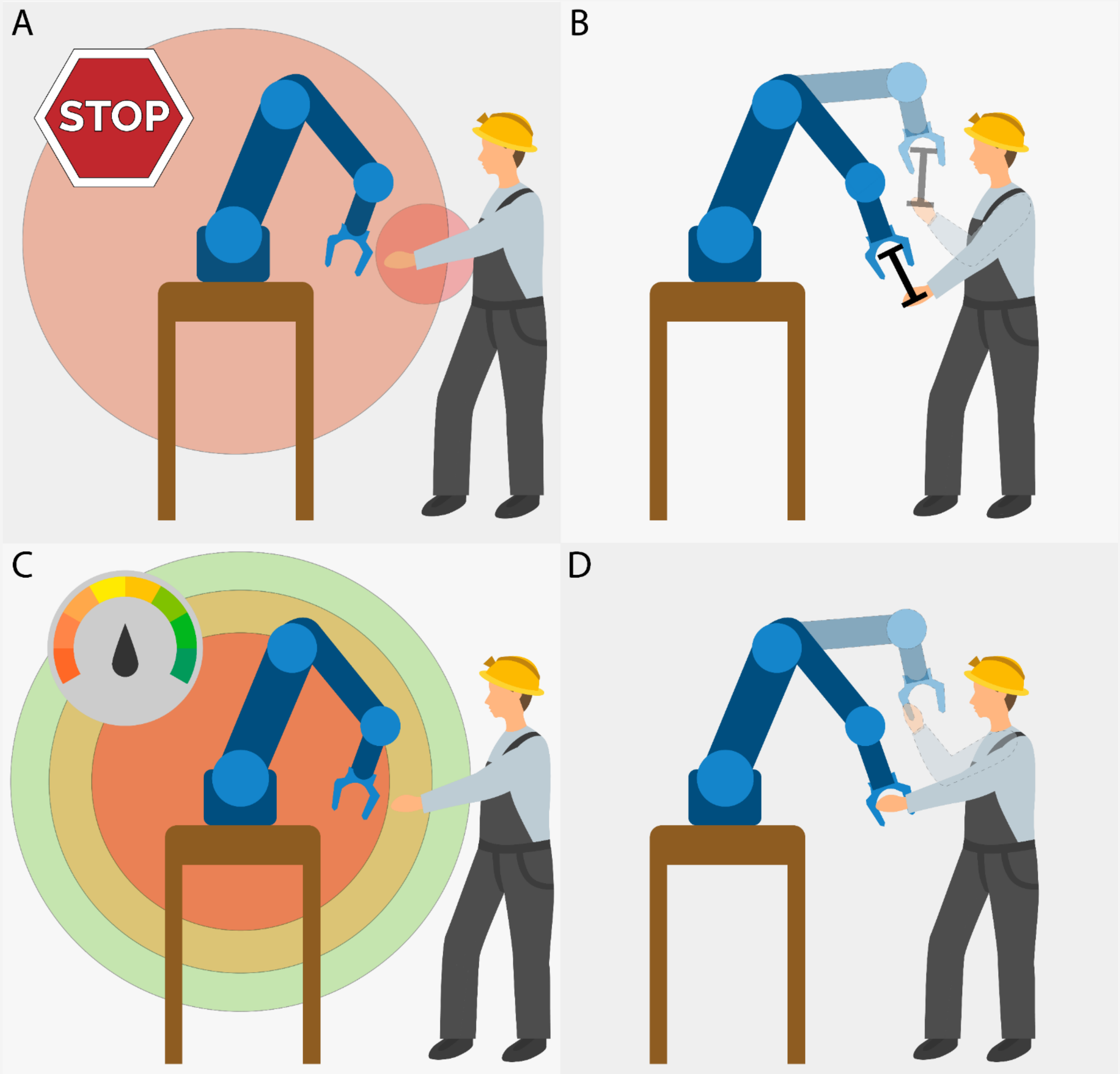
- There are some collaborative operations that can be done in a CWS:

A. "**Safety-rated monitored stop**": if the worker is in the CWS, the robot cannot move

B. "**Hand guiding** ": the worker controls the robot with an input device

C. "**Speed and separation monitoring**": as the distance between the robot and the worker reduces, the speed of the robot reduces too

D. "**Power and force limiting** ": contact between the worker and the robot is allowed



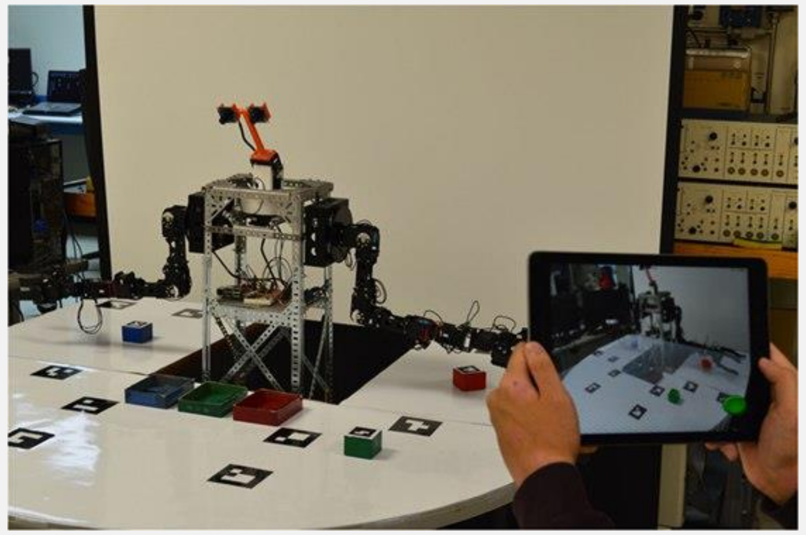
A collaborative operation is not determined by the robot itself, it is defined by the task and the working space.

- Starting from 3734 papers, 63 papers regarding **AR** and **collaborative operations** have been selected and analyzed

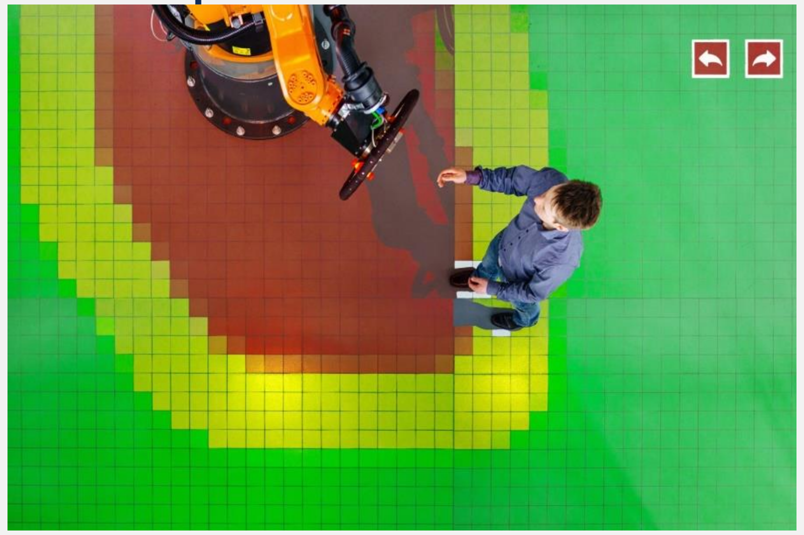
Main Outcomes

QR1

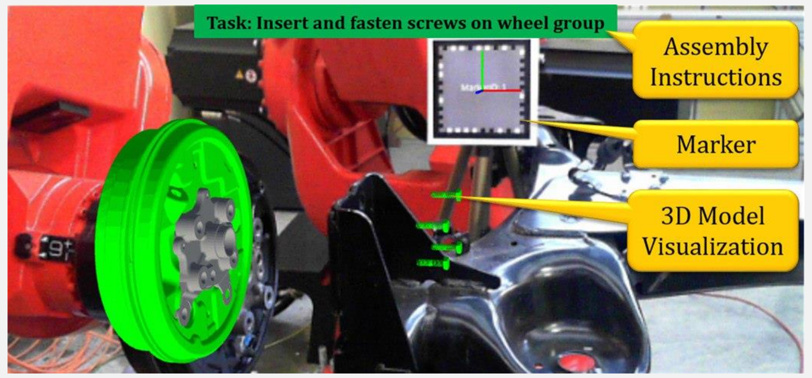
Control Feedback

[1] 

Workspace

[2] 

Informative

[3] 

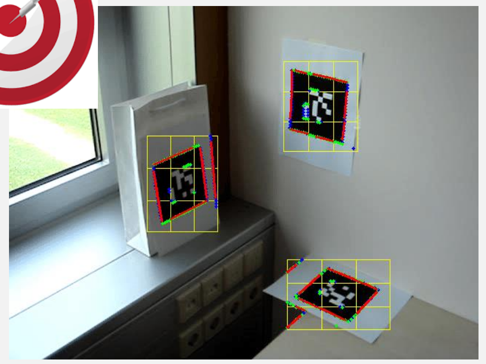
QR2

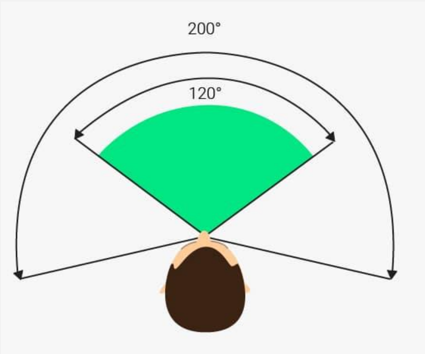
Strengths

< 

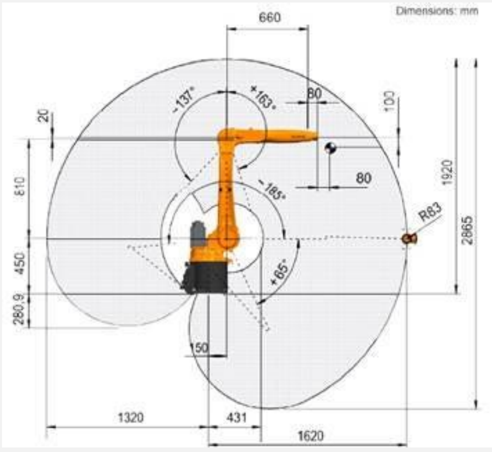
< 

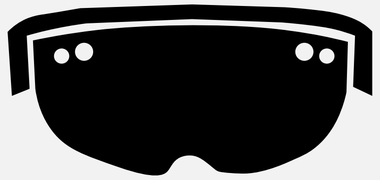
Weakness

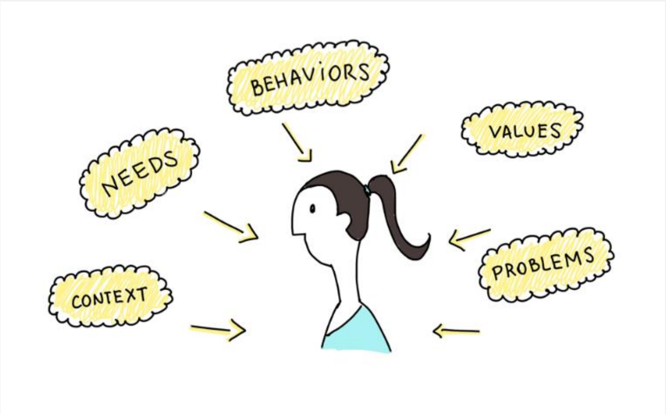


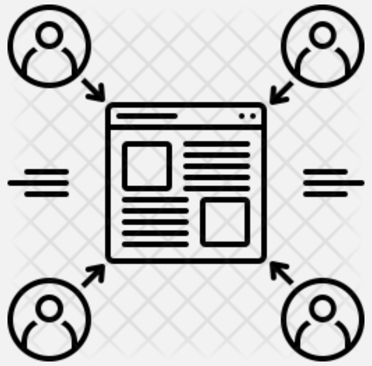


QR3

> 

> 

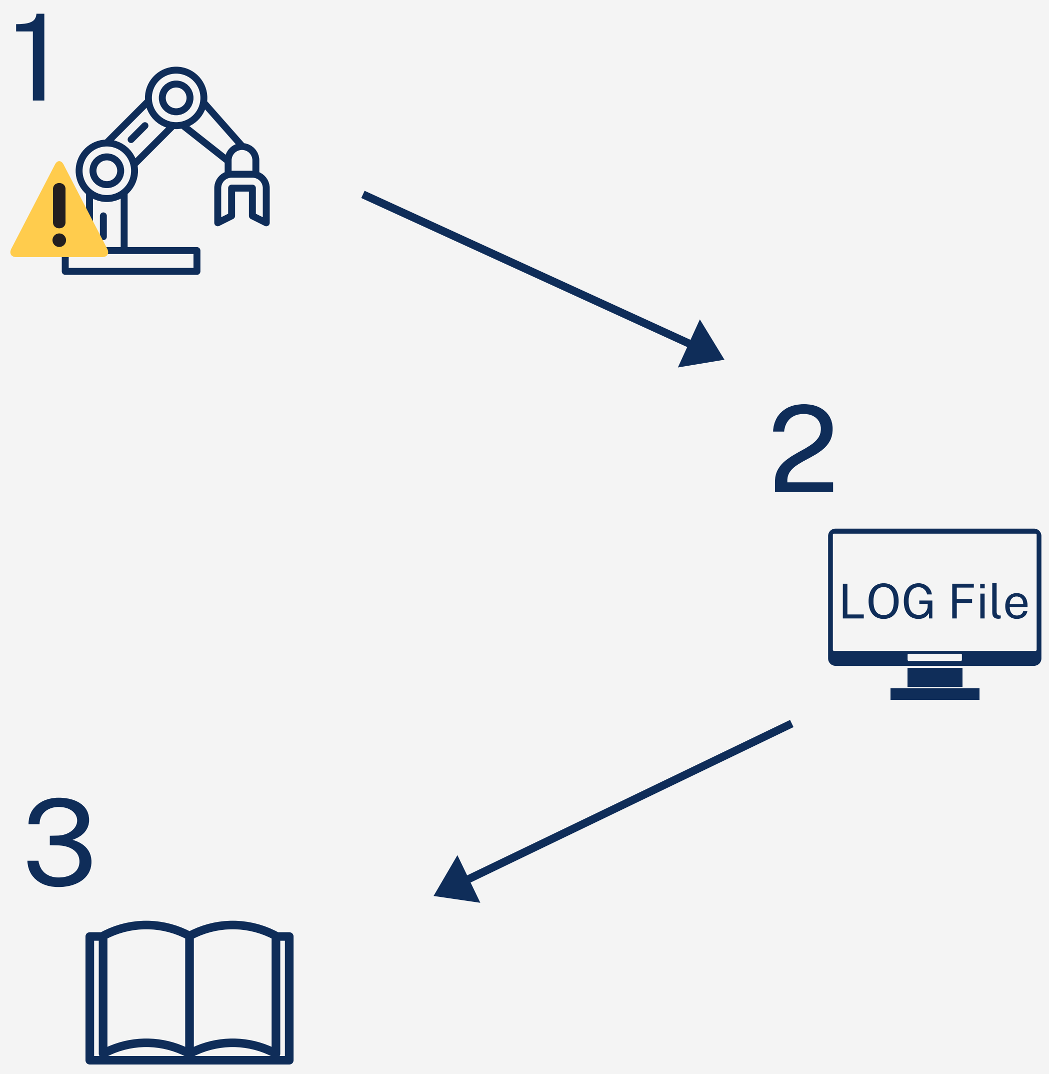




[1] Frank JA, Moorhead M, Kapila V. Mobile mixed-reality interfaces that enhance human–robot interaction in shared spaces. Frontiers in Robotics and AI. 2017 Jun 9;4:20.
[2] Vogel C, Elkmann N. Novel safety concept for safeguarding and supporting humans in human-robot shared workplaces with high-payload robots in industrial applications. In Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction 2017 Mar 6 (pp. 315-316).
[3] Makris S, Karagiannis P, Koukas S, Matthaiakis AS. Augmented reality system for operator support in human–robot collaborative assembly. CIRP Annals. 2016 Jan 1;65(1):61-4.

Informative Area – Fault Visualization

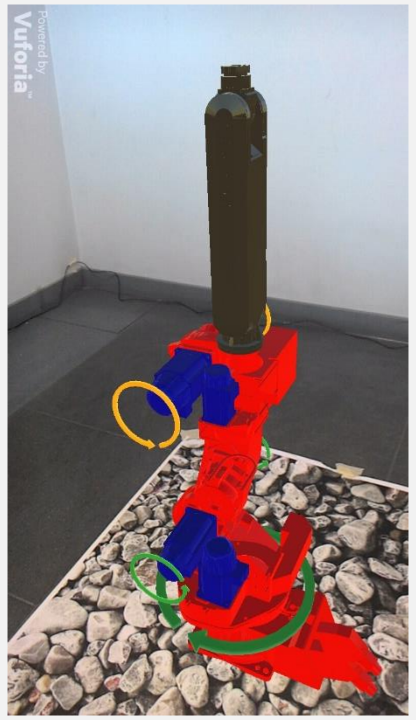
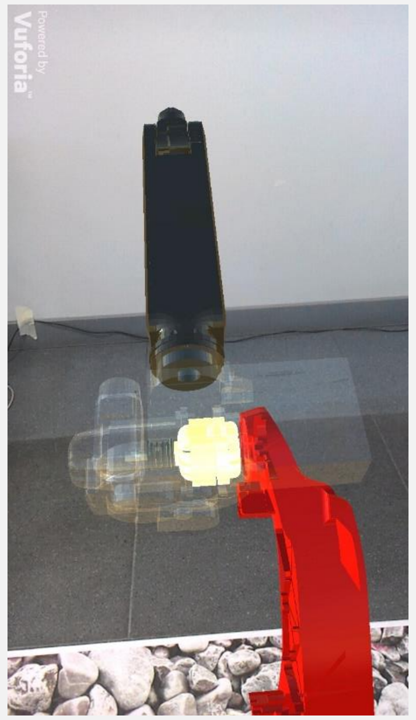
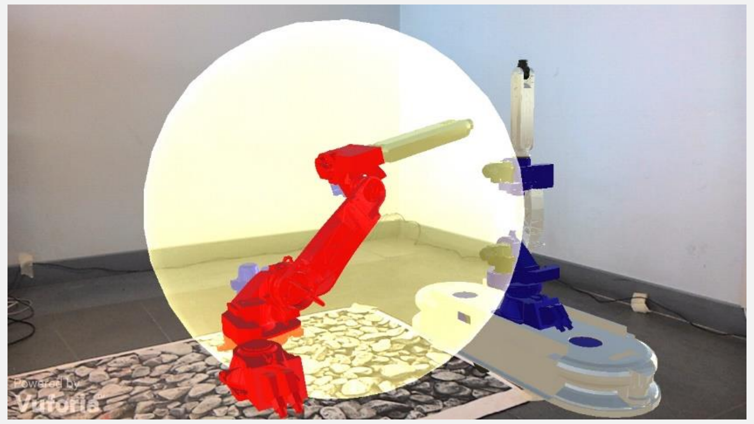
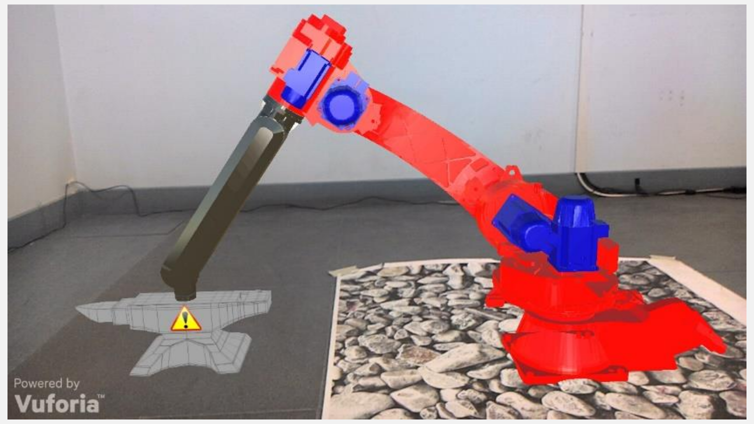
- **Research projects done in collaboration with COMAU for the HuManS regional project**
  - Integration of the most advanced industrial systems with the human capabilities
- **Situations in which the manipulators are affected by faults are not usually considered**



- **Objectives:**

• Preliminary study to verify which AR device should be used for fault visualization
• Methodology to find out which 3D metaphors best represent robot faults
• The use of the 3D metaphors with an adaptive AR application

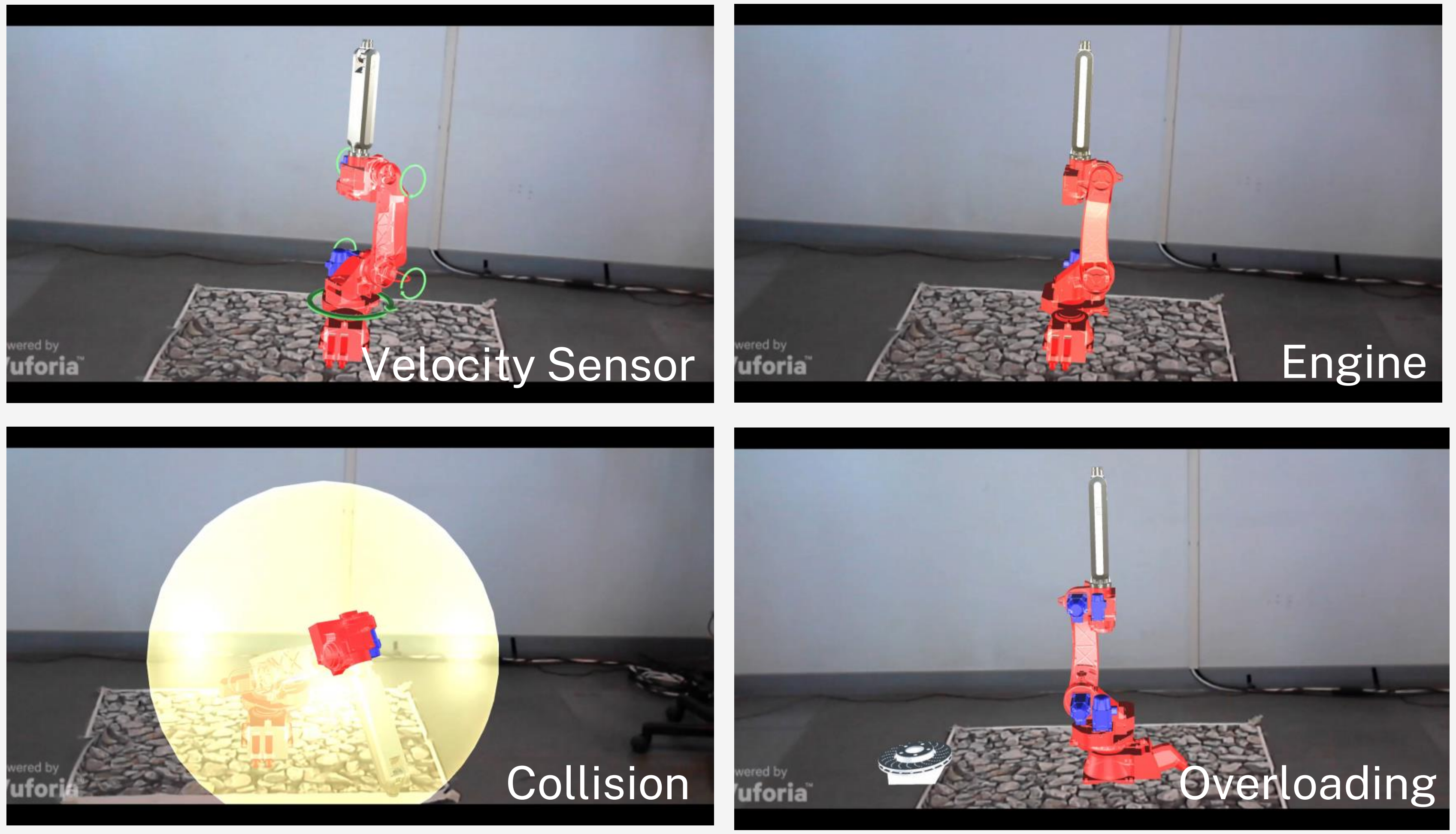
Robot Arm Fault Classification

Sensors	Actuation System	Mechanical Structure	Overloading
Velocity Sensor	Engine	Collision Detection	Exceeding max payload
			

[1] Fantuzzi C, Secchi C, Visioli A. On the fault detection and isolation of industrial robot manipulators. IFAC Proceedings Volumes. 2003 Sep 1;36(17):399-404.
[2] Singh VD, Banga VK. Overloading failures in robot manipulators. InInternational Conference on Trends in Electrical, Electronics and Power Engineering (ICTEEP'2012)/Planetary Scientific Research Centre 2012 (pp. 15-16).

