NimbRo Avatar: Intuitive Immersive Telepresence balancing Interaction, Manipulation, and Mobility

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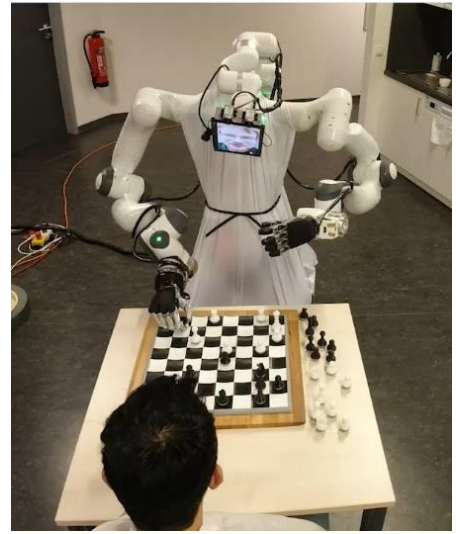
Experience with Teleoperated Robots

- Multiple domains
- Often motivated by competitions and challenges

RoboCup@Home

DARPA Robotics Challenge
DLR SpaceBot Cup

CENTAURO

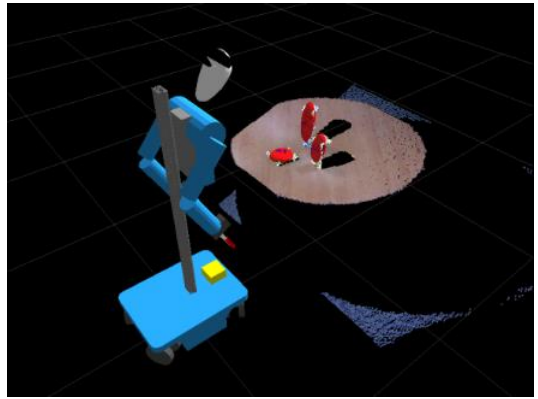


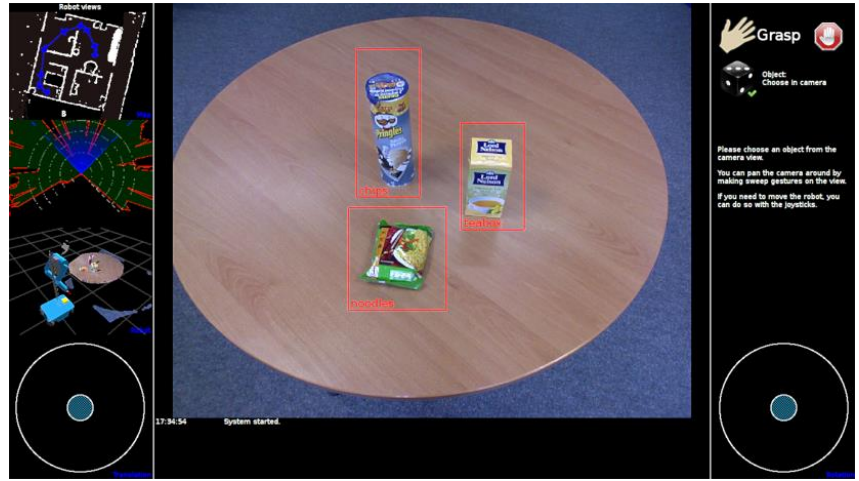
ANA Avatar XPRIZE

Cognitive Service Robot Cosero

Handheld Teleoperation Interface

- Three levels of autonomy / control:
  - Task level
  - Skill level
  - Direct control



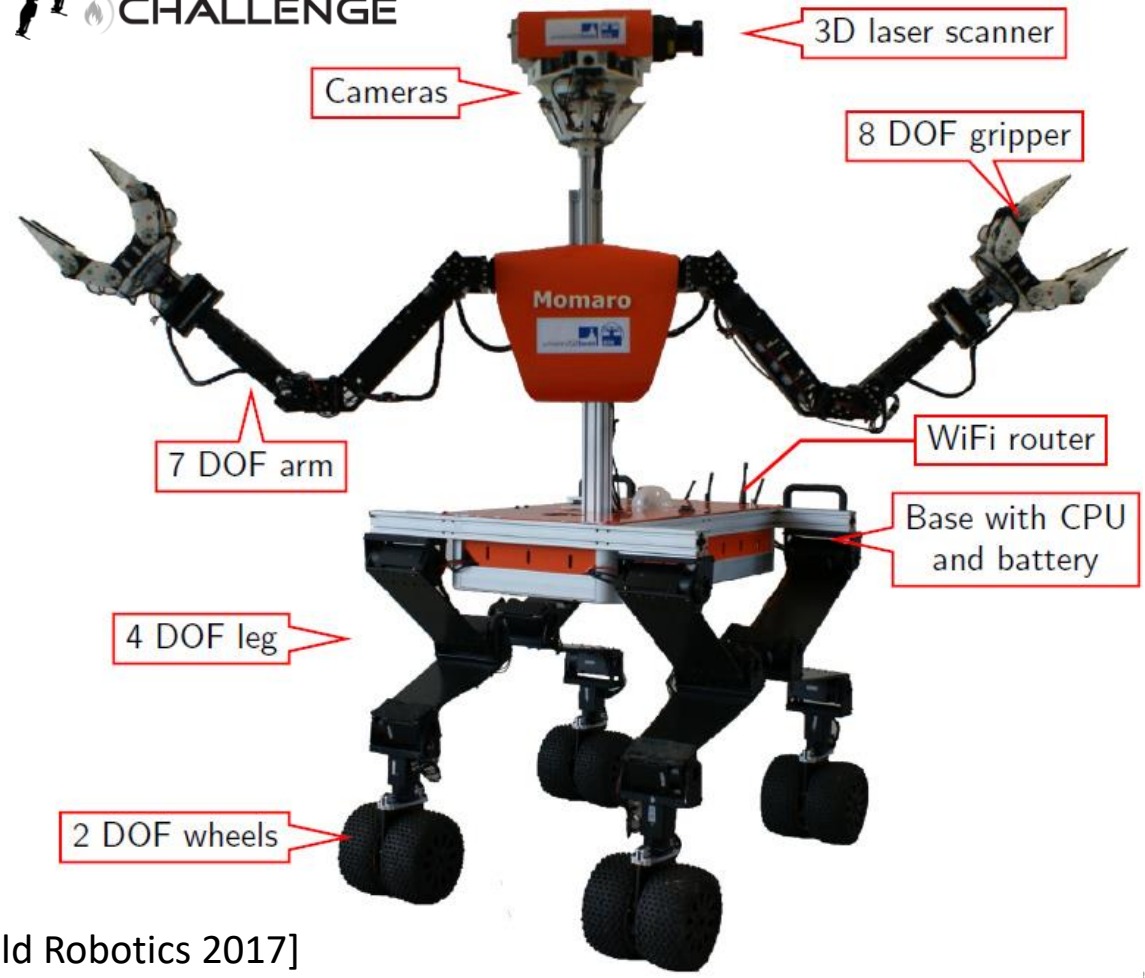


[Schwarz, Stückler, Behnke, HRI 2014]

Mobile Manipulation Robot Momaro

DARPA ROBOTICS CHALLENGE

- Four compliant legs ending in pairs of steerable wheels
- Anthropomorphic upper body
- Sensor head
  - 3D laser scanner
  - IMU, cameras