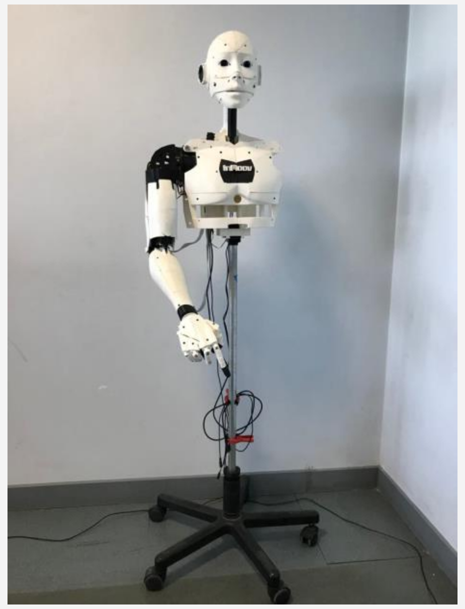
An Augmented Interface to Display Industrial Robot Faults [1]

- Preliminary study (10 users, 20-30 years old)
- Identifying which AR device should be used for displaying industrial robot faults
- Two AR devices: **wearable** and **handheld**
- Two robots: **virtual** (COMAU Smart-5 Six) and **real** (InMoov)



Main Results:

- virtual robot experiment:
  the users preferred the handheld AR interface
- real robot experiment:
  the users preferred the wearable AR interface
- **the narrow FoV of the wearable device did not allow to clearly visualize the virtual assets**



[1] De Pace F, Manuri F, Sanna A, Zappia D. An augmented interface to display industrial robot faults. In International Conference on Augmented Reality, Virtual Reality and Computer Graphics 2018 Jun 24 (pp. 403-421). Springer, Cham.

An Augmented Reality System to Support Fault Visualization in Industrial Robotic Tasks [1]

- The positioning of the virtual assets, or more in general, of the User Interface elements is a challenging and compelling problem

- Few works have analzyed this problem in the robotic domain [2] [3]
  - No user tests [2]
  - No comparison between adaptive and non-adaptive interfaces [3]

- Main Goals:
  - To identify suitable 3D virtual metaphors
  - AR interface capable of displaying the virtual representation of the industrial robot faults in areas:
    - **always visible by the user**
    - **not occluded by the manipulator**

Input

Fault Position	**(P_G)**
User Position	**(P_u)**
User Rotation	**(R_u)**
Field-of-View	**(FoV)**
Robot Position	**(P_R)**
Robot Rotation	**(R_R)**
Fault Typology	**(G)**

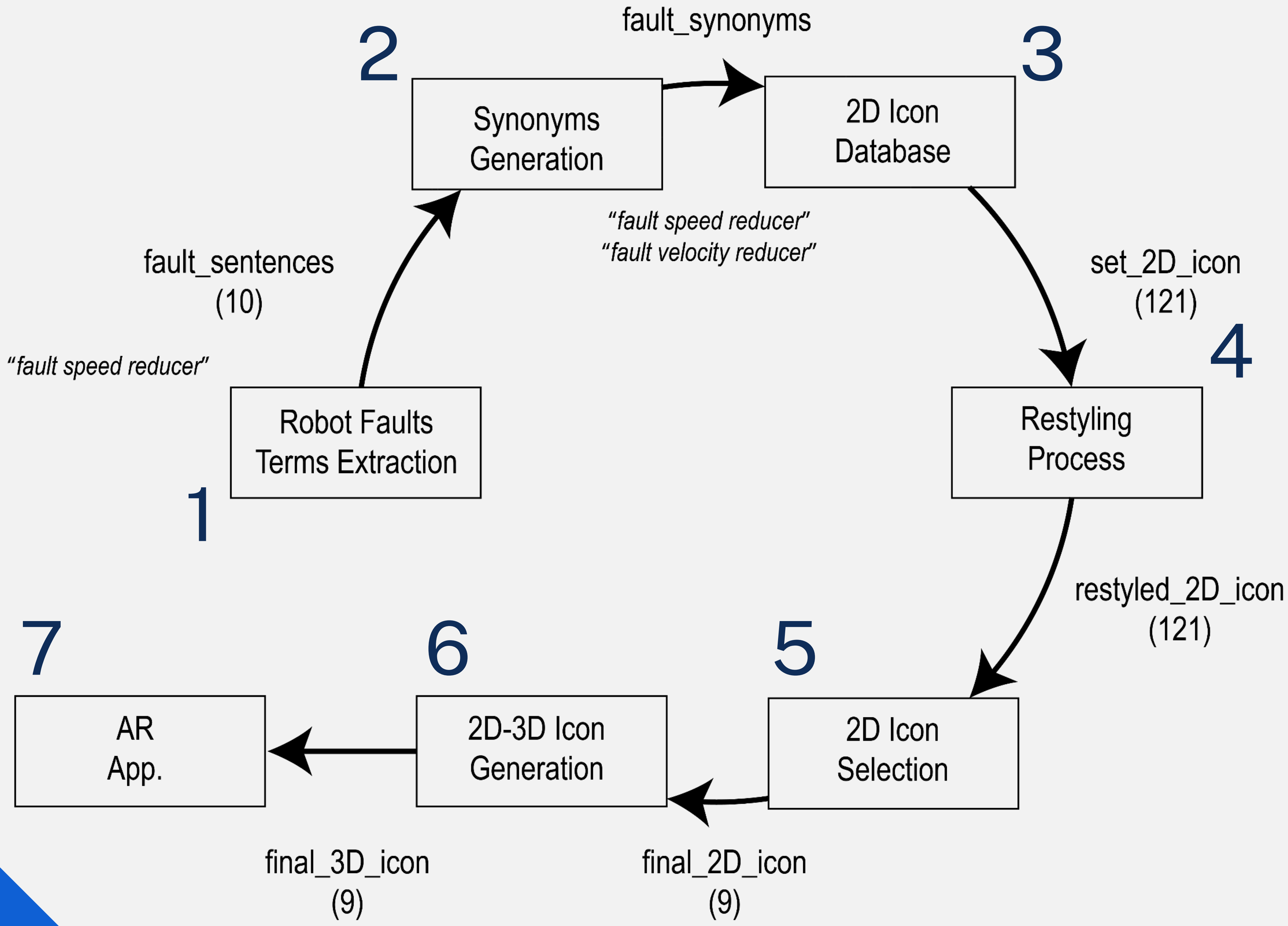
$$f(G, P_G, P_u, R_u, FoV, P_R, R_G) = \begin{bmatrix} I \\ P_I \\ O_I \\ S \end{bmatrix}$$

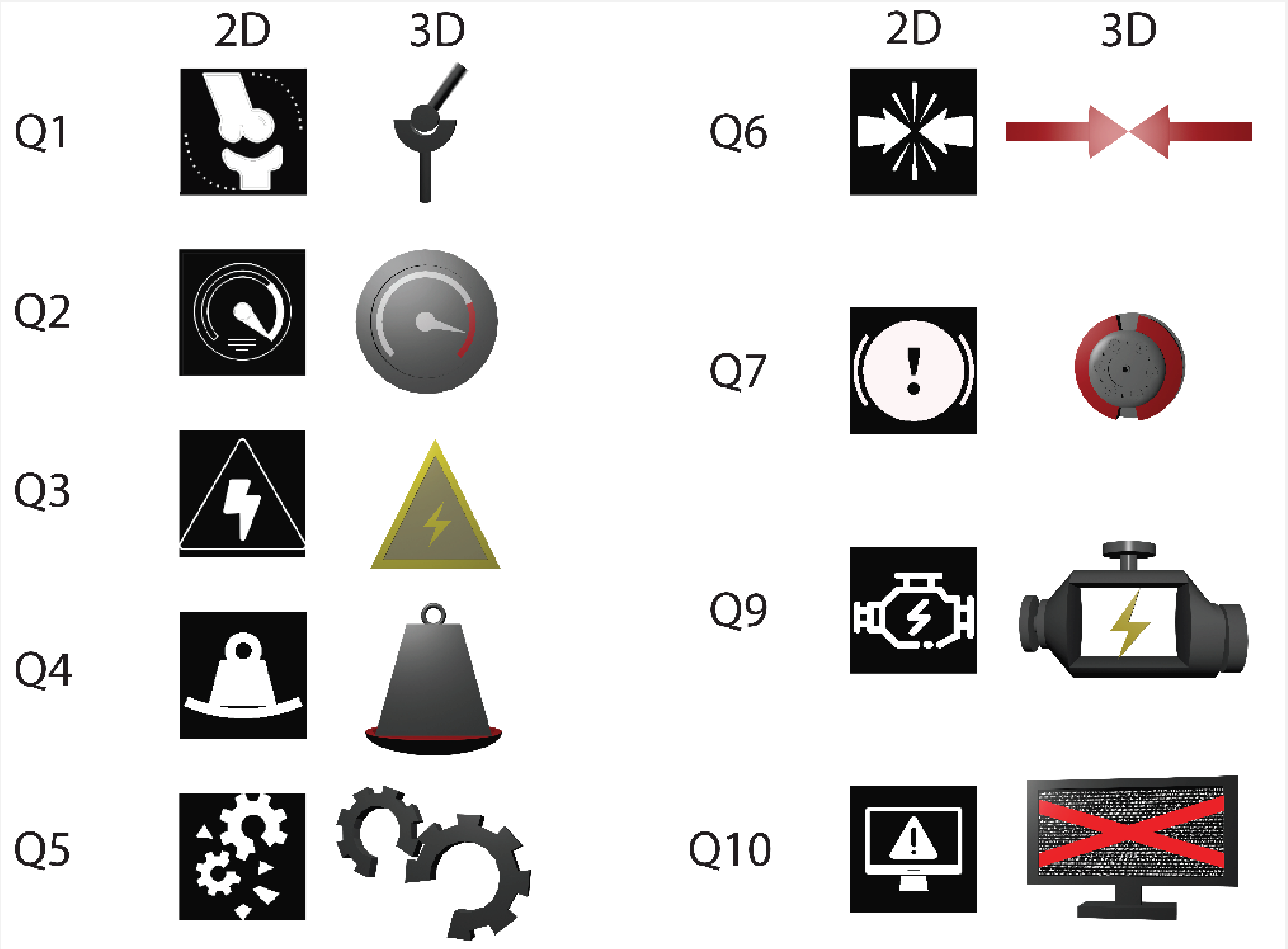
Output

Icon Typology	**(I)**
Icon Position	**(P_I)**
Icon Orientation	**(O_I)**
Icon Scale	**(S)**

[1] Avalle G, De Pace F, Fornaro C, Manuri F, Sanna A. An augmented reality system to support fault visualization in industrial robotic tasks. IEEE Access. 2019 Sep 11;7:132343-59.
[2] Davide De Tommaso, Sylvain Calinon, and Darwin G Caldwell. “A tangible interface for transferring skills”. In: International Journal of Social Robotics 4.4 (2012), pp. 397–408.
[3] Lennart Claassen et al. “Intuitive Robot Control with a Projected Touch Interface”. In: International Conference on Social Robotics. Springer. 2014, pp. 95–104

Virtual Fault Representation

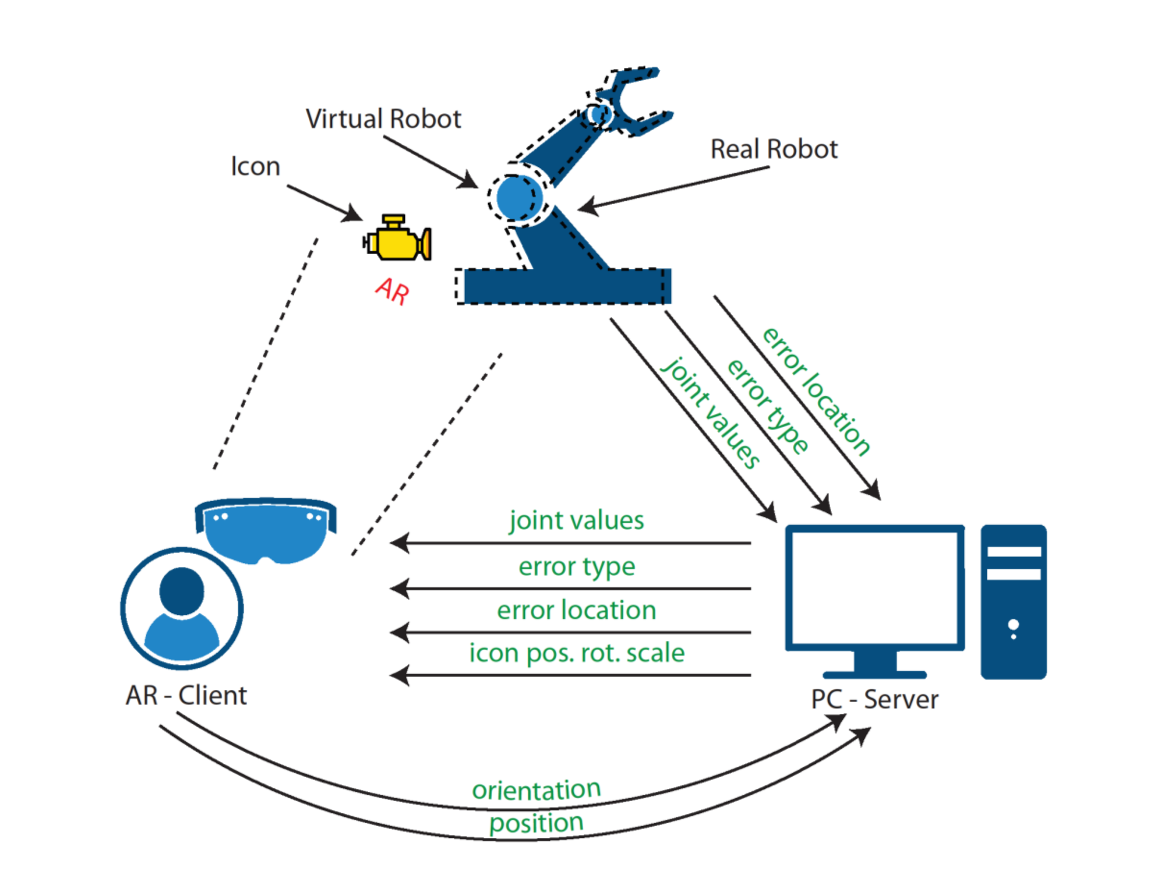


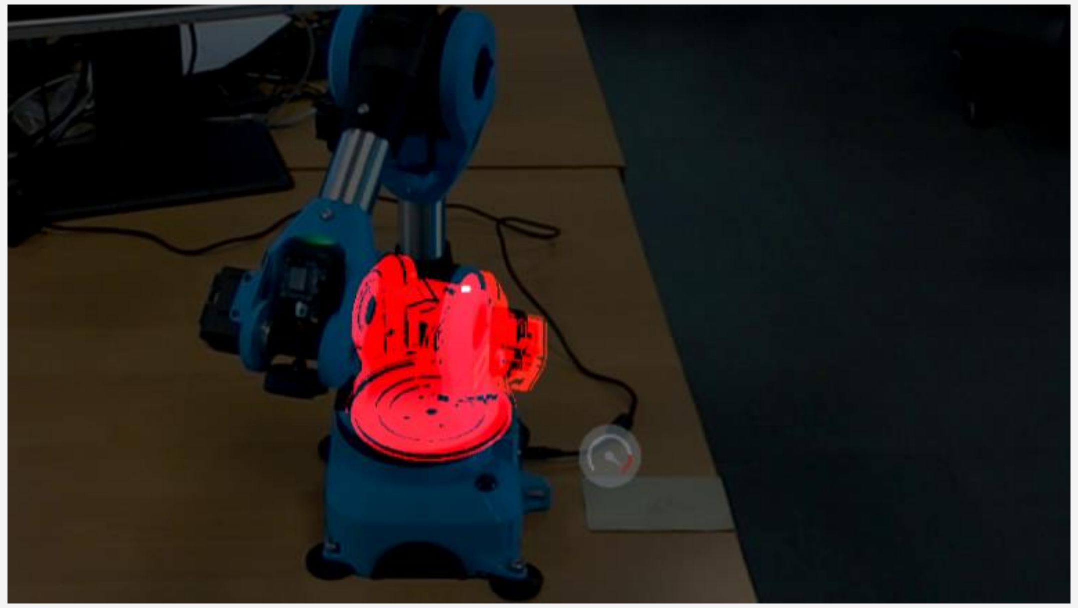


From the ten starting fault categories (step 1), nine have been selected (step 5)

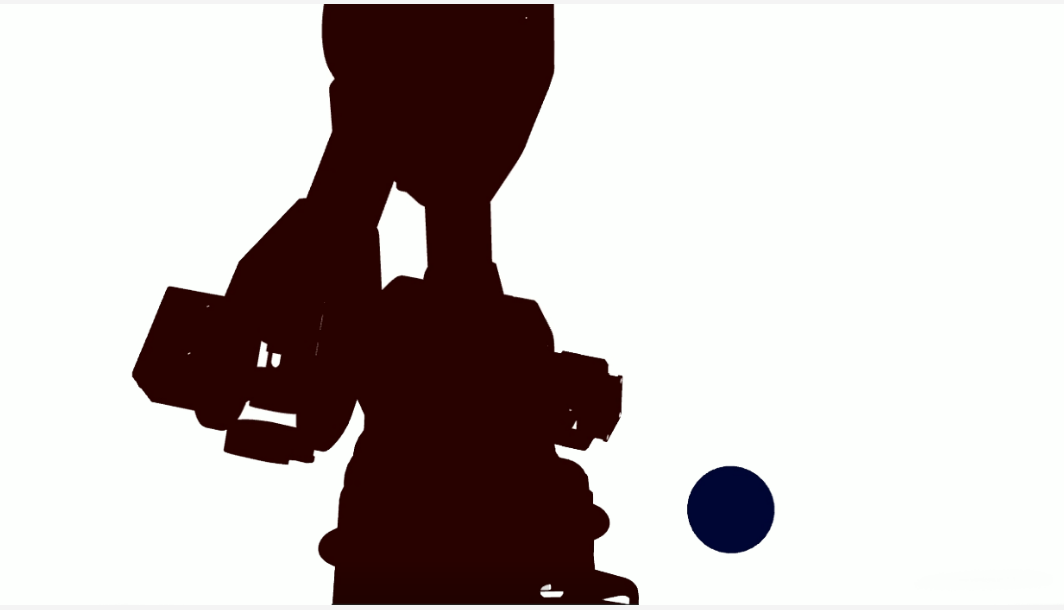
System Architecture

- Two different modalities:
  - non-adaptive (**NAM**)
  - adaptive (**AM**)
- The server and the client have two different representations of the robot, synchronized using the real robot joint values
- The server has its own virtual camera synchronized with the user's camera position and orientation
- An alarm sound and a virtual arrow draw the attention of the user towards the fault location





Client view



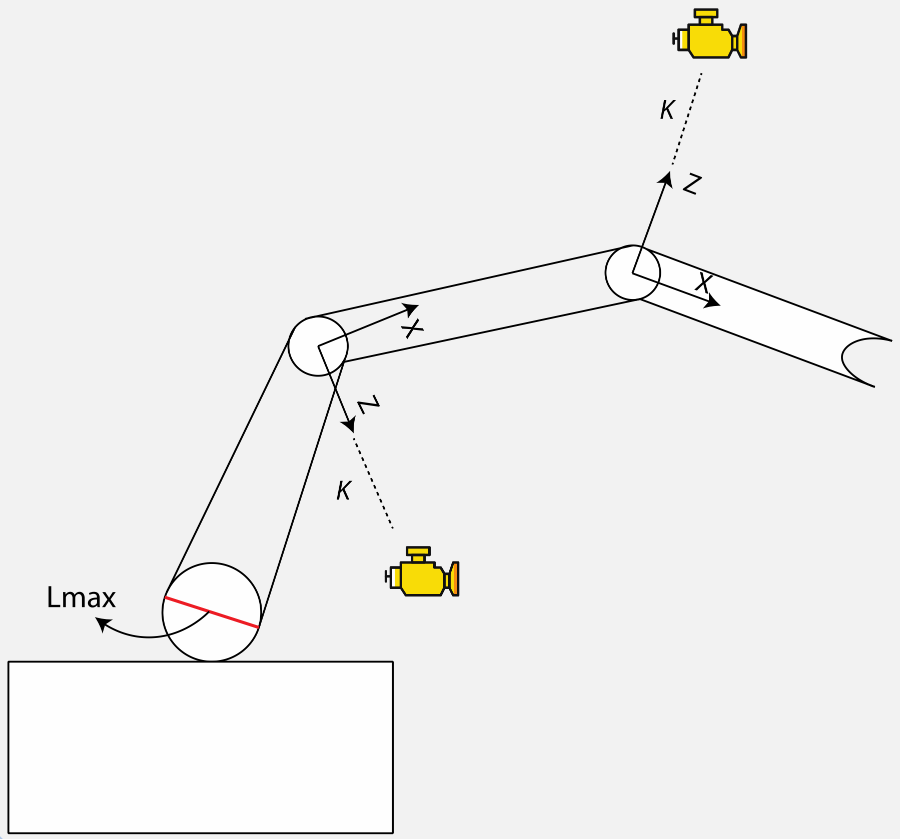
Server view

NAM and AM Virtual Icon Positioning

NAM

K = 2 * L_max
scale = S (constant)
orientation = (0,0,0)°

L_max: diameter of the manipulator's largest joint



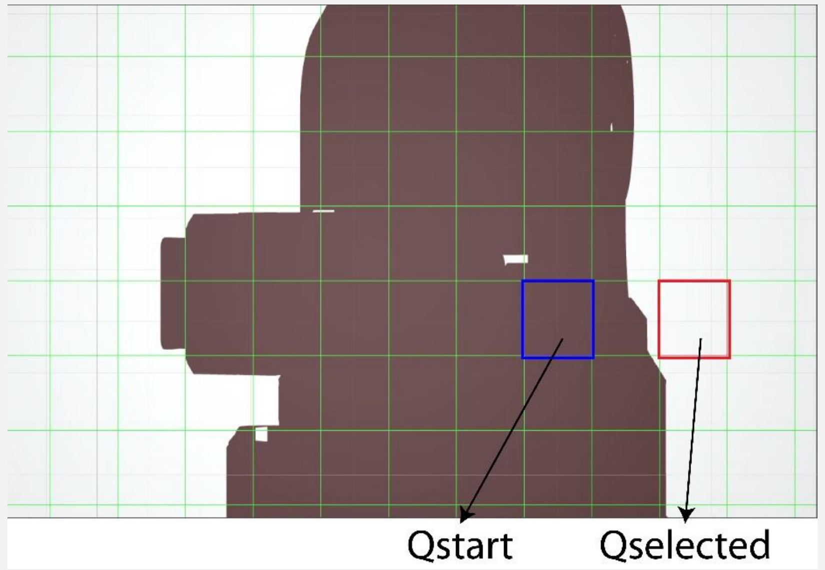
AM

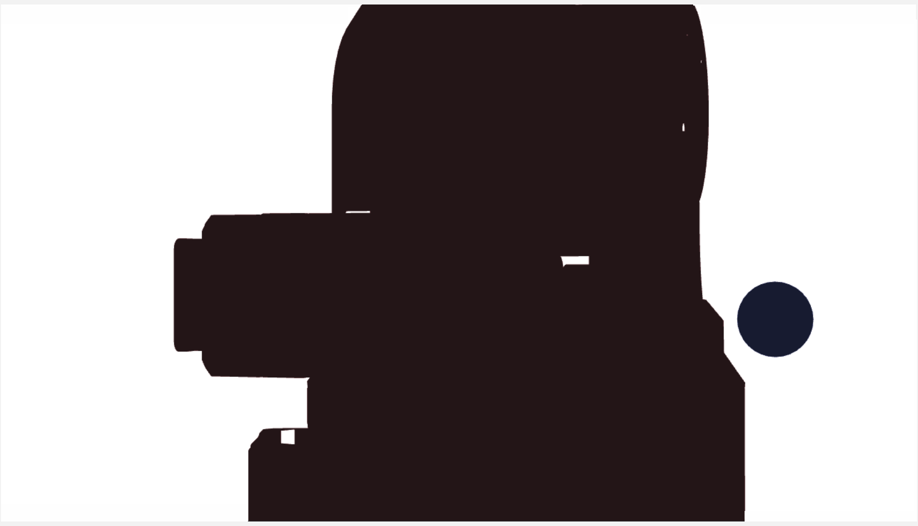
Three different steps:

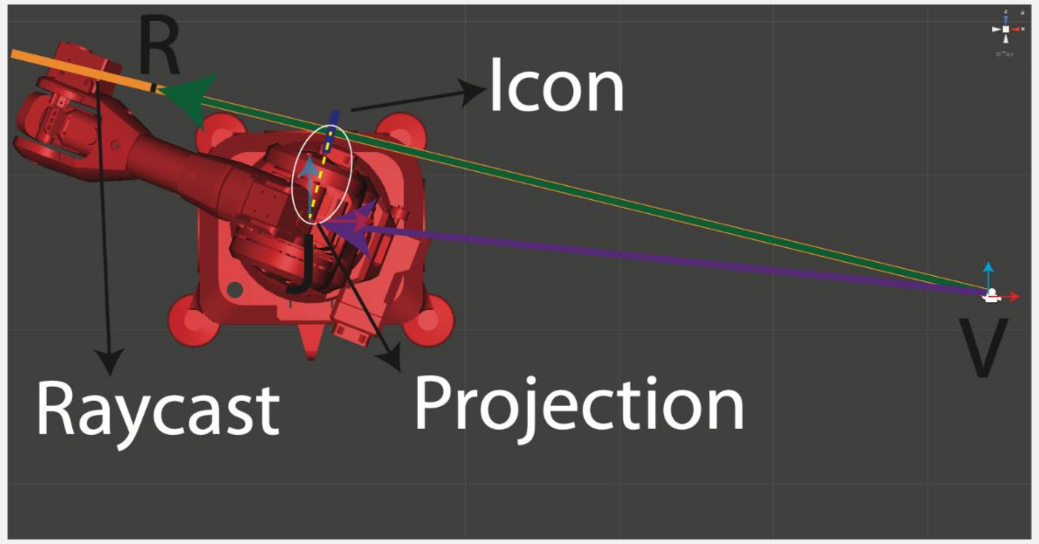
- A1: scale factor determination
  - According to the user-robot distance
- A2: position determination
- A3: orientation determination
  - The virtual icon keeps facing the user

A2: several sub-steps

- Icon's projection on the 2D camera plane
- Determination of the areas not occluded by the manipulator on the camera image
- Computing of the most suitable icon's position on the camera image
- Conversion from 2D to 3D coordinates

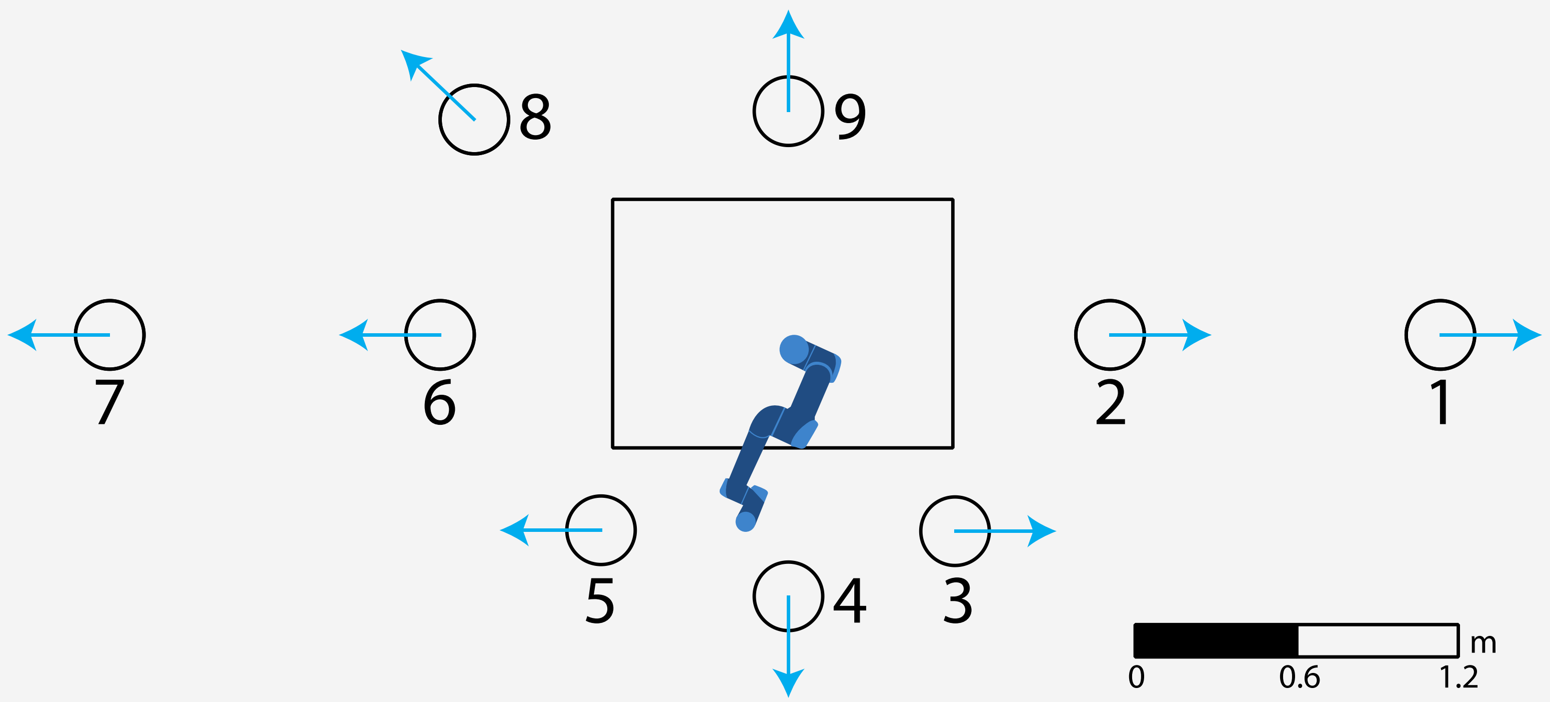






User study

- 34 people have tried both modalities (average age: 25)
  - 76% male, 24% female
  - Moderate knowledge of AR
  - Little knowledge of robotics
- Nine user starting positions (SPs) have been identified. The SPs have been determined considering both near and far positions with respect to the robot
- Each tester starts the experiment from a specific SP, wearing the HoloLens device and giving his/her back to the robot
- The real robotic arm is already stuck in the fault configuration
- When the alarm sound informs the user of the occurrence of a new fault, the user can start moving freely around the environment, trying to identify which type of fault has occurred and on which joint in the shortest possible time



Analyzed Data

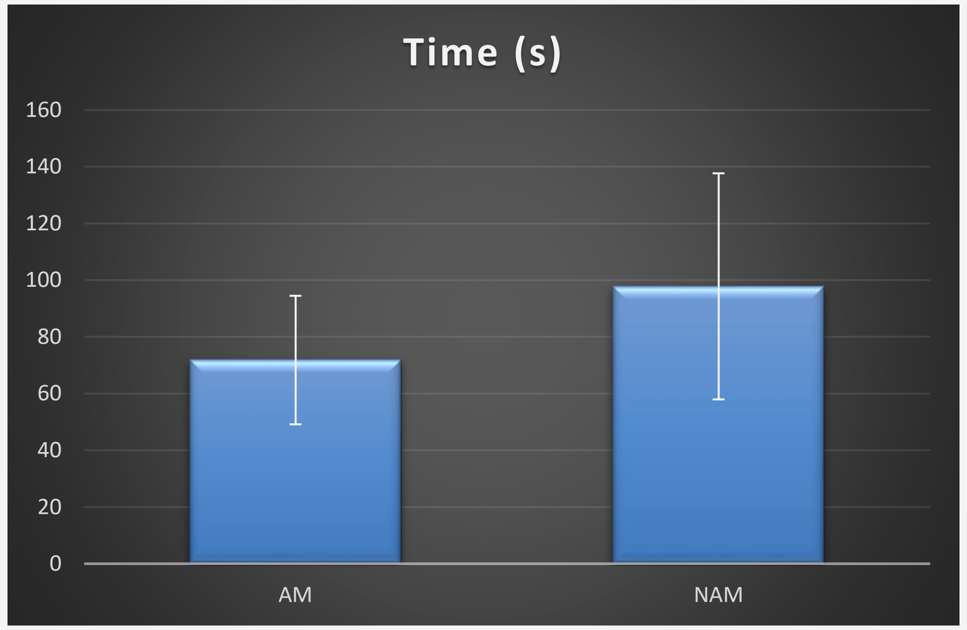
Objective:

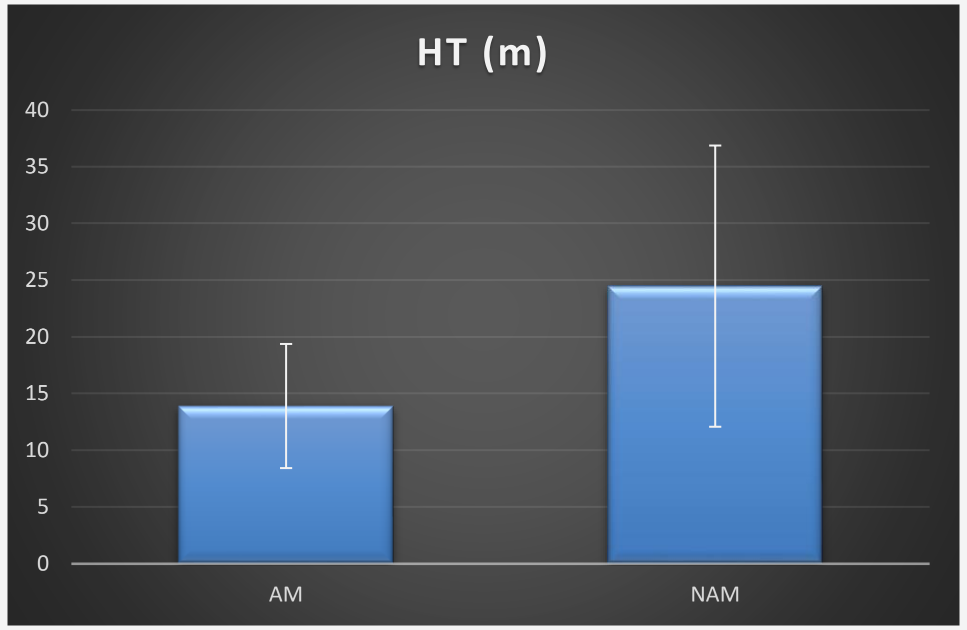
- Time
- Head Translations (HT)
- Head Rotations (HR)

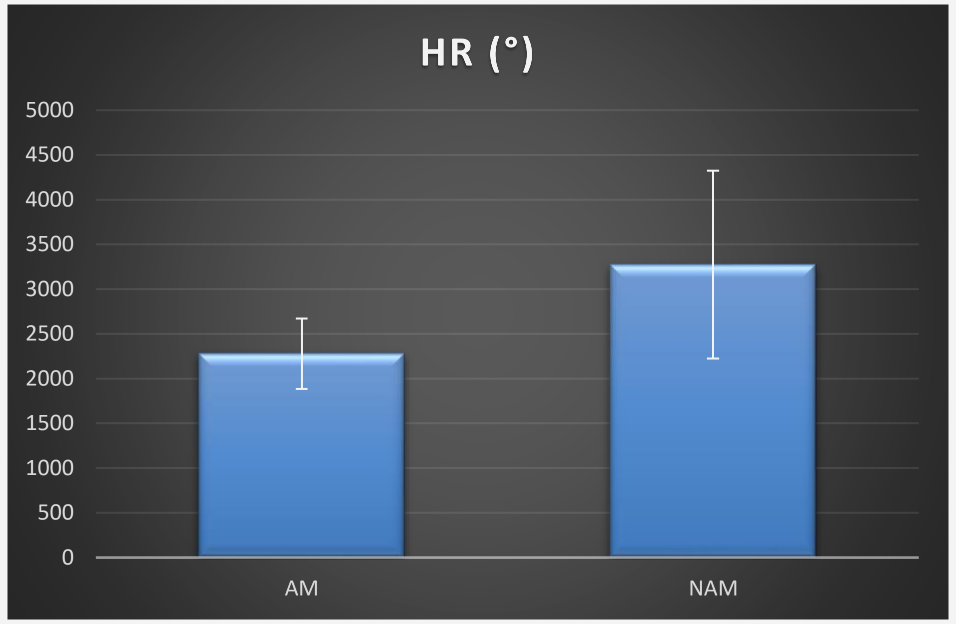
Subjective:

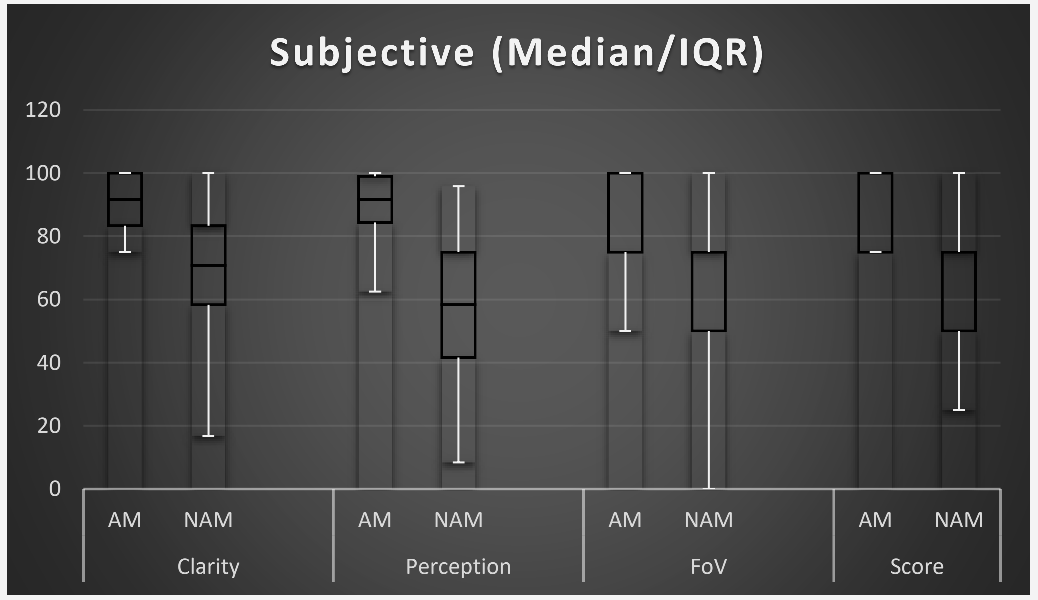
- Clarity
- Perception
- FoV Suitability
- Global score

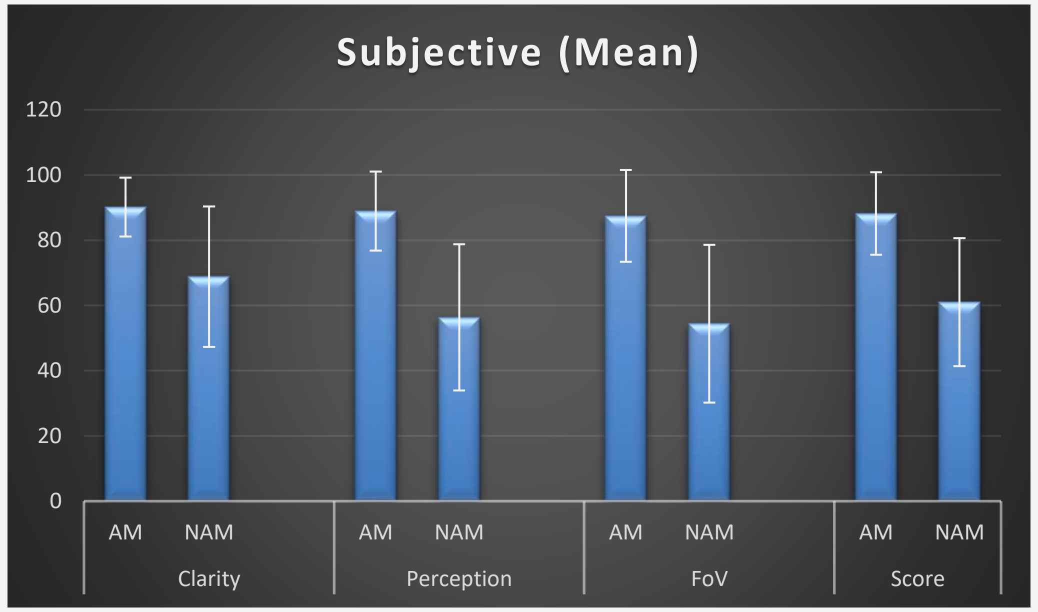
Results and Conclusion











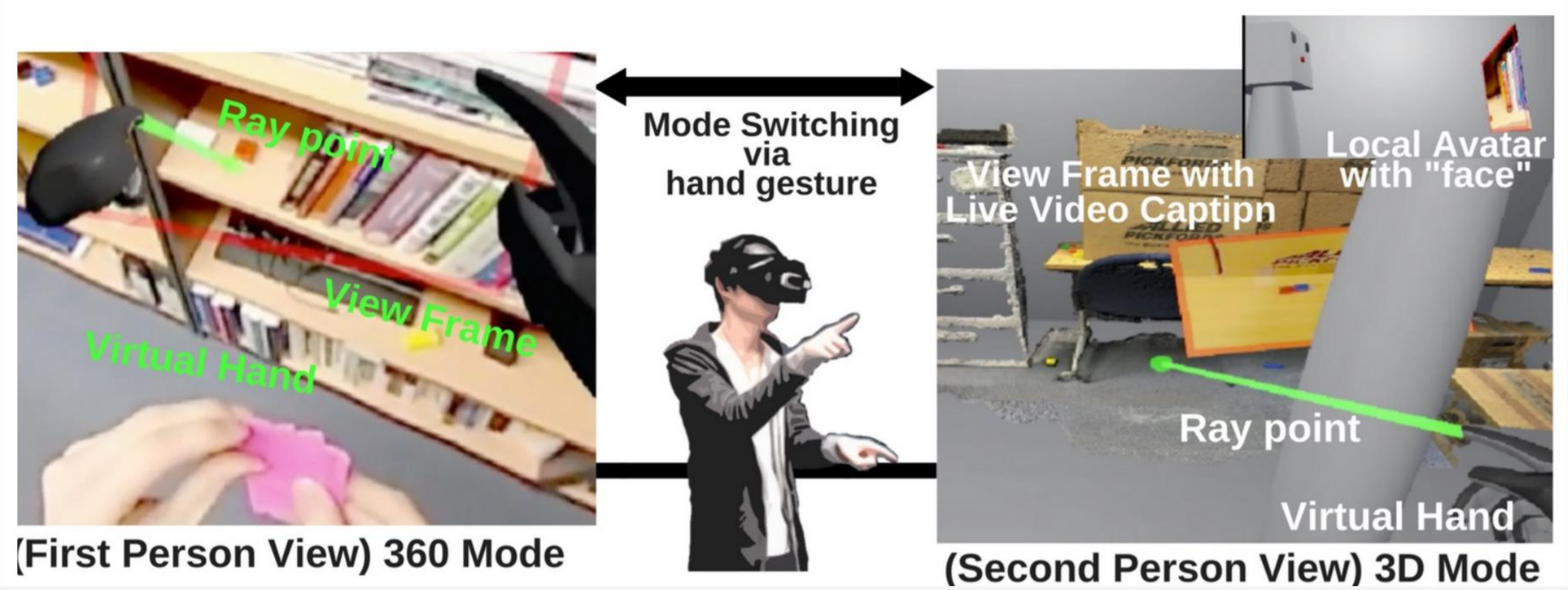
Data analyzed with the Wilcoxon Signed Rank Test