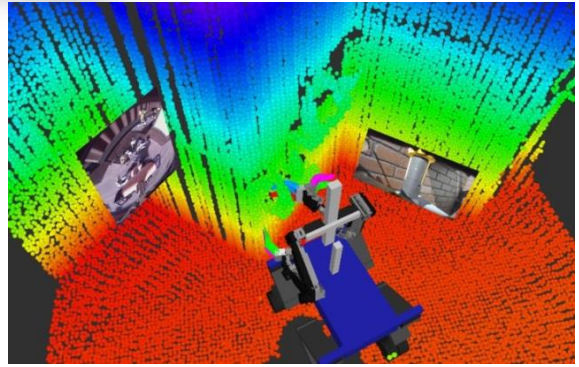


[Schwarz et al. Journal of Field Robotics 2017]

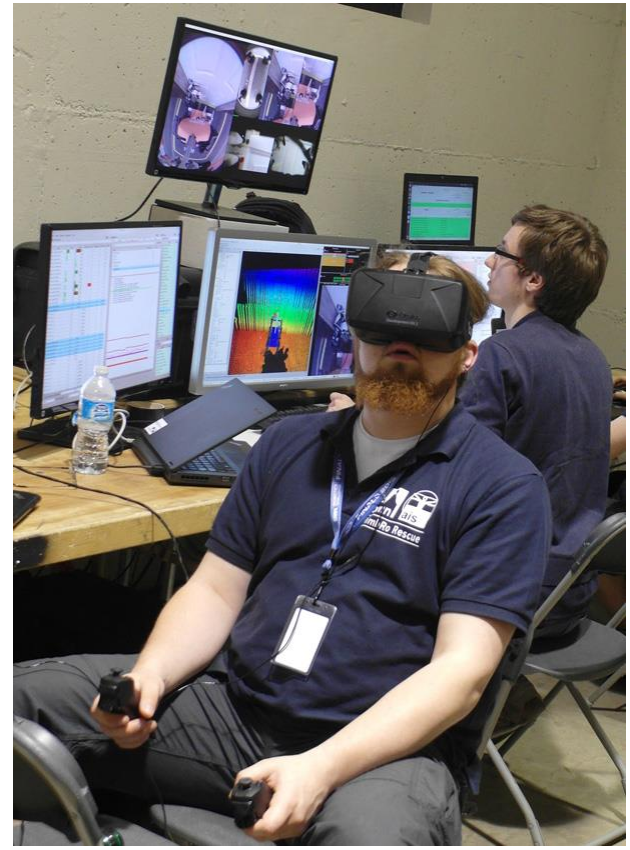
Manipulation Operator Interface

- 3D head-mounted display

- 3D environment model + images



- 6D magnetic tracker



[Rodehutskors et al., Humanoids 2015]

DARPA Robotics Challenge

[Schwarz et al. Journal of Field Robotics 2017]

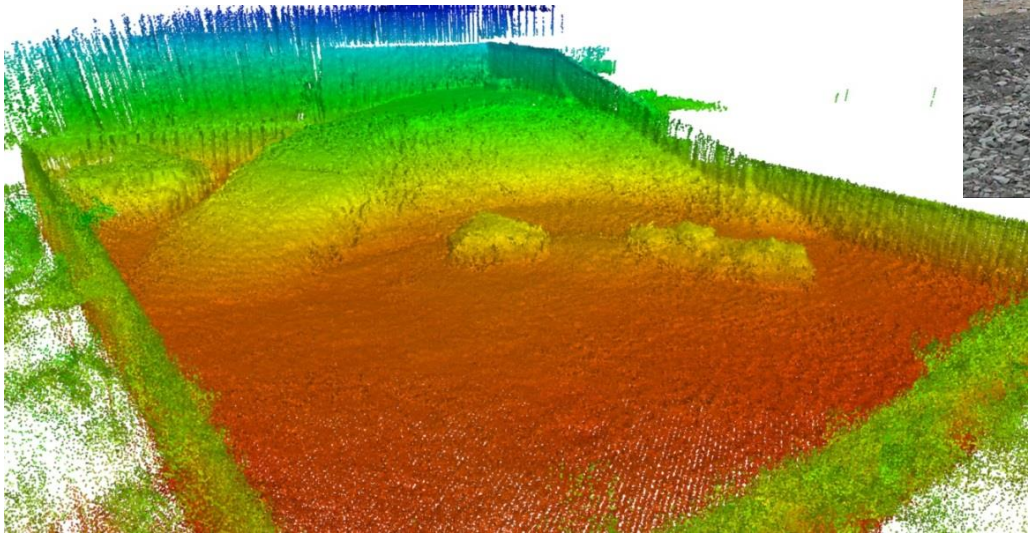
Team NimbRo Rescue

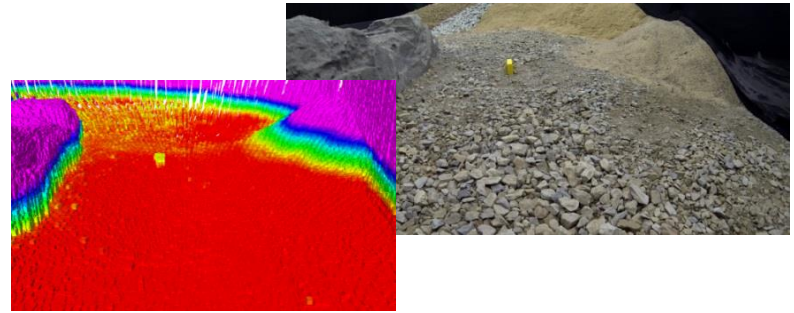
Best European Team (4th place overall), solved seven of eight tasks in 34 minutes

[Schwarz et al. Journal of Field Robotics 2017]

DLR SpaceBot Cup 2015

- Mobile manipulation in rough terrain



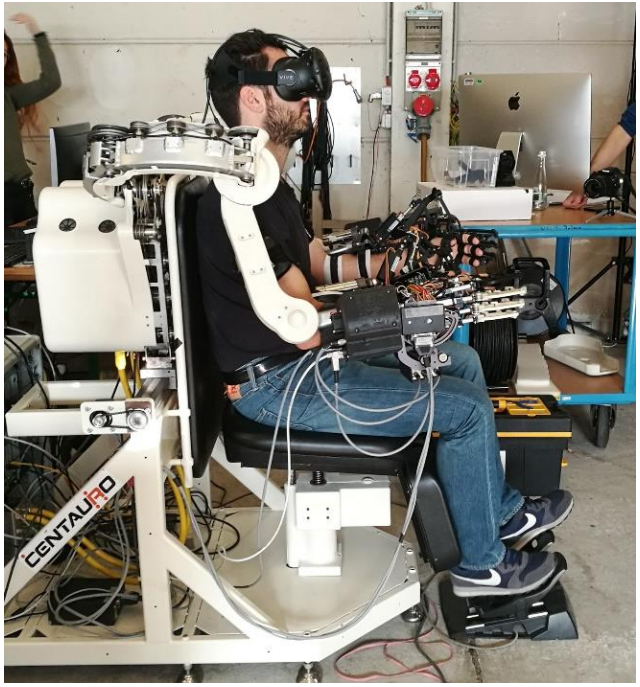


[Schwarz et al., Frontiers on Robotics and AI 2016]