- Time Comparison: $p = 0.001$, $d = 0.556$
- HT Comparison: $p = 0$, $d = 0.839$
- HR Comparison: $p = 0$, $d = 0.848$
- Clarity Comparison: $p = 0$, $d = 0.730$
- Perception Comparison: $p = 0$, $d = 0.84$
- FoV Comparison: $p = 0$, $d = 0.775$
- Score Comparison: $p = 0$, $d = 0.819$

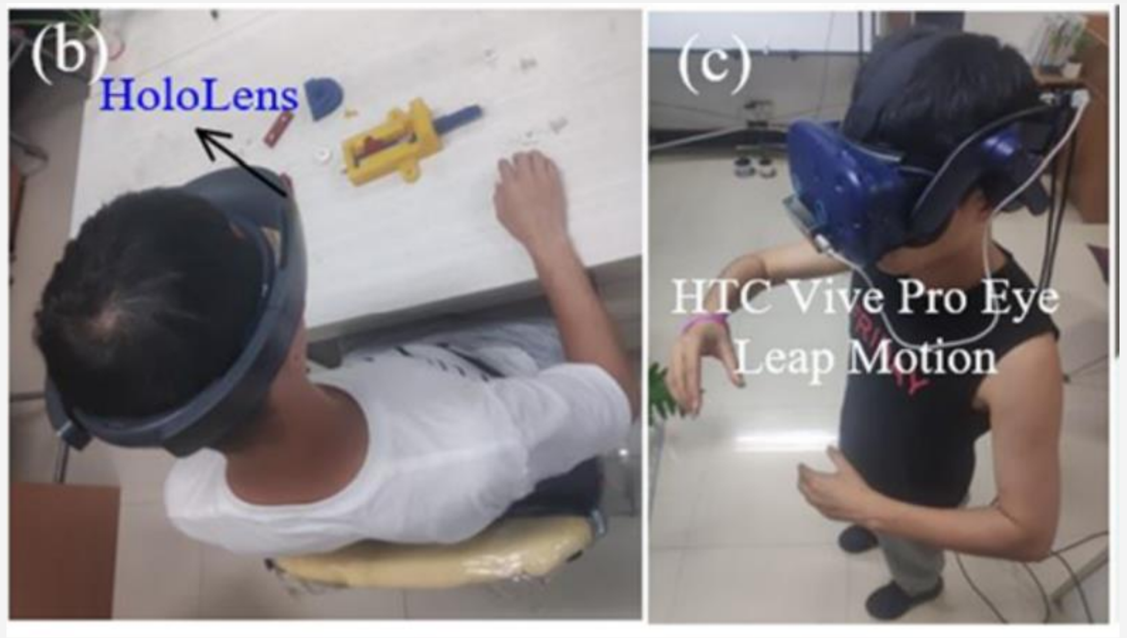
Training– Collaborative AR/VR Systems

- The state of the art related to operators' training present a plethora of interesting works
- Remote skilled – local unskilled operators' paradigm
- Usually they employ:
  - Abstract virtual metaphors (e.g., arrows, generic shapes, etc.)
  - Visualization of the human body parts

- The visualization of full virtual avatars in robotic training scenarios had not been properly explored
  - **Goal**:
    analyze how a robotic training scenario could benefit from a fully animated avatar controlled by a remote skilled operator by comparing it with a traditional remote assistance system, based on abstract metaphors



[1]



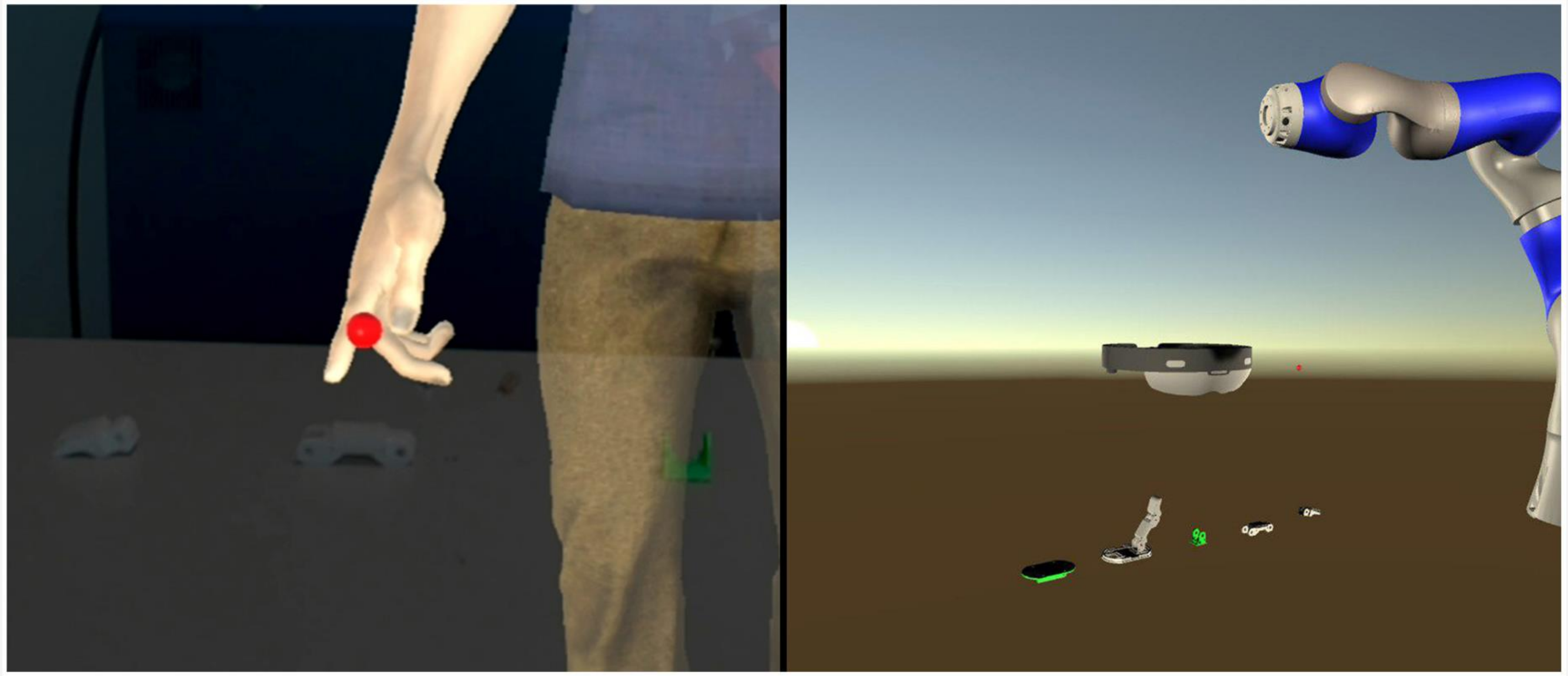
[2]

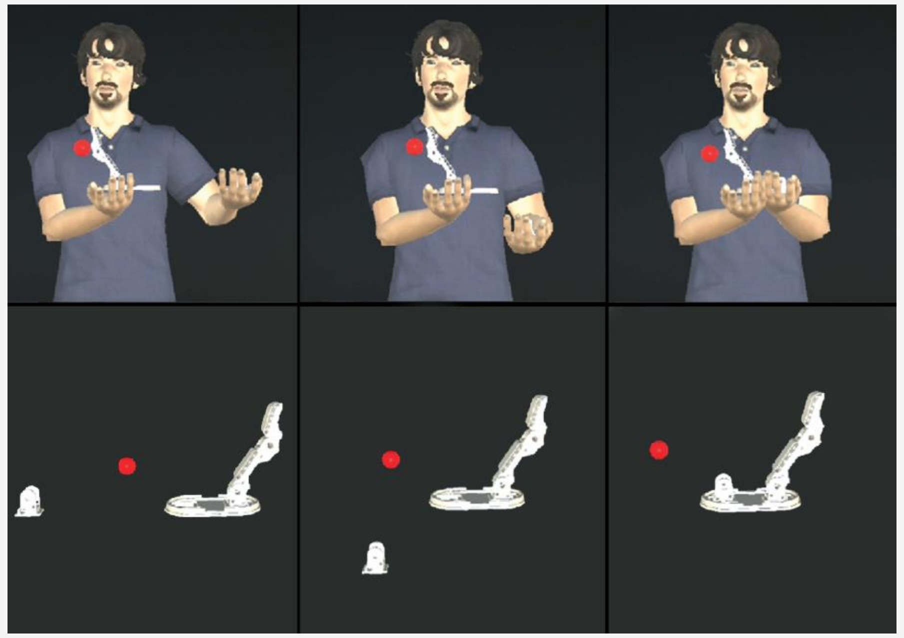
[1] Teo T, Lawrence L, Lee GA, Billinghurst M, Adcock M. Mixed reality remote collaboration combining 360 video and 3d reconstruction. InProceedings of the 2019 CHI conference on human factors in computing systems 2019 May 2 (pp. 1-14).
[2] Wang P, Bai X, Billinghurst M, Zhang S, Wei S, Xu G, He W, Zhang X, Zhang J. 3DGAM: using 3D gesture and CAD models for training on mixed reality remote collaboration. Multimedia Tools and Applications. 2020 Sep 2:1-26.

A Comparison Between Two Different Approaches for a Collaborative Mixed-Virtual Environment in Industrial Maintenance [1]

- Local AR unskilled operator (HoloLens 1)
- Remote VR skilled operator (Oculus Rift DK2 Kit)
- The remote operator guides the local user through a training procedure
- The local users have to build a real robotic hand
- After building it, they have to place the robotic hand on the end-effector of a real manipulator
- **Comparison** between **abstract** metaphors and **avatar** assistance
- Two different conditions:
  - **Audio Channel** (20 students)
  - **Non-Audio Channel** (6 students)
- Two questionnaires to assess:
  - **Usability** of the AR interface (from [2])
  - **Sense of collaboration**, **asset effectiveness**, **audio effect** (custom questionnaire, CQ)

Unskilled user | Skilled user

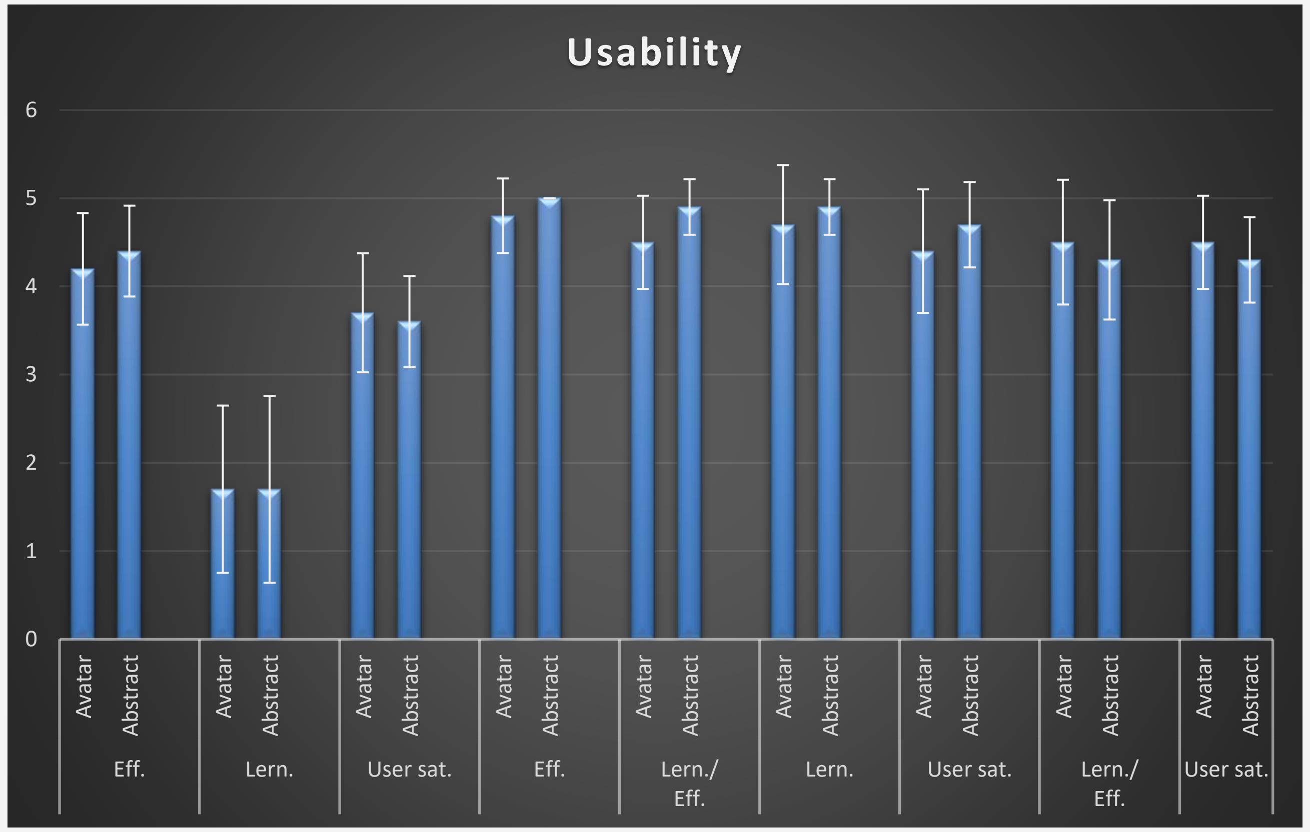


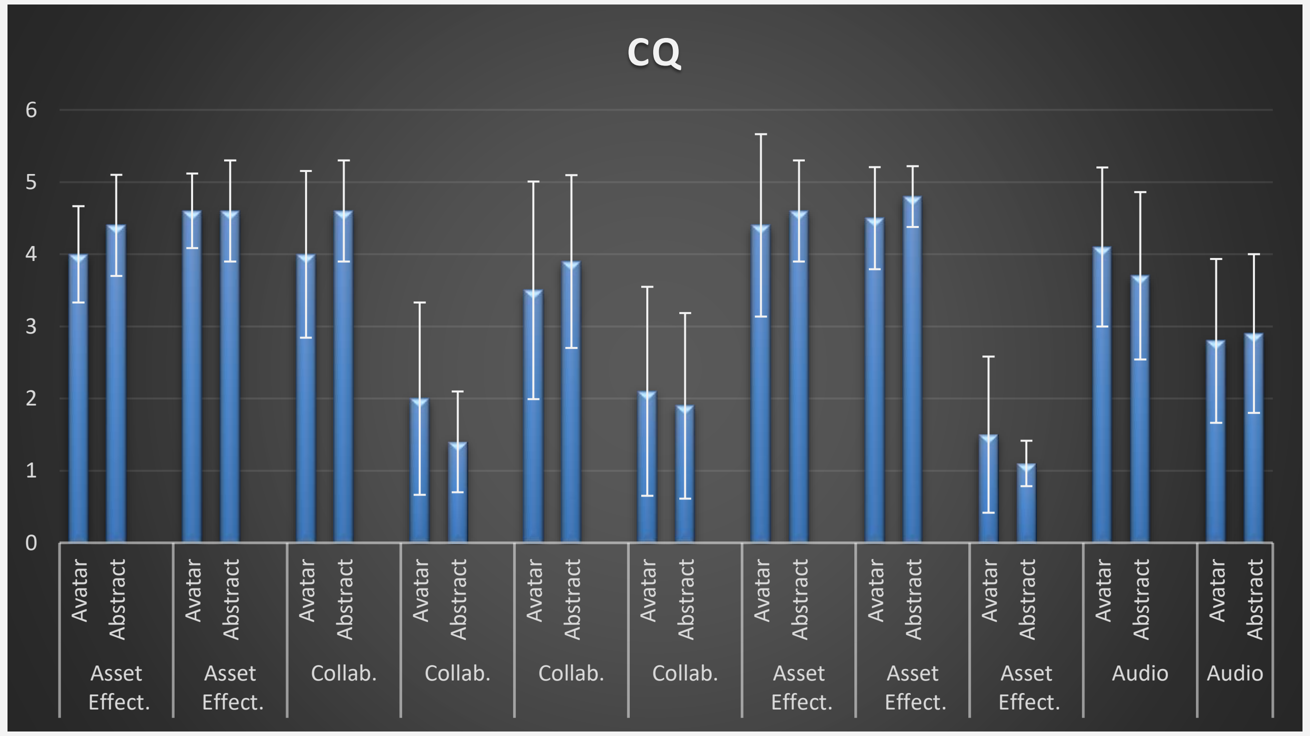


[1] De Pace F, Manuri F, Sanna A, Zappia D. A comparison between two different approaches for a collaborative mixed-virtual environment in industrial maintenance. Frontiers in Robotics and AI. 2019 Mar 27;6:18.
[2] Jarkko Polvi et al. User Interface Design of a SLAM-based Handheld Augmented Reality Work Support System. Tech. rep. VRSJ Research Report, 2013

Results: Audio Condition

- Users:
  - Average age = 24.5
  - 70% male
  - 30% female
  - Moderate knowledge of AR
- Two-tailed t-test
  - $p > 0.05$ for all the questions (low/medium effect sizes)
- Abstract seemed to perform better
- It seems that the virtual arrows are more efficient than the avatar to clearly explain the steps of the procedure
- The results concerning the learning questions are quite similar
- **The avatar seems to not improve the sense of human-human collaboration**
- **The audio channel plays an important role in the interaction**





Results: No-Audio Condition

Users:

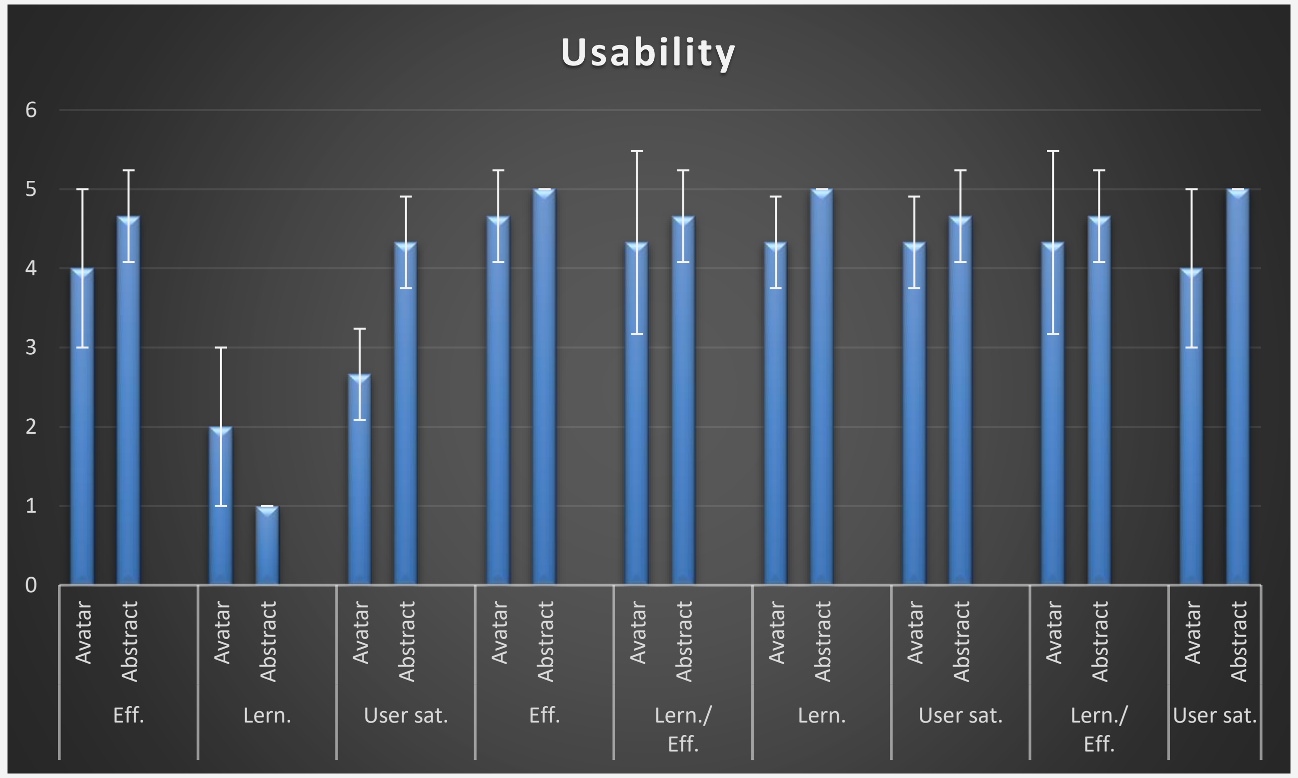
- Average age = 21.3
- 50% male
- 50% female
- Moderate knowledge of AR