[Schwarz et al., Frontiers on Robotics and AI 2016]

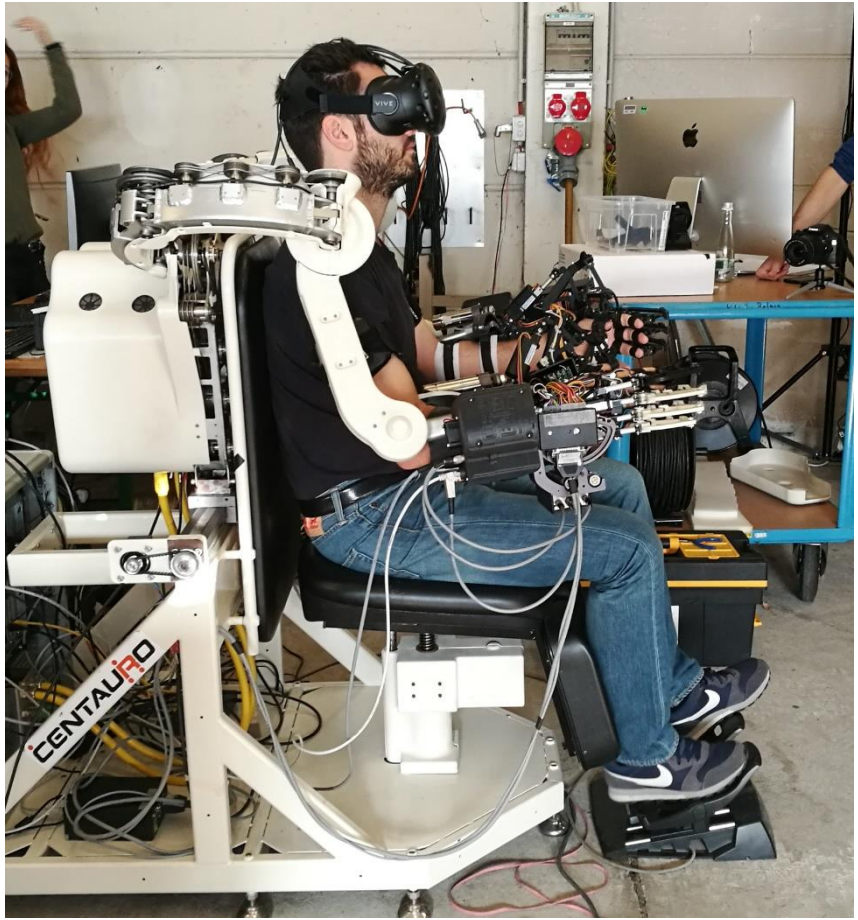
Robust Mobility and Dexterous Manipulation in Disaster Response by Fullbody Telepresence in a Centaur-like Robot

- Four-legged robot with steerable wheels and anthropomorphic upper body
- Immersive teleoperation through exoskeleton with HMD



[Klamt et al., Journal of Field Robotics 2020]

Immersive Operator Interface



Stereo Visual and Audio Feedback
- Head-Mounted Display
- Audio Headset

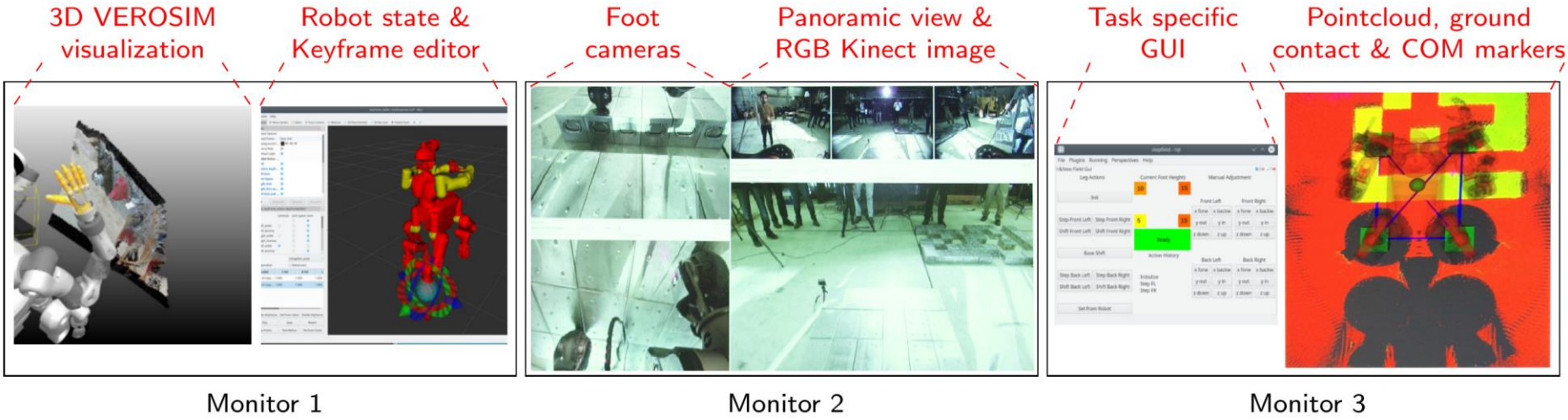
Arm-Hand Movements
- Arm and wrist exoskeleton
- 7 DoFs, wide workspace
- Force and torque feedback

Grasping Control
- Hand exoskeleton
- Independent Fingers
- Force feedback

Navigation
- 3 DoFs Pedals

[Klamt et al., Journal of Field Robotics 2020]