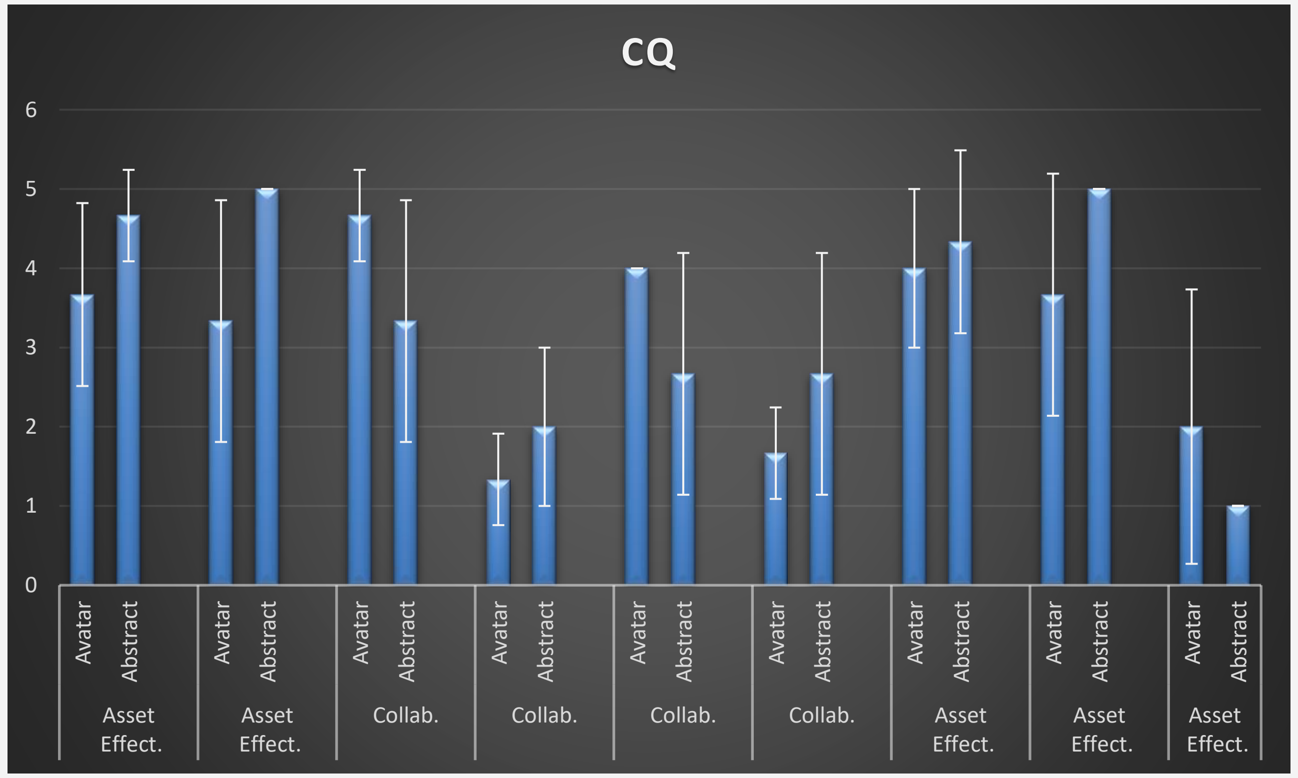
Two-tailed t-test

- p > 0.05 for all the questions (low/medium effect sizes)

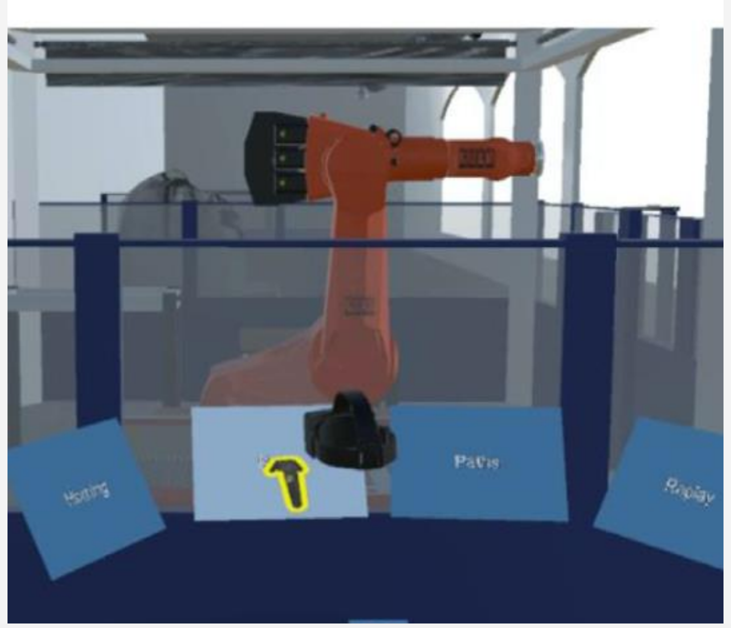
The avatar seems to not improve the usability

The avatar may increase the sense of human-human collaboration but it does not affect the performances



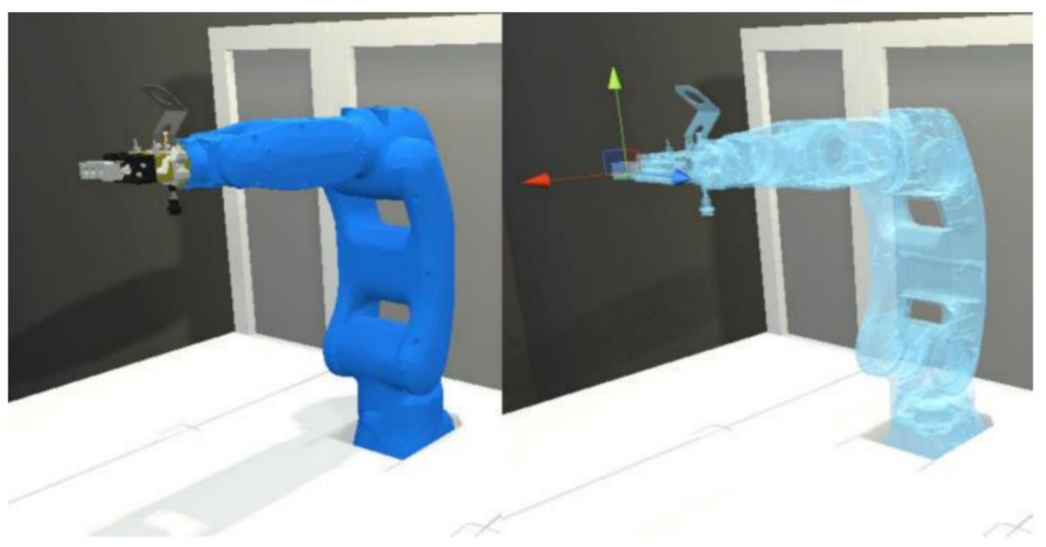


Virtual Interfaces in the Human-Robot Interaction context



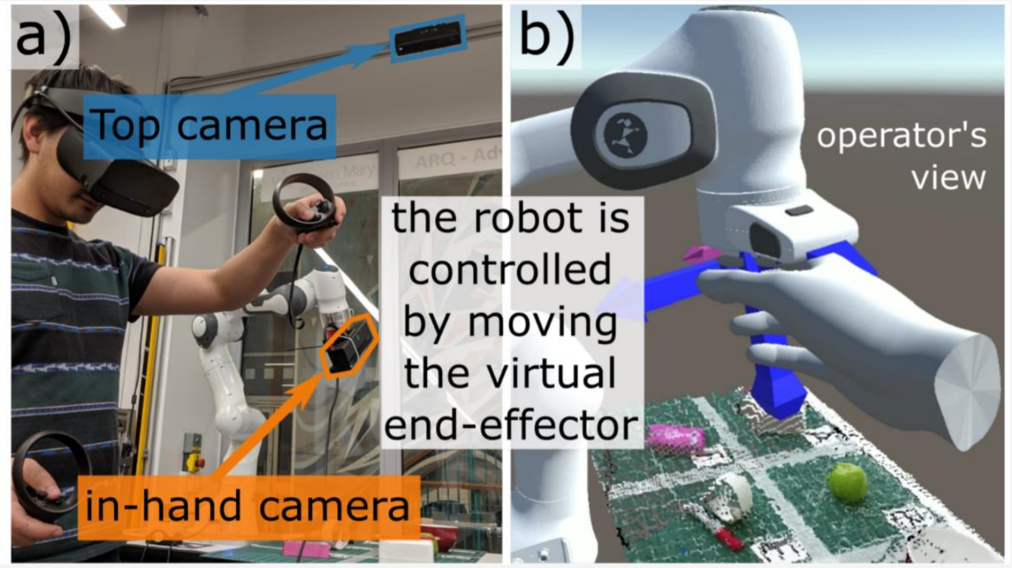
Training
[1]

VR



Digital-Twin
[2]

[3] Telerobotics [4]



Goal: Improve the telerobotic context

[1] Pérez L, Diez E, Usamentiaga R, García DF. Industrial robot control and operator training using virtual reality interfaces. Computers in Industry. 2019 Aug 1;109:114-20.

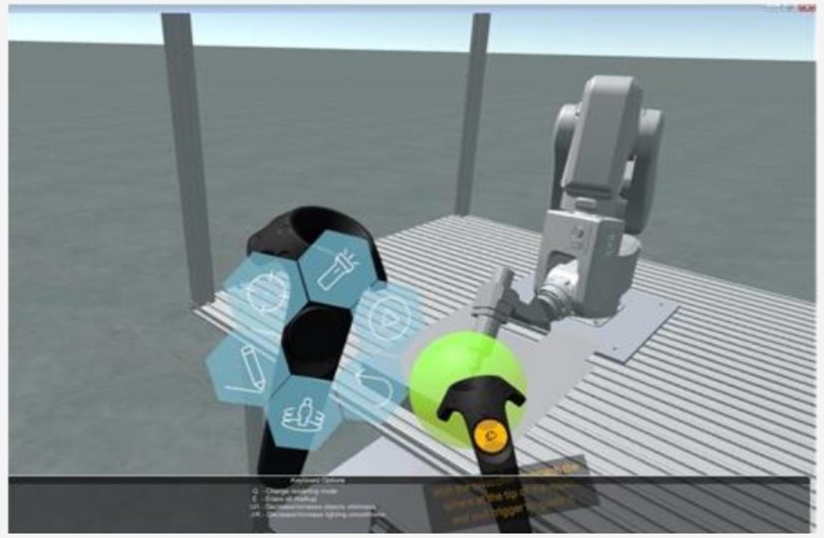
[2] Kuts V, Otto T, Tähemaa T, Bondarenko Y. Digital twin based synchronised control and simulation of the industrial robotic cell using virtual reality. Journal of Machine Engineering. 2019;19.

[3] Martín-Barrio A, Roldán JJ, Terrile S, del Cerro J, Barrientos A. Application of immersive technologies and natural language to hyper-redundant robot teleoperation. Virtual Reality. 2020 Sep;24(3):541-55.

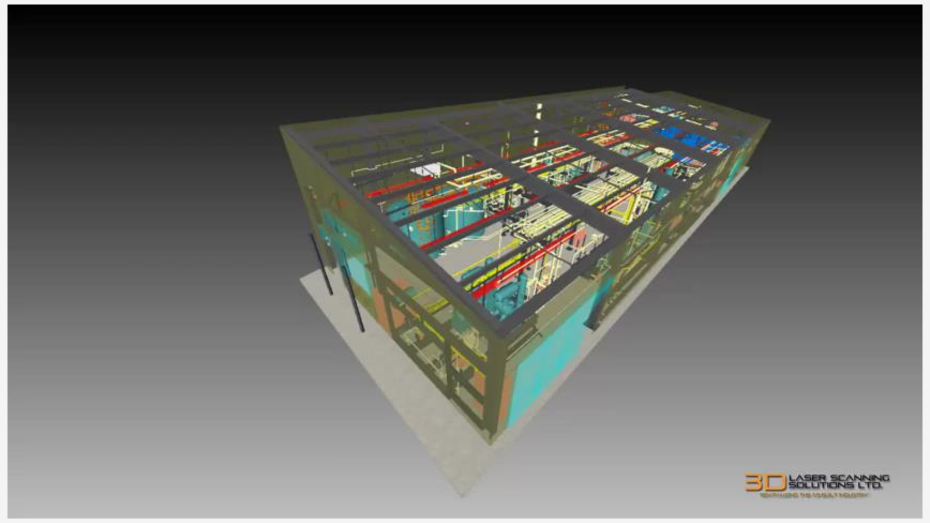
[4] Omarali B, Denoun B, Althoefer K, Jamone L, Valle M, Farkhatdinov I. Virtual reality based telerobotics framework with depth cameras. In2020 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN) 2020 (pp. 1217-1222). IEEE.

VR in Telerobotics

[1]



Pre-modeled Env.



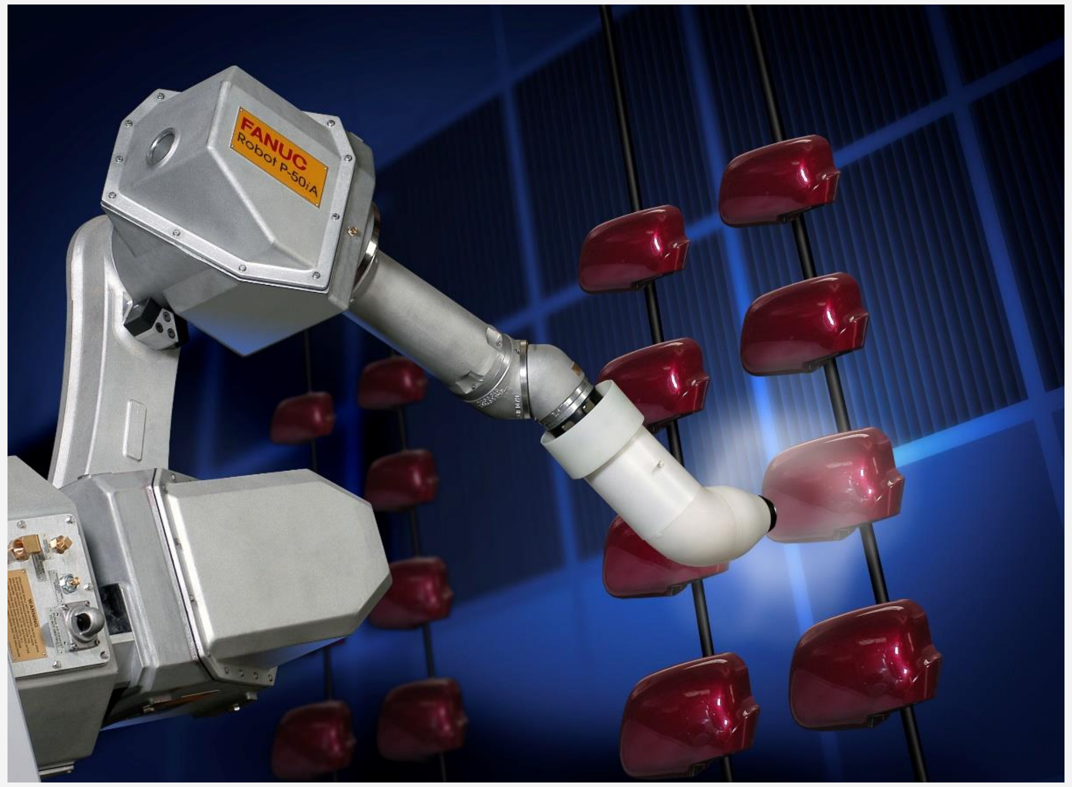
Pre-scanned Env.

[2]

Real-time scanned Env.

Real-time scanned Env. **>> "Enhanced VR System" (EVR)**

- Real environment scanned and acquired using sensors (RGB-D)
- Data is transmitted over the network and it is used to visualize in real-time the robot workspace
- The operator can control the robot using an immersive VR device



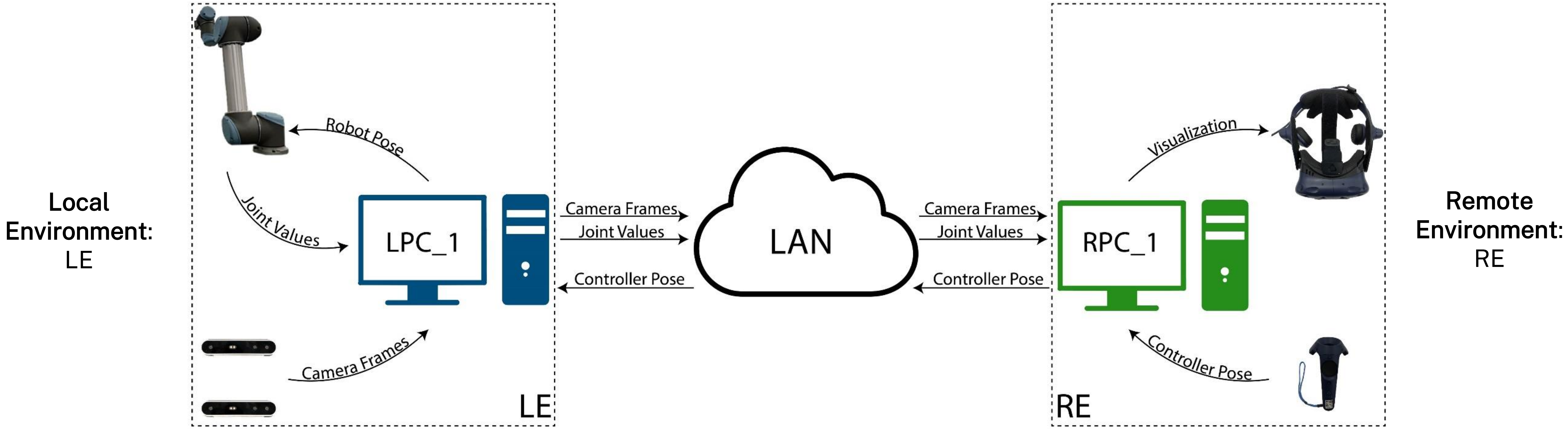
- Usually, these teleoperation systems are employed for **pick-and-place scenarios**
- **There is a lack of studies** that analyze their effectiveness for **robotic tasks that require high-accuracy**:
  - Surgery
  - Welding
  - Painting

[1] Holubek R, Ružarovský R, Sobrino DR. Using virtual reality as a support tool for the offline robot programming. Vedecké Práce Materiálovotechnologickej Fakulty Slovenskej Technickej Univerzity v Bratislave so Sídlom v Trnave. 2018;26(42):85-91.

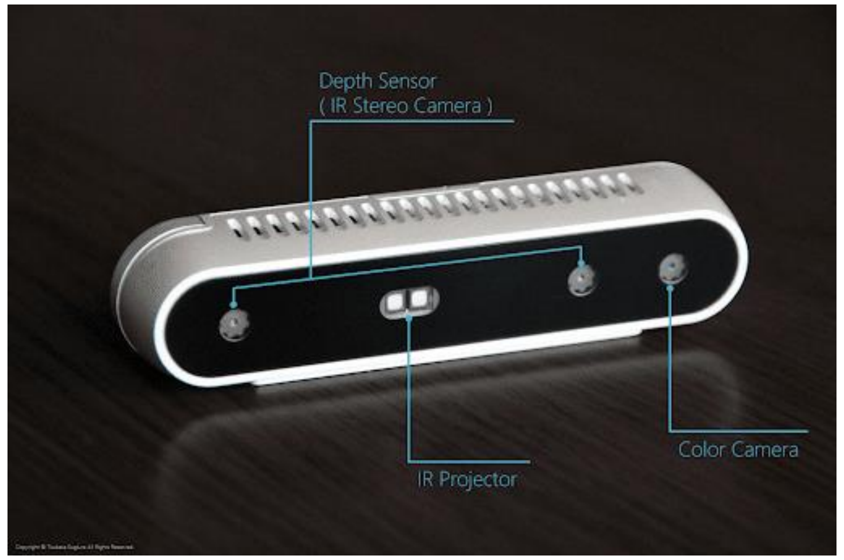
[2] Whitney D, Rosen E, Ullman D, Phillips E, Tellex S. Ros reality: A virtual reality framework using consumer-grade hardware for ros-enabled robots. In2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) 2018 Oct 1 (pp. 1-9). IEEE

Leveraging Enhanced Virtual Reality Methods and Environments for Efficient, Intuitive, and Immersive Teleoperation of Robots [1]

- Research project done in collaboration with the **Emphatic Computing Lab** and the **Mechatronic Department** of the **University of Auckland**, **New Zealand**.
- The labs are headed by **Professors Mark Billinghurst** and **Minas Liarokapis**, leading experts in the HCI and robotic domain, respectively.



- Universal Robot UR5
- Two Intel RealSense D415 cameras
- Personal Computer running ROS Melodic (LPC_1)
- HTC Vive Pro
- One Vive controller
- Personal Computer running Windows and a Unity3D App (RPC_1)



Intel RealSense D415 camera

[1] De Pace F, Gorjup G, Bai H, Sanna A, Liarokapis M, Billinghurst M. Leveraging Enhanced Virtual Reality Methods and Environments for Efficient, Intuitive, and Immersive Teleoperation of Robots.