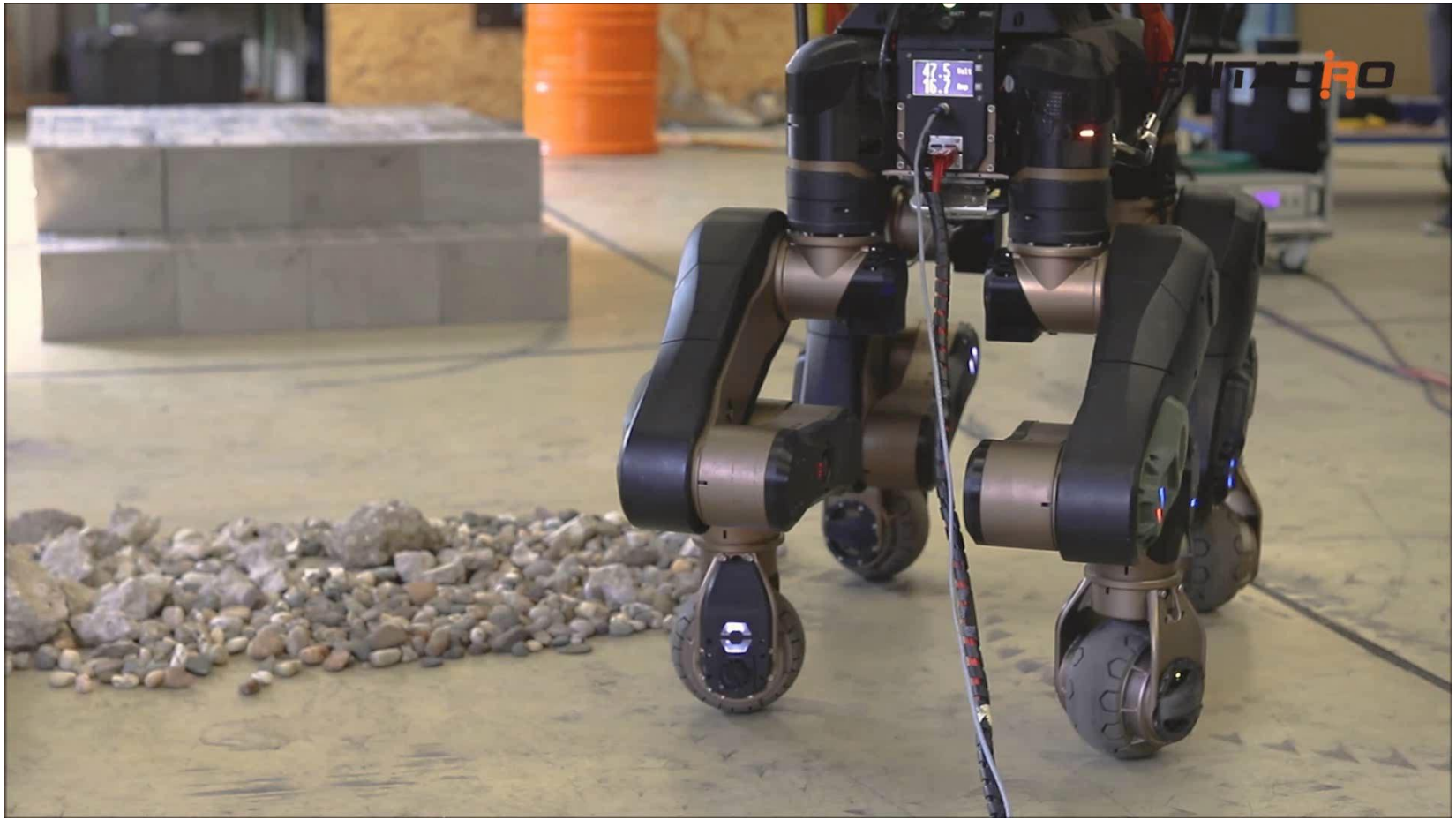
Teleoperation with Joystick and Spacemouse



- Flexible user interfaces for locomotion and manipulation tasks
- 3D situation awareness
- Motion editor

[Klamt et al., Journal of Field Robotics 2020]

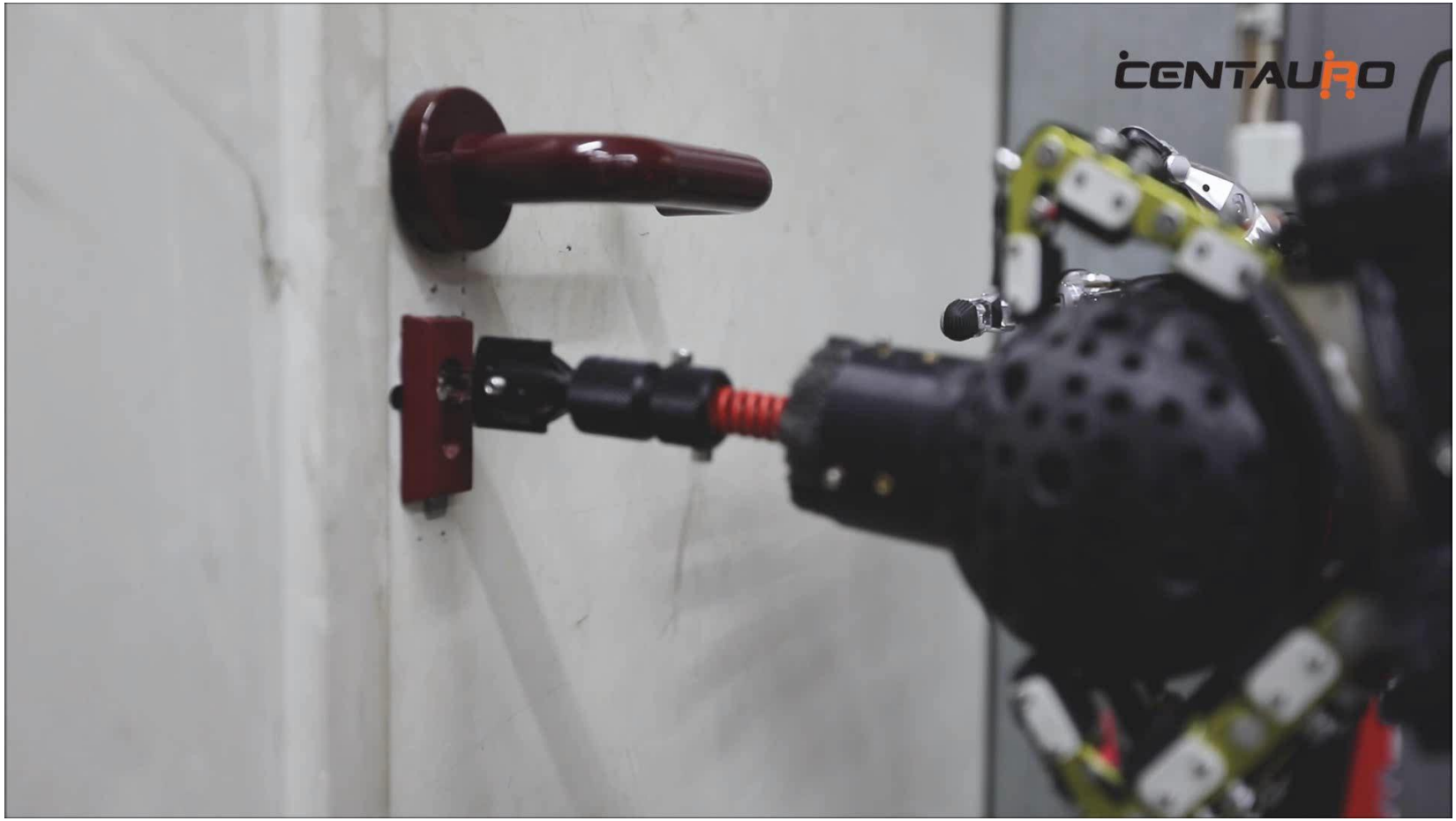
CENTAURO Evaluation @ KHG: Locomotion Tasks



[Klamt et al. RAM 2019]

Grasping an Unknown Power Drill and Fastening Screws

CENTAURO: Complex Manipulation Tasks



[Klamt et al. RAM 2019]

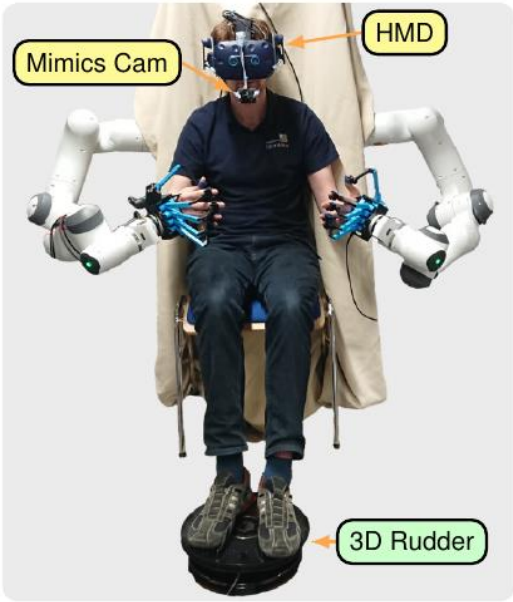
ANA Avatar XPRIZE Competition

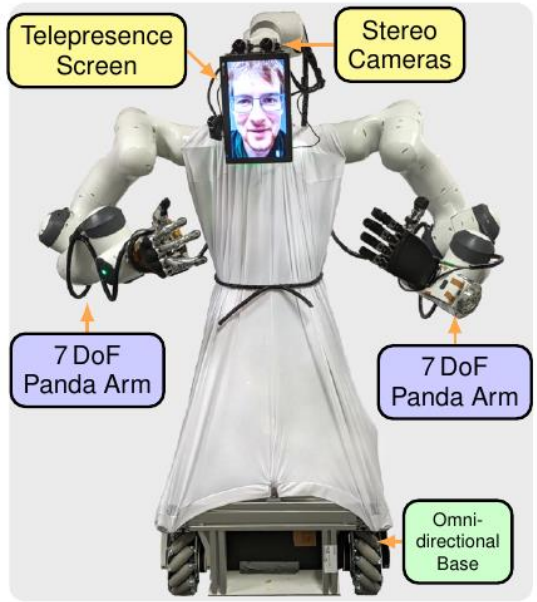
- Requires mobility, manipulation, human-human interaction
- Focuses on the immersion in the remote environment and the presence of the remote operator

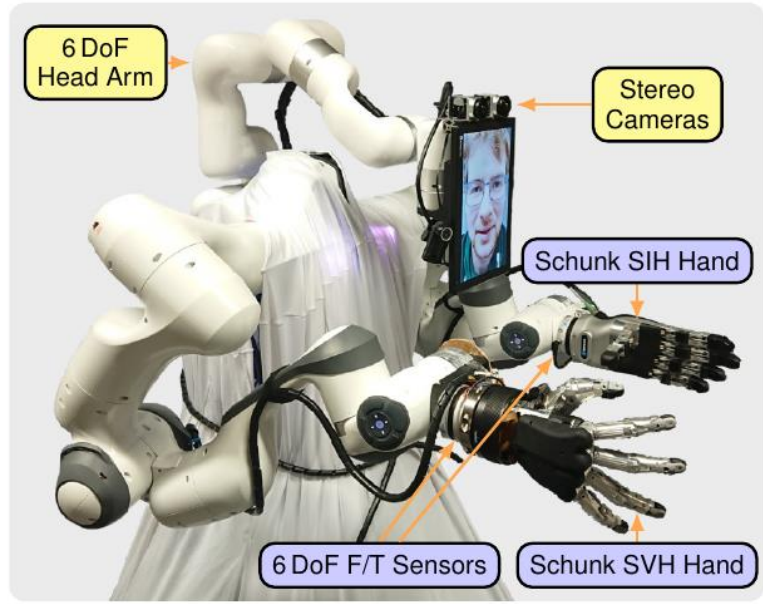
NimbRo Avatar

ANA AVATAR XPRIZE

- Two-armed avatar robot designed for teleoperation with immersive visualization & force feedback
- Operator station with HMD, exoskeleton and locomotion interface





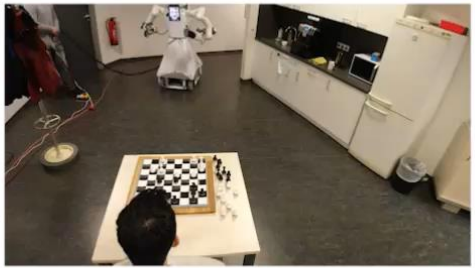


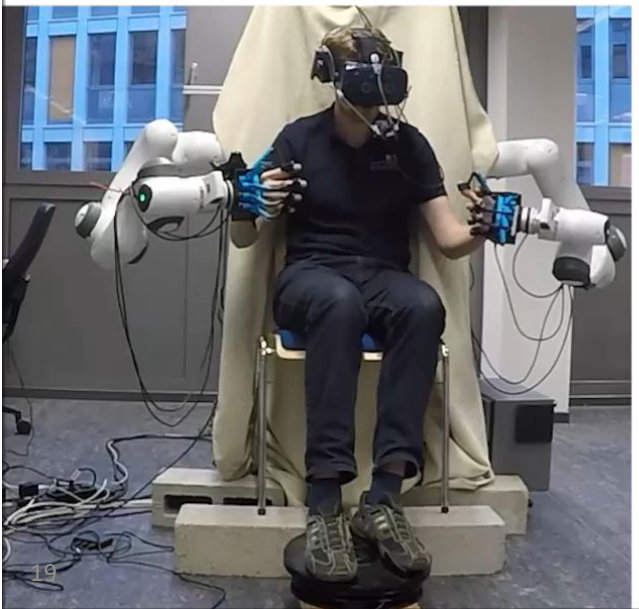
[Schwarz et al. IROS 2021]