The Point Cloud Streaming and Rendering

Camera Handshake

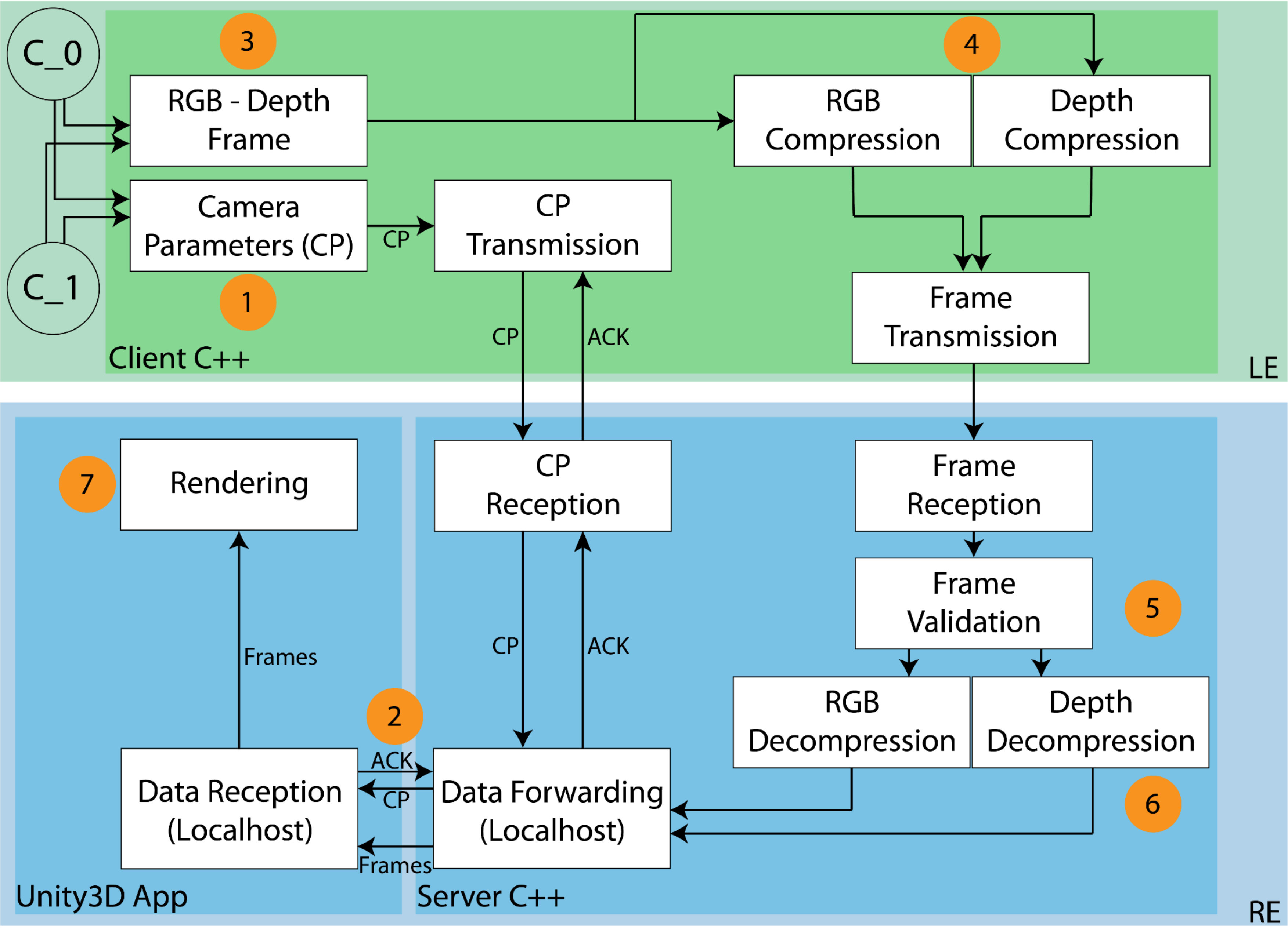
- Intrinsic camera parameters and number of cameras are sent to RE (steps 1, 2)

Streaming

- RGB and depth frames are compressed and sent over UDP to RE (steps 3,4)
- The frames are checked and validated to correctly reconstruct the original frames (steps 5, 6)
- The validated frames are sent to the Unity3D app for the rendering (step 7)

Rendering

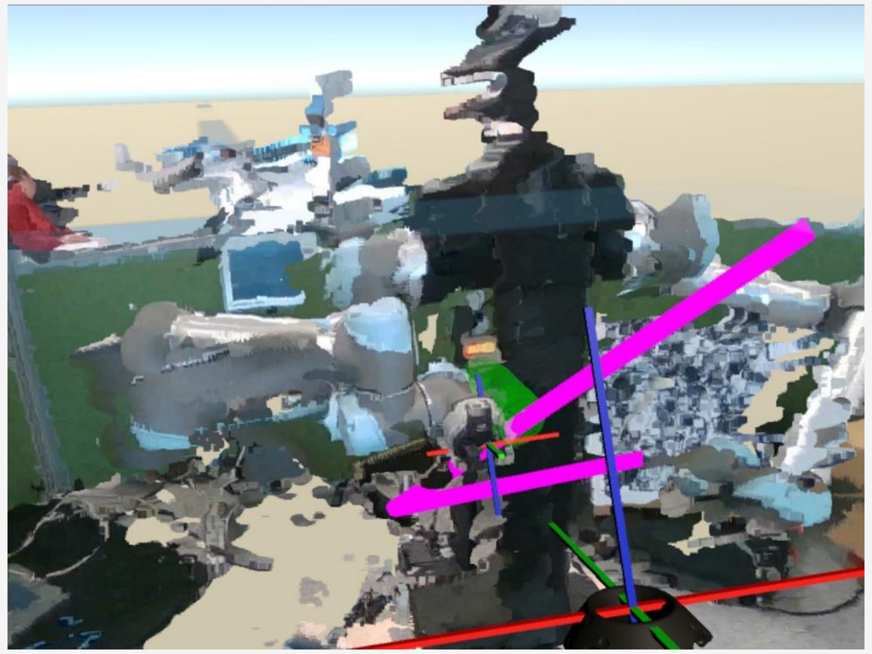
- Using the intrinsic parameters, the depth map is converted to a list of 3D vertices on the CPU
- The list is sent to the GPU to apply the color information



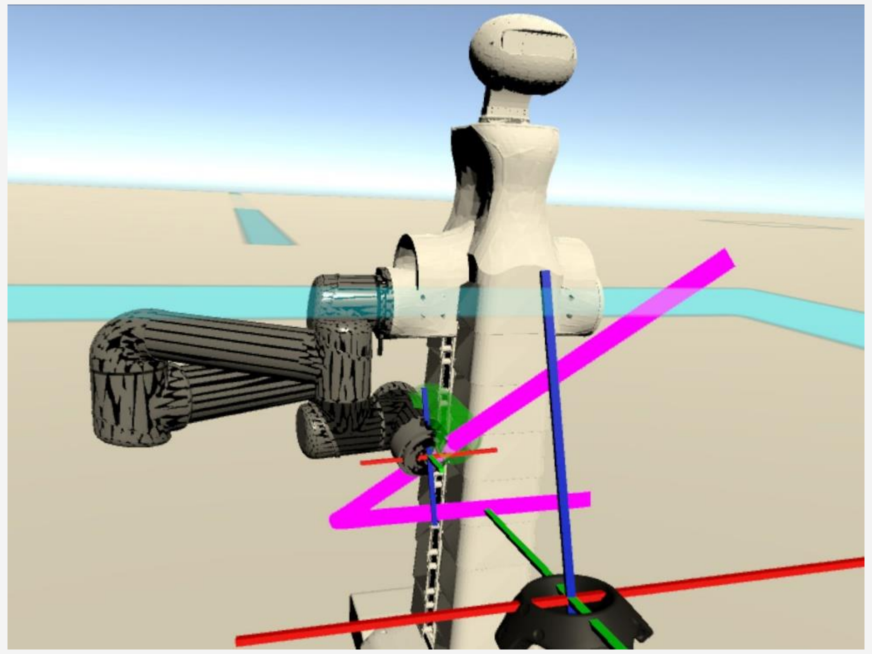
Interface Comparison

Goal: analyze effectiveness of EVR interfaces in accurate robot tasks by comparing three different interfaces:

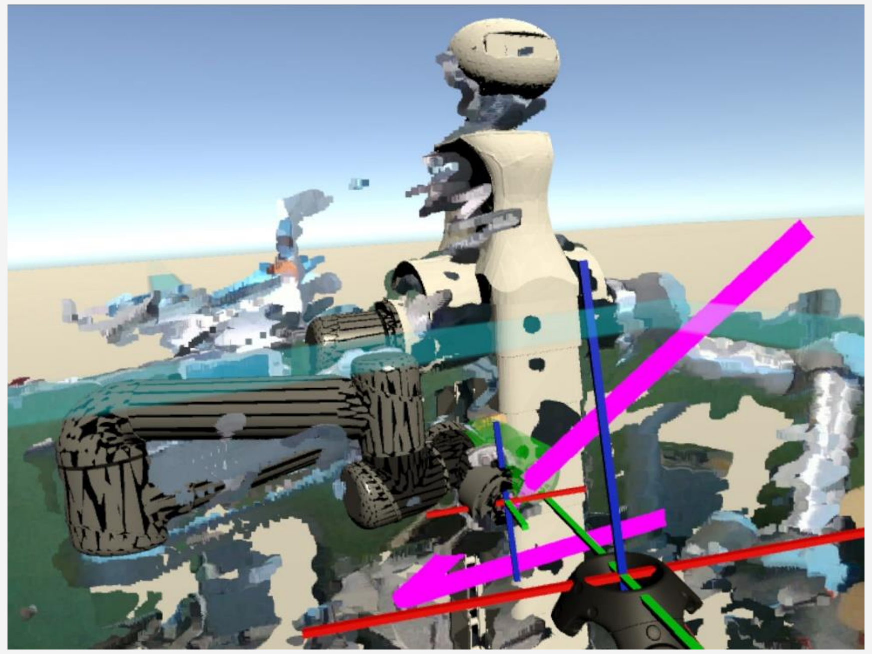
- **EVR**
- EVR with the CAD robot model superimposed on the reconstructed one (**EVRR**)
- “Pure” **VR**



EVR



VR



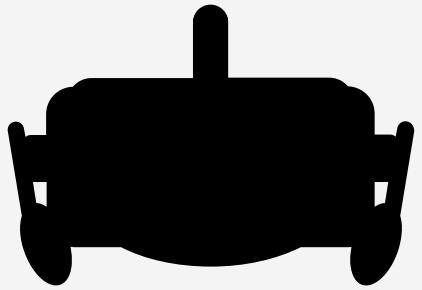
EVRR

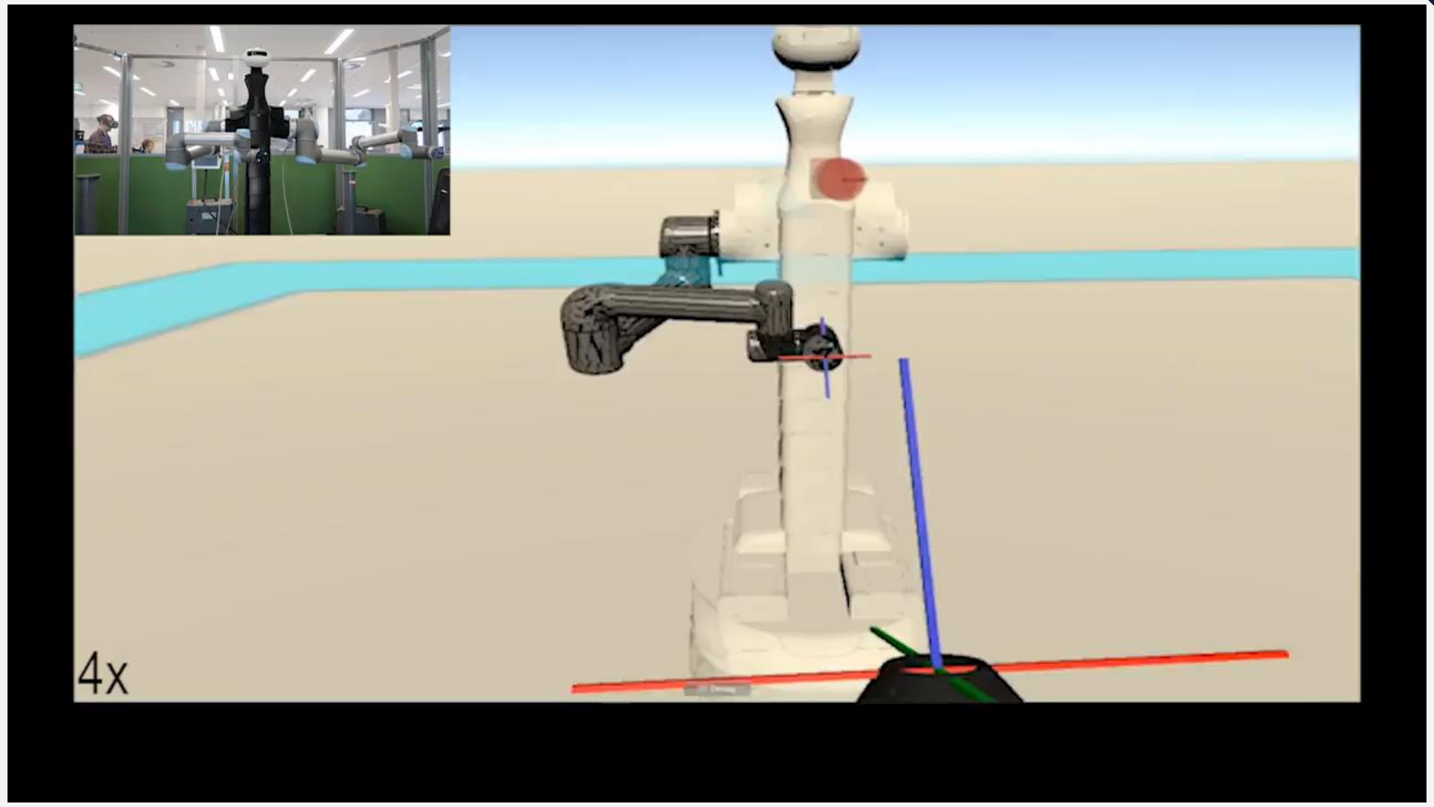
Real Robot

The User Study

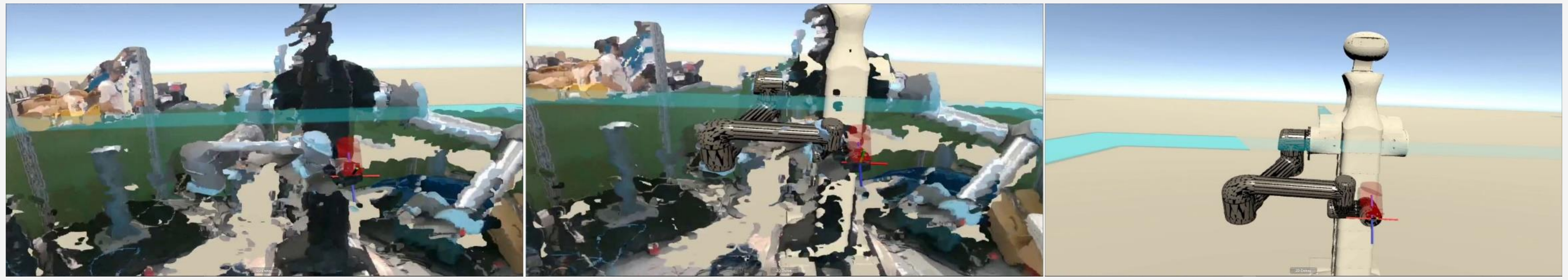
- Eighteen users (average age: 28)
  - Average knowledge of both AR and robotics
- Six Tasks
  - Three Pose Tasks (PTs)
  - Three Speed Tasks (STs)

- VR Hardware

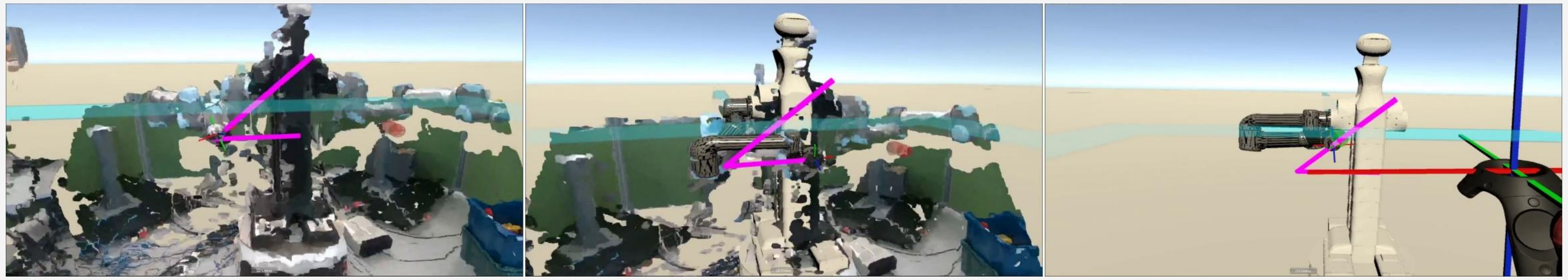




Example of PT



Example of ST



Analyzed Data

Objective (compared with pre-recorded trajectories):
- End-Effector pose (PT)
- End-Effector trajectory (ST)

Subjective:
- Interface usability (SUS)
- Interface workload (NASA-TLX)
- “Attention”, “Spatial Situation”, and “Presence” (MEC-SPQ)

Main Results

PT

	VR	EVR	EVRR	VR-EVR	EVRR-EVR
P0T	0.007	0.0327	0.01	p=0.0 d=0.877	p=0.0 d=0.846
P1T	0.009	0.033	0.015	p=0.0 d=0.877	p=0.0 d=0.723
P2T	0.009	0.048	0.062	p=0.0 d=0.877	*

- T: translational error (Normalized)
- R: rotational error (Normalized)
    - No statistically significant differences

ST

	VR	EVR	EVRR	VR-EVR	EVRR-EVR
S0T	0.012	0.018	0.016	p=0.001 d=0.774	p=0.006 d=0.649
S0R	0.108	0.146	0.119	p=0.003 d=0.692	*
S2T	0.012	0.028	0.013	p=0.0 d=0.596	p=0.0 d=0.587
S2R	0.128	0.213	0.112	p=0.005 d=0.662	p=0.0 d=0.846

- Users' and robot's trajectories have been analyzed using **Dynamic Time Warping algorithm**
- T (translational) and R (rotational) errors: the sum of distances between individual matched points, divided by the total number of points

Questionnaires

	VR	EVR	EVRR	VR-EVR	EVRR-EVR	VR-EVRR
SUS	83	58	79	p=0.0 d=0.830	p=0.0 d=0.80	*
NASA	37	63	39	p=0.0 d=0.871	p=0.0 d=0.861	*
Attention	48	42	47	p=0.014 d=0.584	p=0.005 d=0.662	*
Spatial Situation	15	39	46	p=0.0 d=0.853	p=0.007 d=0.644	p=0.0 d=0.882
Presence	31	40	45	*	p=0.014 d=0.584	p=0.004 d=0.661

- SUS, NASA and Attention: **EVR the worst one**
- Spatial Situation and Presence: **the "pure" VR interface seems to be inadequate**

Overall

- VR is generally the best one and there are **no differences between VR and EVRR**
- For PT and ST: for VR and EVRR, both T and R errors were in the **range of 1 cm**, which is still insufficient for high-precision tasks like welding
- The pure **EVR interface is not adequate** to control robotic arms in high accuracy tasks
- The **visualization** of the virtual robot greatly improves **the effectiveness of the interface**
- **Pure point cloud carries artifacts** -> problems in visualizing the contours of the robots, especially the end-effector contour
- **Pure point cloud is not "stable"**, it changes every frame generating an "unstable" visualization

Future Works

- Improve point cloud visualization
- Improve Streaming
- Improve Control Algorithm

Gaming

Overview

Characteristics of "Hybrid" Games

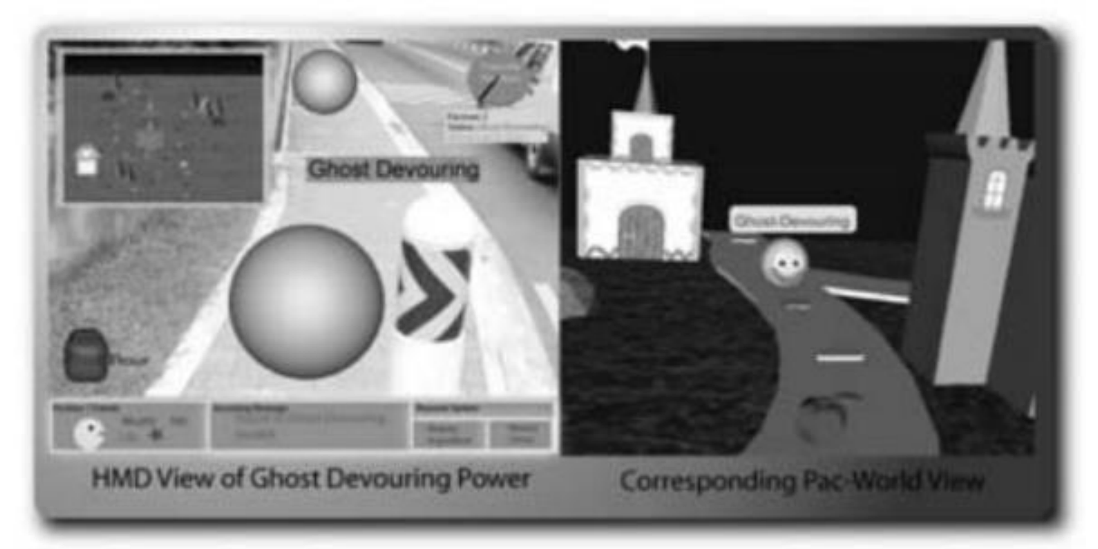
Tabletop Game: Usability Evaluation

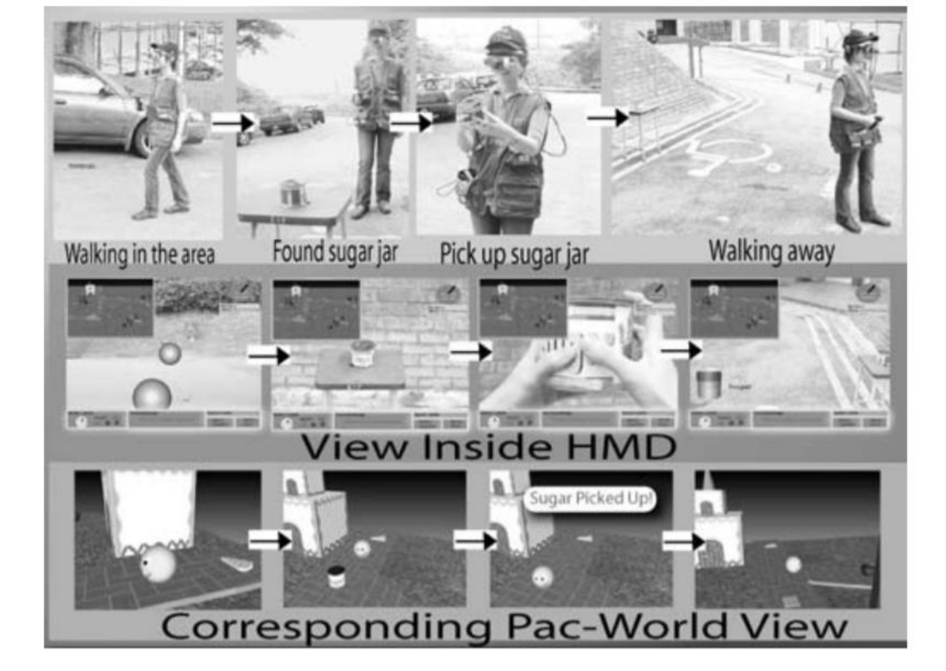
First-Person Shooter Game: Usability Evaluation

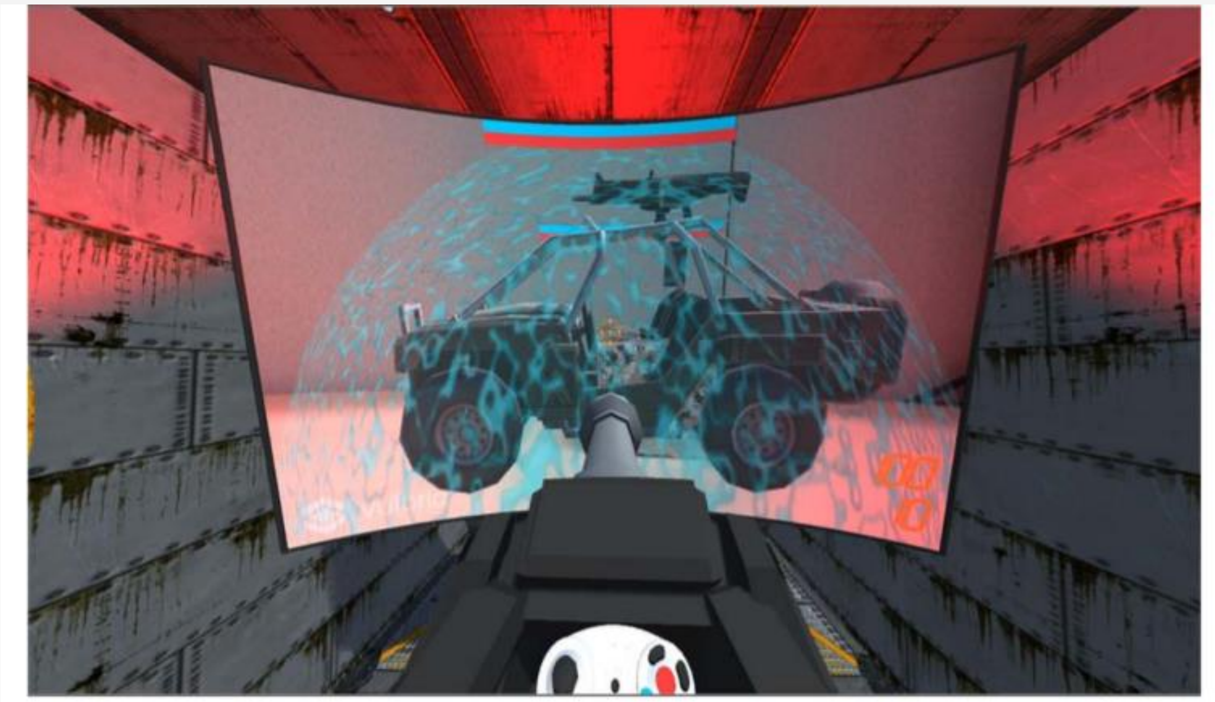
Framework for Hybrid Games

Hybrid Games

- In the gaming context, an interesting domain is represented by the “hybrid” games, that is, games that can be experienced using concurrently both AR and VR interfaces
  - Human Pacman [1]
  - Clash Tanks [2]
  - ...