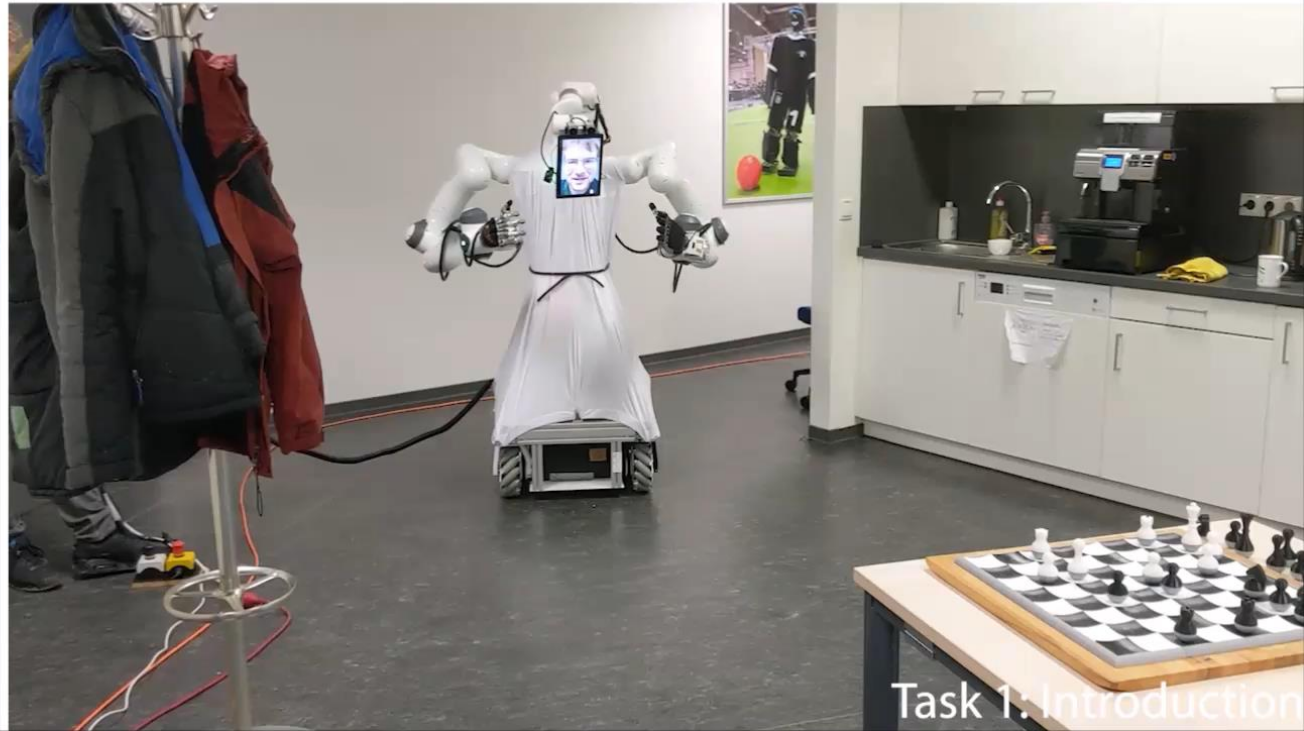
Team NimbRo: Semifinalist Submission

Operator VR view

Avatar left stereo camera

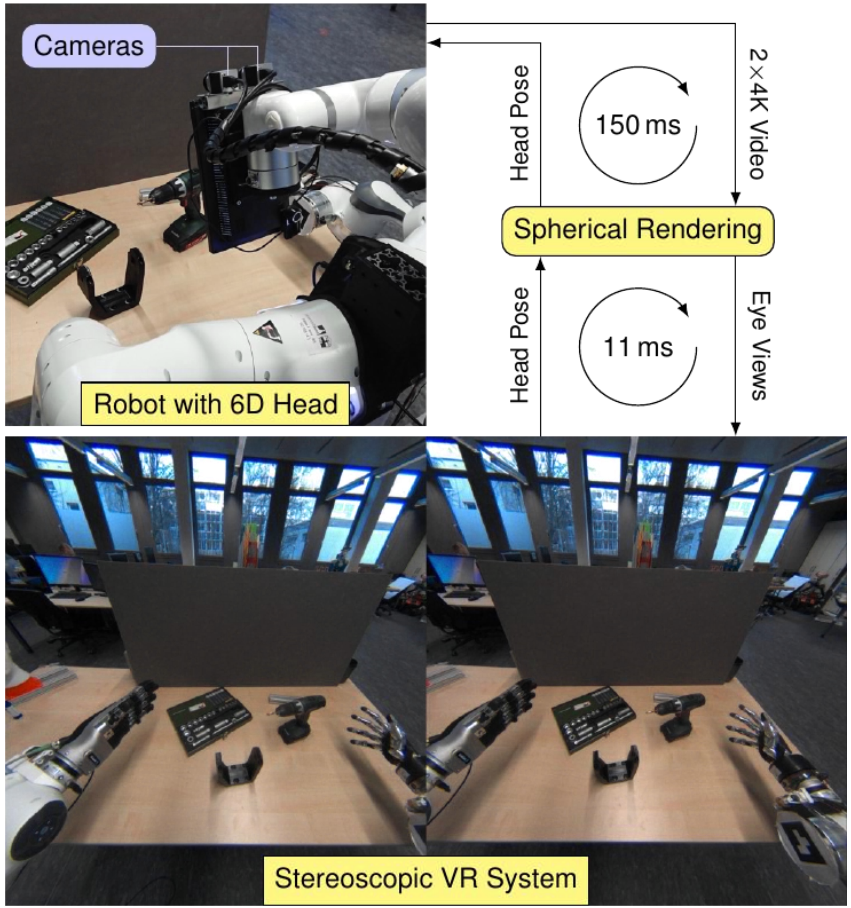




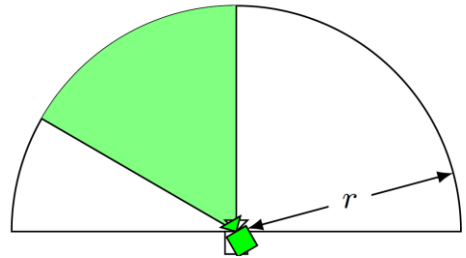


Task 1: Introduction

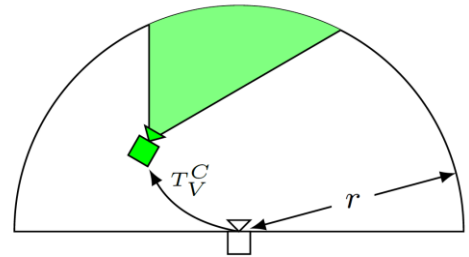
NimbRo Avatar: Immersive Visualization



- 4K wide-angle stereo video stream
- 6D neck allows full head movement
  - Very immersive
- Spherical rendering technique hides movement latencies
  - Assumes constant depth



Exact for pure rotations

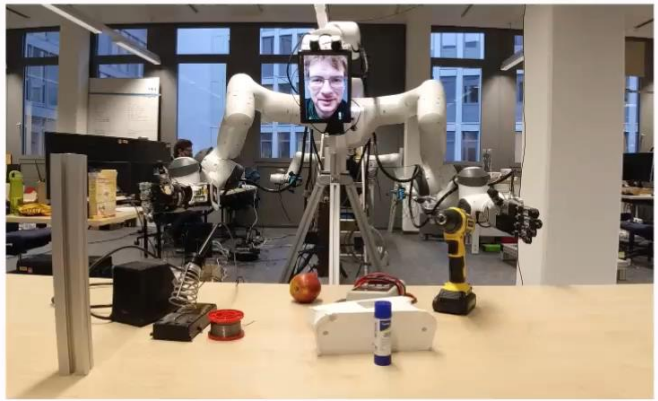


Distortions for translations

[Schwarz and Behnke Humanoids 2021]

NimbRo Avatar: Immersive Visualization

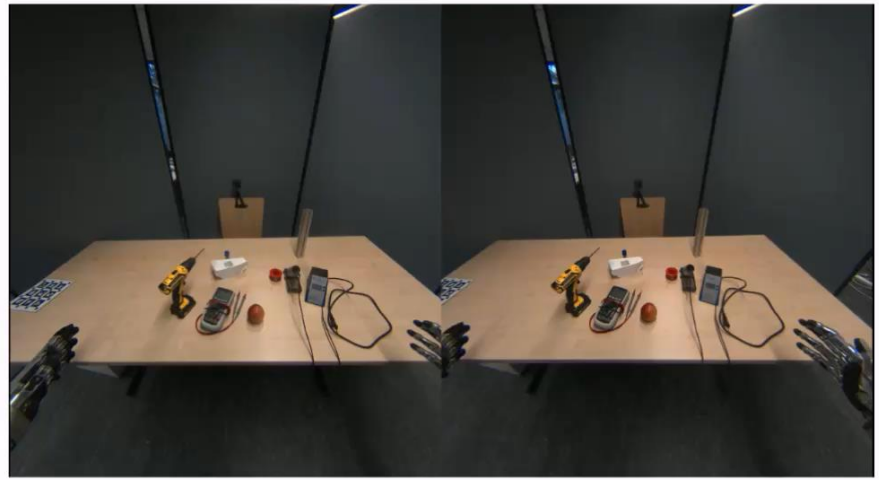
Avatar Robot



Wide-Angle Stereo

Operator

HMD View



[Schwarz and Behnke Humanoids 2021]

NimbRo Avatar: Operator Face Animation

- Operator image without HMD
- Capture mouth and eyes
- Estimate gaze direction and facial keypoints
- Generate animated operator face using a neural network

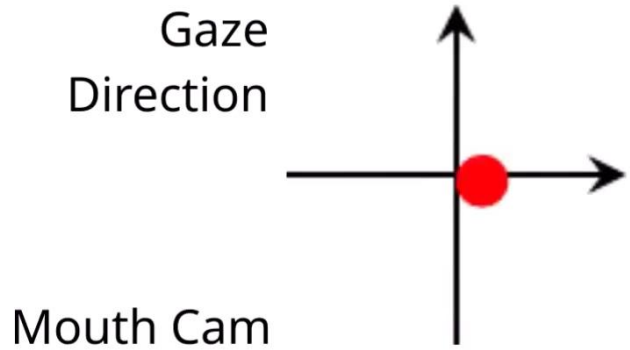
Left Eye

Mouth

Right Eye

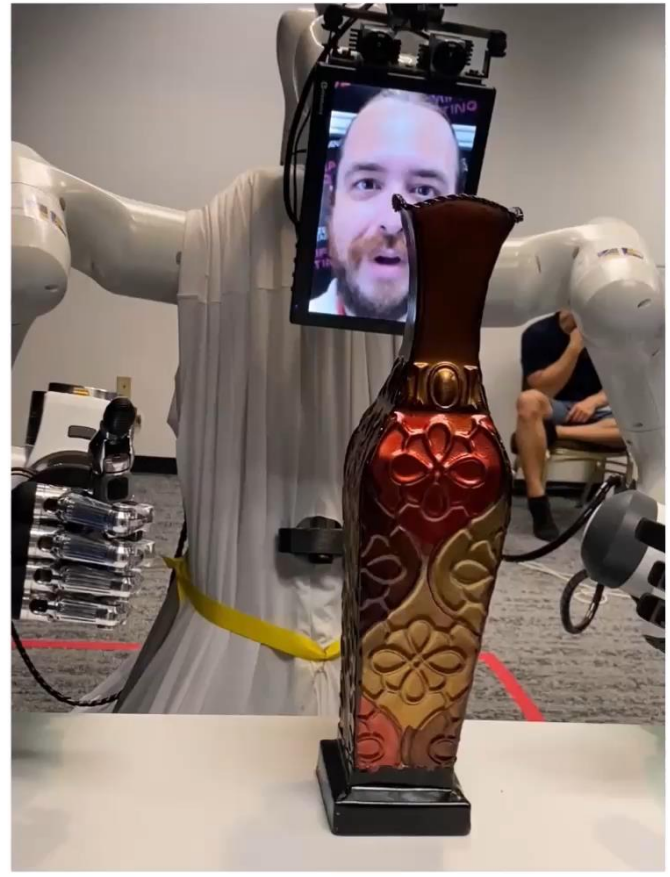
[Rochow et al. IROS 2022]

NimbRo Avatar: Operator Face Animation



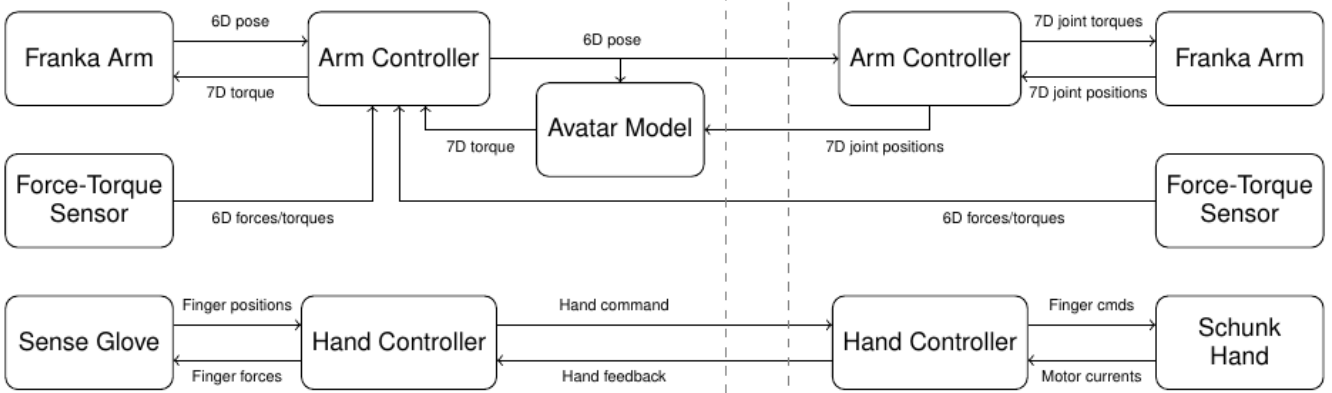
Mouth Cam

Output



[Rochow et al. IROS 2022]

NimbRo Avatar: Manipulation with Force and Haptic Feedback



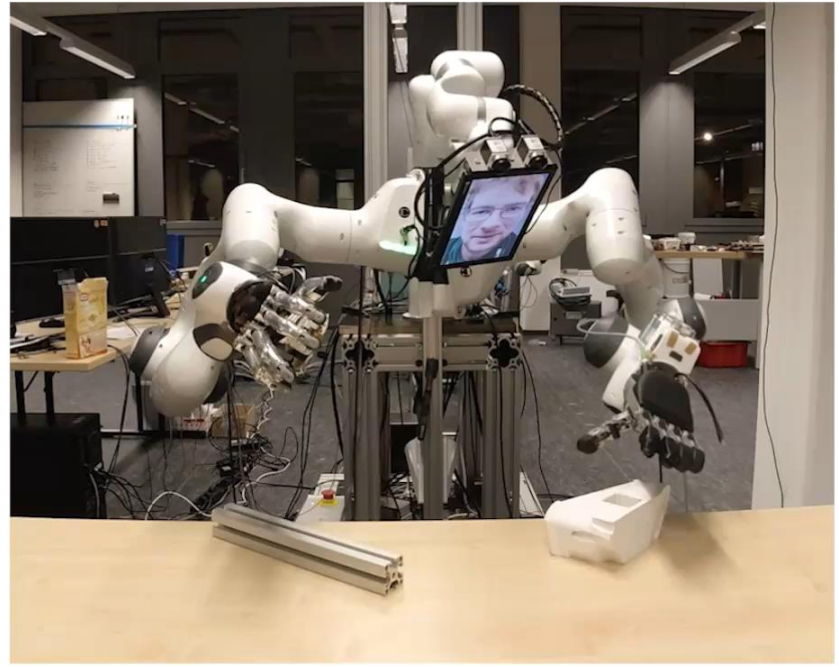
- Arm exoskeleton (Franka Emika Panda), F/T sensor (OnRobot HEX), hand exoskeleton (SenseGlove)
- Avatar side: Arm + F/T sensor + Schunk SVH / SIH hand
- Provides force feedback for wrist and haptic feedback for fingers
- Avatar limit avoidance using predictive model to reduce latencies

[Lenz and Behnke ECMR 2021]