Main Characteristic

→ The games highlight the peculiarities of the AR/VR interfaces

Goal

→ User studies to assess the usability of VR/AR interfaces for games that convey to both players **similar game experiences**

[1] Cheok AD, Goh KH, Liu W, Farbiz F, Fong SW, Teo SL, Li Y, Yang X. Human Pacman: a mobile, wide-area entertainment system based on physical, social, and ubiquitous computing. Personal and ubiquitous computing. 2004 May 1;8(2):71-81.
[2] Ranade S, Zhang M, Al-Sada M, Urbani J, Nakajima T. Clash tanks: An investigation of virtual and augmented reality gaming experience. In2017 Tenth International Conference on Mobile Computing and Ubiquitous Network (ICMU) 2017 Oct 3 (pp. 1-6). IEE

Virtual and Augmented Reality Interfaces in Shared Game Environments: A Novel Approach [1]

Use case: chess game

- It does not derive from a virtual game neither from an augmented one
- The players are "forced" to play the same role

Goal

Usability evaluation

How

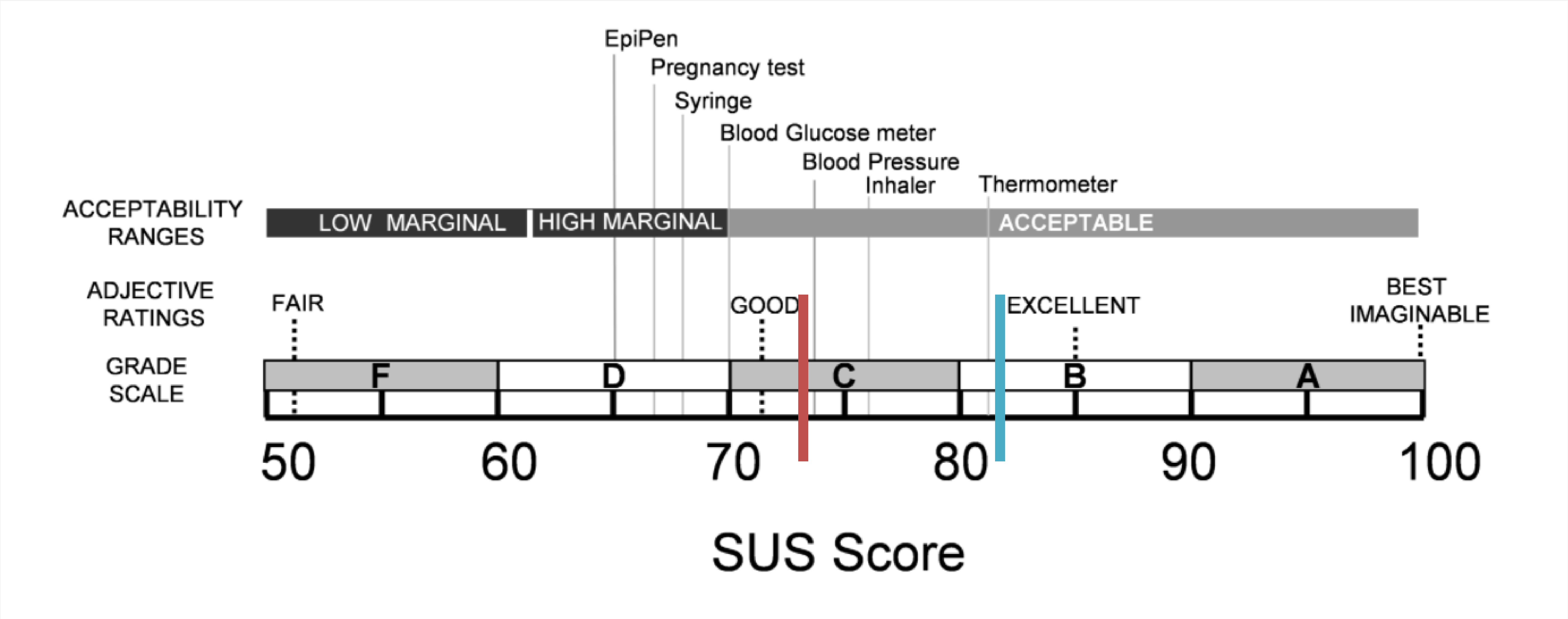
Comparing the usability of two different interfaces: AR and VR

Test

- 20 volunteers (average age: 27)
  - 60% male
  - 40% female
  - Moderate knowledge of both VR and AR
- 10 pairs
- System Usability Scale (SUS)

[1] De Pace F, Manuri F, Sanna A, Zappia D. Virtual and Augmented Reality Interfaces in Shared Game Environments: A Novel Approach. In INTETAIN 2018 Nov 21 (pp. 137-147).

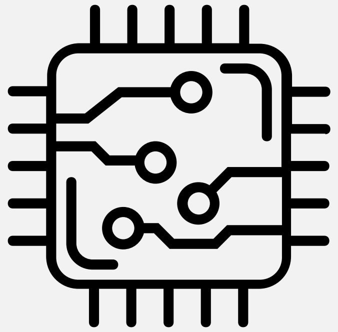
Results

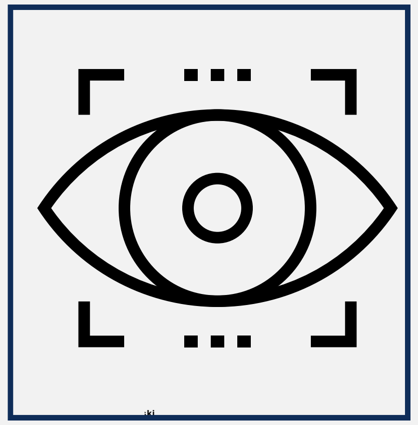


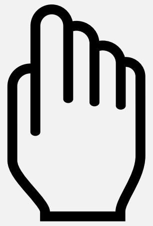
AR

VR

- Data analyzed with the Wilcoxon Signed Rank Test
  - $p = 0.007$, $d = 0.6$
- AR Limitations

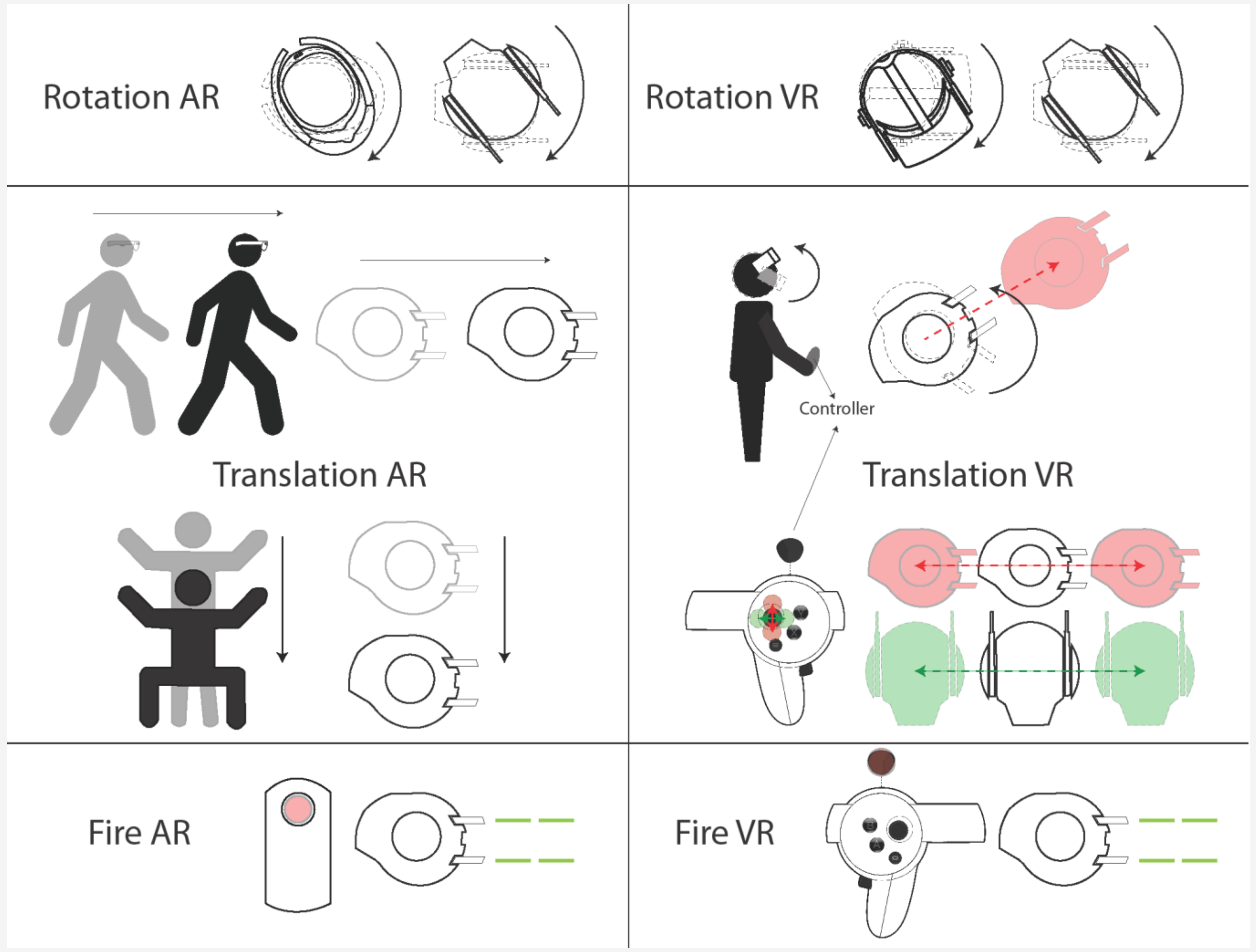






An Evaluation of Game Usability in Shared Mixed and Virtual Environments [1]

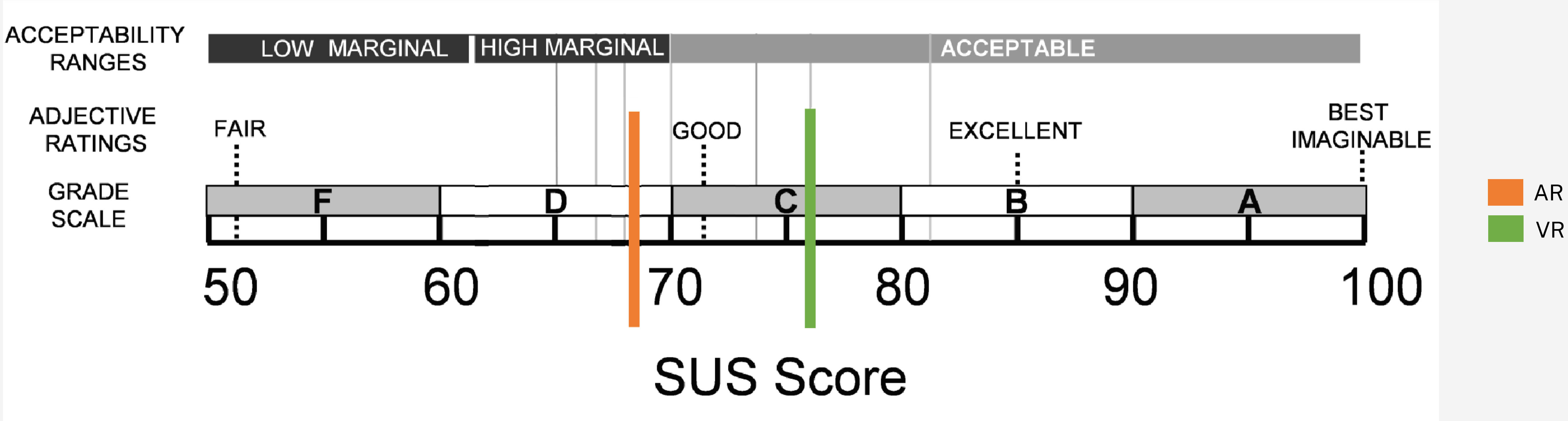
- Given the limitations of the narrow FoV, I investigated whether it could have the same effects in games that require huge physical movements
- **Goal**: evaluate the impact of the FoV on the usability of a first-person shooter AR/VR game
- How: making comparable the interaction system (but for the FoV)



- 10 users (average age: 27)
  - 90% male
  - 10% female
  - Little knowledge of both VR and AR

[1] De Pace F, Manuri F, Sanna A, Zappia D. A comparison between two different approaches for a collaborative mixed-virtual environment in industrial maintenance. Frontiers in Robotics and AI. 2019 Mar 27;6:18

Results



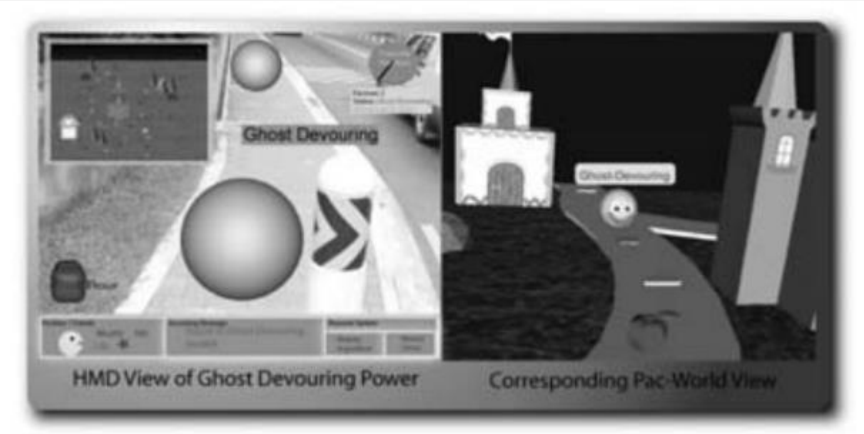
- Data analyzed with the Wilcoxon Signed Rank Test:
  - $p = 0.386$, $d = 0.27$
- It cannot be claimed that an application is more usable than the other one, even if a slight preference for the VR solution can be noticed
- Despite these limited outcomes, the majority of the users indicated the FoV as the main limitation of the AR interface
- The possibility of moving in the real environment is the most appreciated aspect of the AR interface
- **Future Work**: running the experiment using devices that provide more similar characteristics

Frameworks for hybrid environments

- Several systems allow different users to interact with digital assets at the same time
- Usually, they employ the same interfaces (e.g., gaming) or interfaces from the same “macro-area” (e.g., desktop and Head-Mounted Display for VR)
- When they use DIFFERENT (e.g., AR and VR) interfaces, they convey different user-experiences

  The experience is hardware dependent
- Some frameworks support different devices:
  - VHD++, MORGAN, Instantreality ([1-2-3])
  - Probably the most famous one is the **Microsoft Mixed Reality Toolkit** ([4])

[5]



[6]

PRO(s)

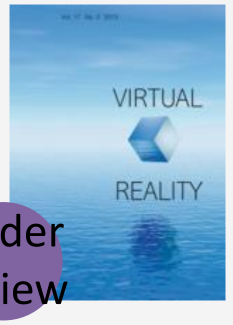
- Management of different devices
- Abstraction layer (e.g., input layer)
  - Ad-hoc custom features

CON(s)

- No multiplayer logic
- No creation of hybrid environment
  - Alignment of virtual and real worlds

[1] Ohlenburg J, Herbst I, Lindt I, Fröhlich T, Broll W. The MORGAN framework: enabling dynamic multi-user AR and VR projects. In Proceedings of the ACM symposium on Virtual reality software and technology 2004 Nov 10 (pp. 166-169).
[2] Ponder M, Papagiannakis G, Molet T, Magnenat-Thalmann N, Thalmann D. VHD++ development framework: Towards extendible, component based VR/AR simulation engine featuring advanced virtual character technologies. In Proceedings Computer Graphics International 2003 2003 Jul
[3] Behr J, Bockholt U, Fellner D. Instantreality—A Framework for Industrial Augmented and Virtual Reality Applications. In Virtual Reality & Augmented Reality in Industry 2011 (pp. 91-99). Springer, Berlin, Heidelberg.
[4] https://github.com/microsoft/MixedRealityToolkit-Unity/releases/tag/v2.4.0
[5] Du J, Shi Y, Zou Z, Zhao D. CoVR: Cloud-based multiuser virtual reality headset system for project communication of remote users. Journal of Construction Engineering and Management. 2018 Feb 1;144(2):04017109.
[6] Cheok AD, Goh KH, Liu W, Farbiz F, Fong SW, Teo SL, Li Y, Yang X. Human Pacman: a mobile, wide-area entertainment system based on physical, social, and ubiquitous computing. Personal and ubiquitous computing. 2004 May 1;8(2):71-81.

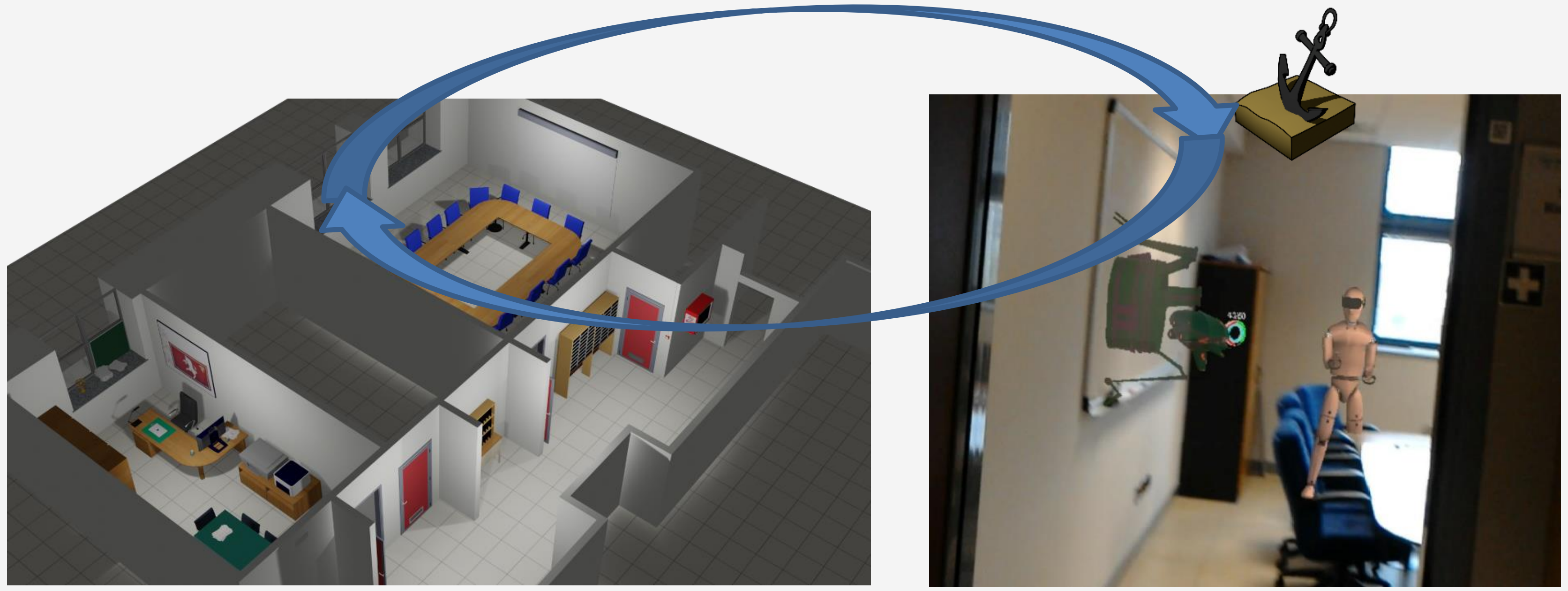
Harmonize: a shared environment for extended immersive entertainment

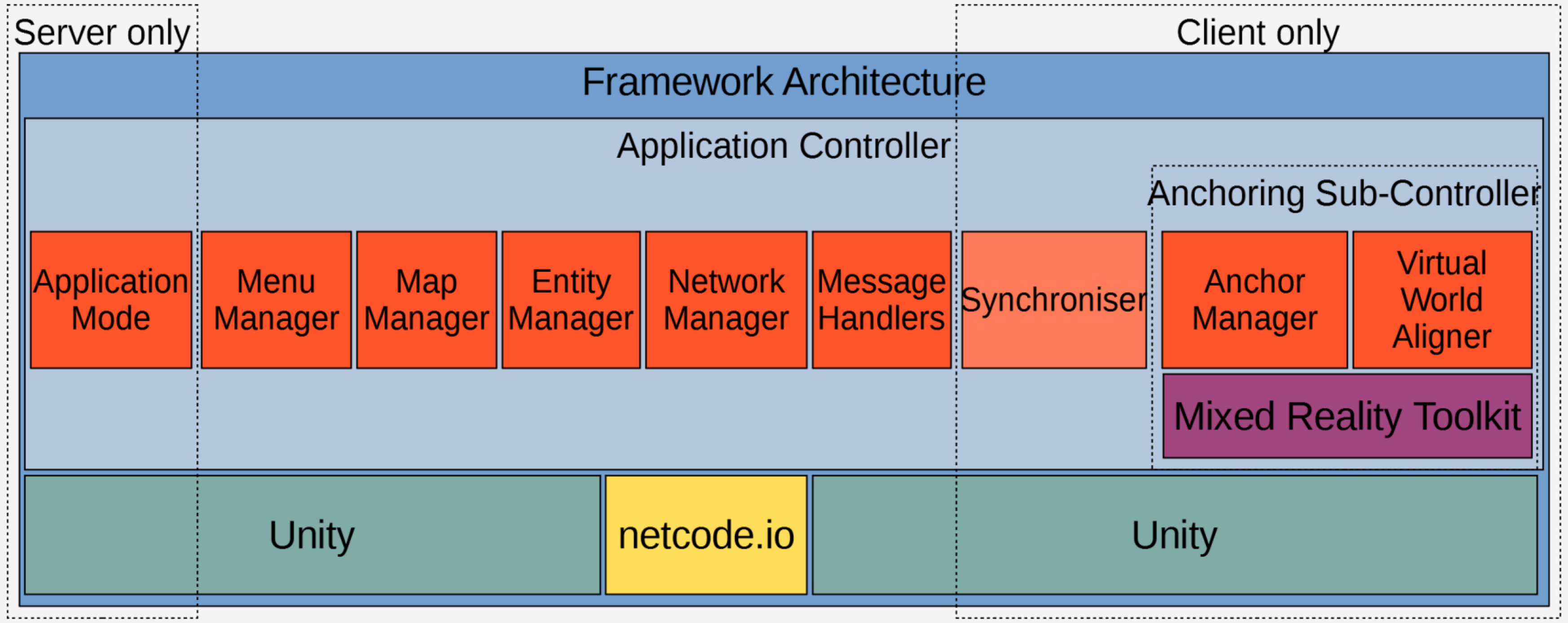


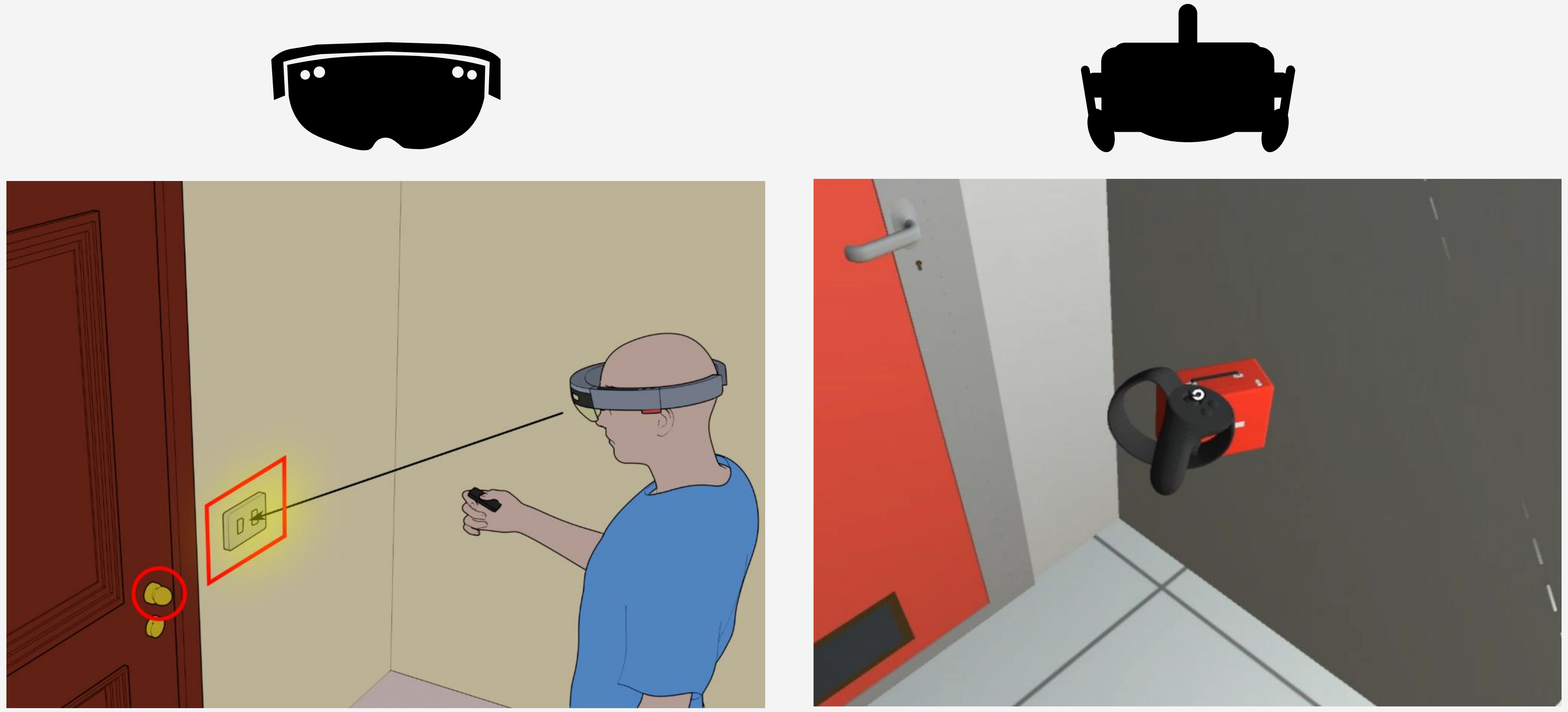
Under review

Goal

- Framework to support:
  - Different devices
    - Providing the “same type” of interaction independently of the employed hardware
  - Multiplayer logic
    - low-level logic, packet transmission, etc.
    - app life-cycle (lobby creation, etc.)
  - Alignment of virtual and real environments
- Virtual and real worlds alignment:
  - “anchor(s)” used as common reference system
  - they are added by the AR player







The User Study

Test case:

- 20 users (10 pairs, average age: 25)
  - 80% male
  - 20% female
  - Moderate knowledge if VR
  - Little knowledge of AR
- First-person shooter
- Politecnico di Torino offices
- AR and VR players have to collaborate to destroy some virtual enemies

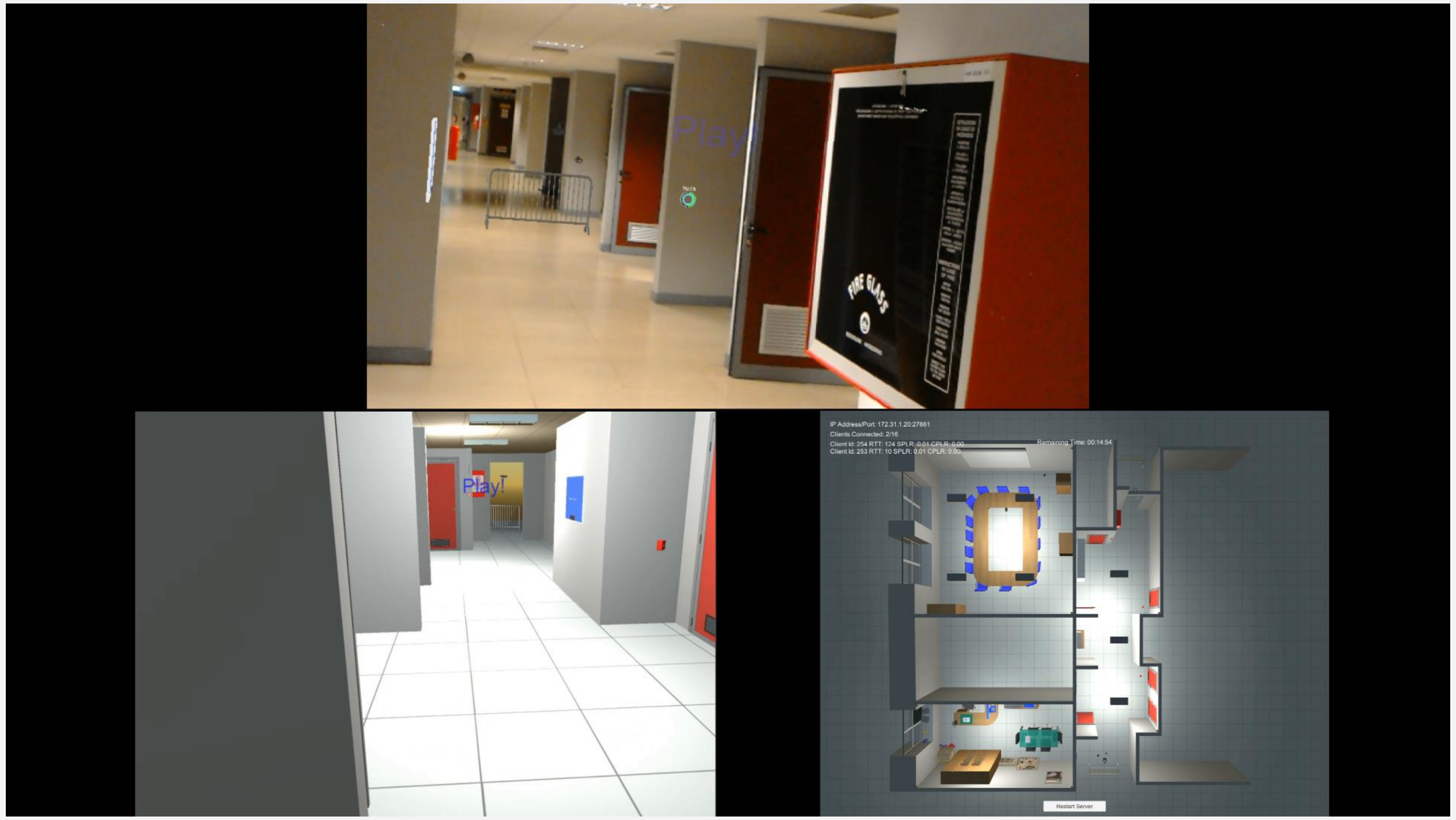
Evaluated Parameters:

Objective:

- Tracking Loss (**TL**)
- Time Tracking Recovering (**TTR**)
- **RTT**
- Packet Loss (**PL**)

Subjective:

- Usability (**SUS**)
- Game Experience Questionnaire (**GEQ**)
  - In-Game Experience
  - Post-Game Experience
  - Social Presence



Results

Objective

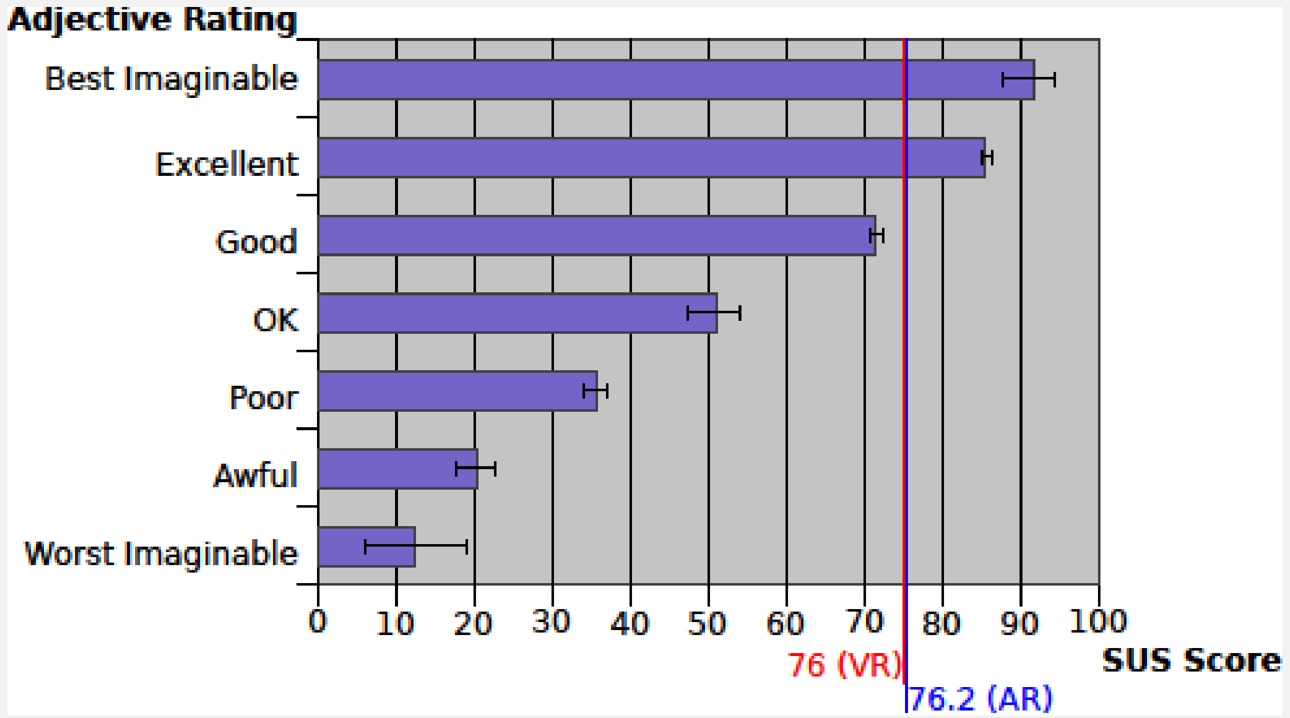
TL	TTR	RTT	PL
1.35	~ 5s	200ms	1%

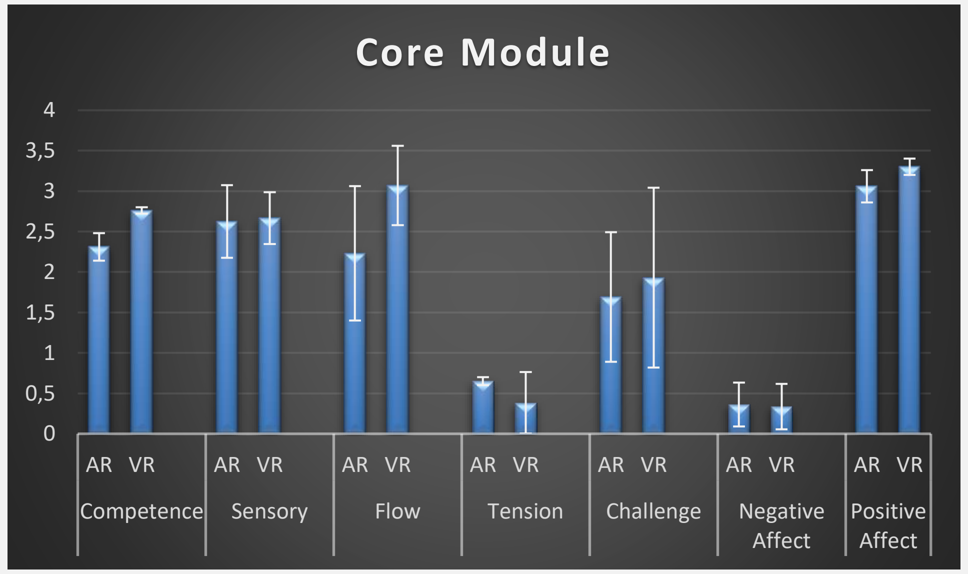
Subjective

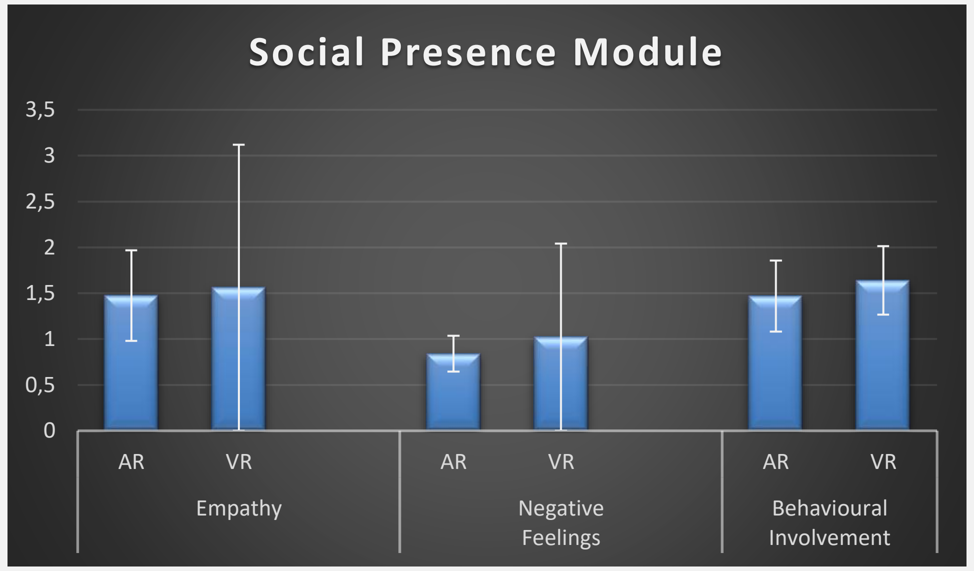
- Data analyzed with the Wilcoxon Signed Rank Test:
  - Competence: $p = 0.042$, $d = 0.45$
  - Flow: $p = 0.042$, $d = 0.45$
  - Positive Affect: $p = 0.042$, $d = 0.45$

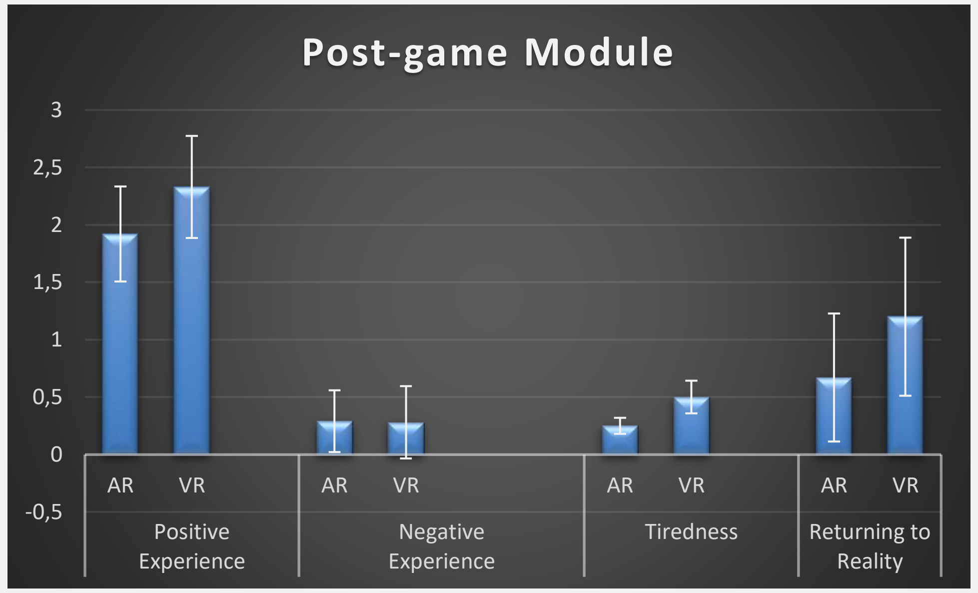
  - Behavioural Involvement: $p = 0.027$, $d = 0.49$

  - Positive Experience: $p = 0.026$, $d = 0.50$









- **Future Work:**
  - Improving Real Environment Reconstruction

Conclusion

Industry 4.0

- Different uses of AR, with particular emphasis on the HRC domain (very few user studies)
- Static and adaptive AR interfaces to display industrial robot faults
- AR-VR training environment to verify which metaphors best help trainees during robotic tasks
- Assessment of an EVR interface to remotely control a robotic manipulator

Gaming

- Usability of VR and AR interfaces when employed to interact with tabletop games
- User study to verify whether the FoV could affect the game experience in hybrid games that require wide physical movements
- Innovative framework to ease the development of hybrid environments

Main Limitations

- Choice of the users for the user tests
  - Very limited number and potentially biased
- Absence of control tasks
- The results concerning the impact of the FoV on the usability of hybrid games cannot be easily extended and generalized

Main Achievements

Publications

- Tot. journal papers: 6 (+2 under revisions)
- Tot. proceedings: 5
- Tot. book chapters: 2

Contribution to the scientific community

- Reviewer for:

Journals:

- EEE Access (6 reviews)
- Sensors (2 reviews)
- Applied Science (5 reviews)
- ACM Computing Survey (1 review)
- ACM TOCHI (on going)

Conferences:

- IEEE ICRA 2021 (1 review)

Awards

- "**Best Young Researcher Paper Award**" of the 5th International Conference on Augmented and Virtual Reality and Computer Graphics 2018
- **First prize in the 2nd Year PhD Award Competition 2020.**

Training Activities

- 40 soft skill hours
- 106 hard skill hours

Teaching Activities

- Collaborator for Polito Courses (Computer Science, Computer Animation)
- Mentor for Challenge@Polito
- Teacher for Specialization Courses

PhD Abroad

- Six months in New Zealand (Auckland)
- Collaboration with the Emphatic Computing Lab and the Mechatronic Department

Natural and multimodal interfaces for human-machine and human-robot interaction

Thank you for the attention

Questions & Answers

Torino, 12/07/2021