NimbRo Avatar: Manipulation with Force and Haptic Feedback

User Study Task

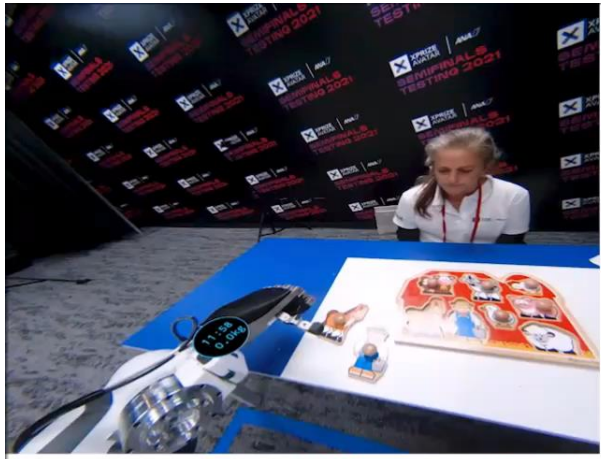
perfomed by a trained operator

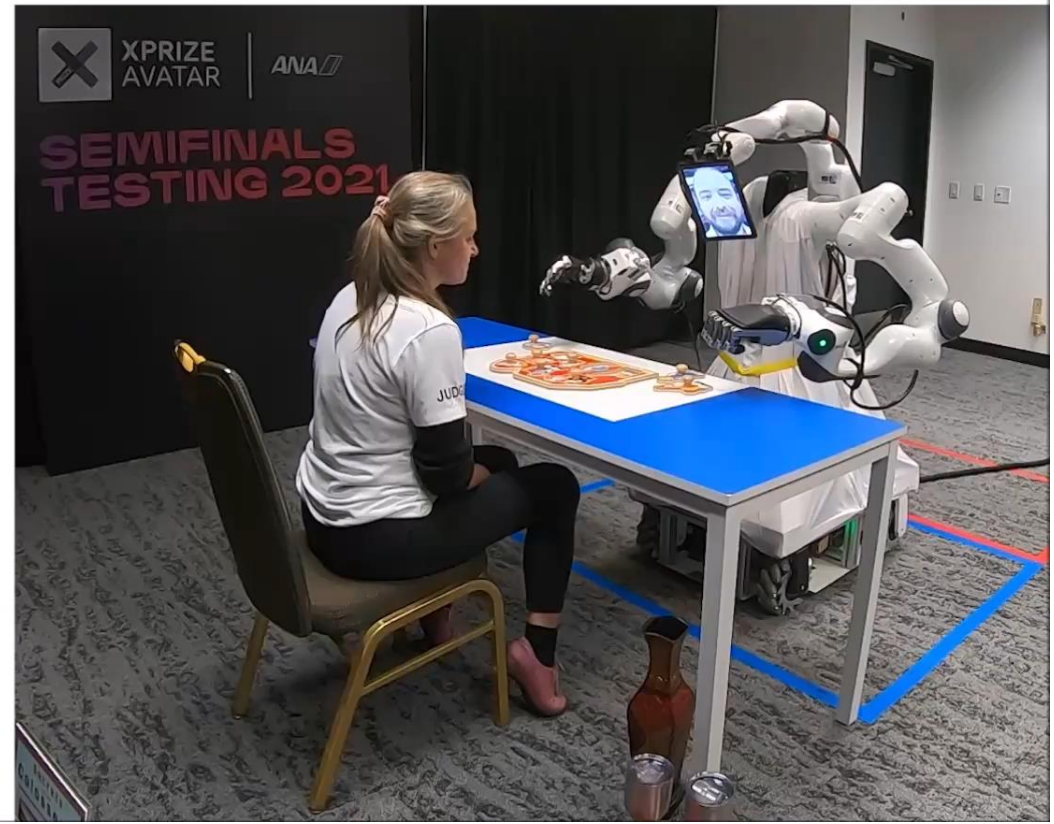


[Lenz and Behnke ECMR 2021]

NimbRo Avatar

Avatar XPRIZE Semifinals





[Schwarz et al. IROS 2021]

Conclusions

- Designed an Avatar system for intuitive immersive telepresence
- Very good immersive visualization
- Operator-Recipient interaction with facial animation
- Bimanual human-like manipulation with force and haptic feedback
- Omnidirectional drive with birds-eye navigation view
- Scored 99/100 points, ranked 1st in the Semifinals
- Judges seemed to enjoy our system

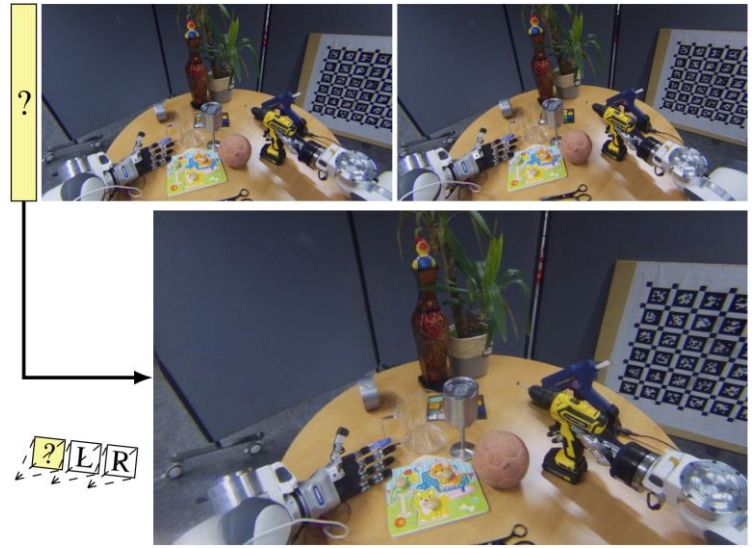
Outlook to Finals

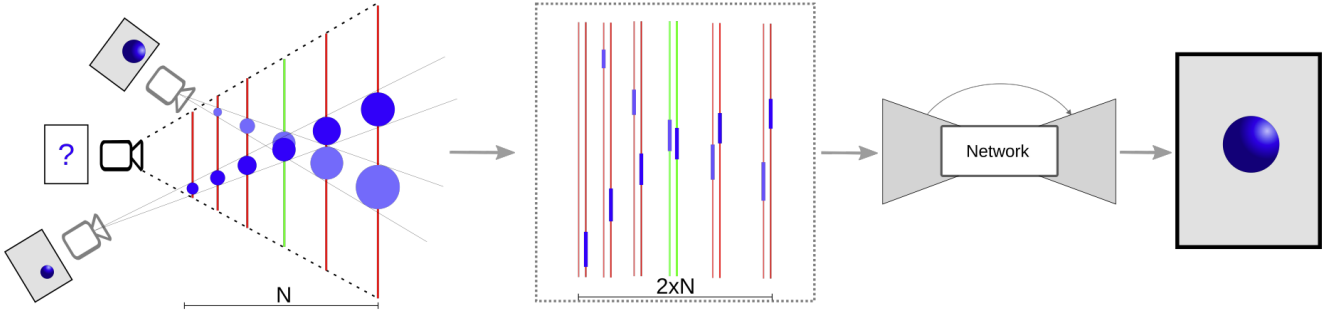
- Finals will be quite different from semifinals
- Untethered avatar robot, more mobility
- Movable operator station
- 10 tasks in a sequence
- System reliability extremely important
- Tasks fulfillment has highest importance in scoring
- Subjective criteria also important
- Trial time to break ties

- Working hard to adapt to new requirements and improve every aspect of our system

FaDIV-Syn: Fast Depth-Independent View Synthesis

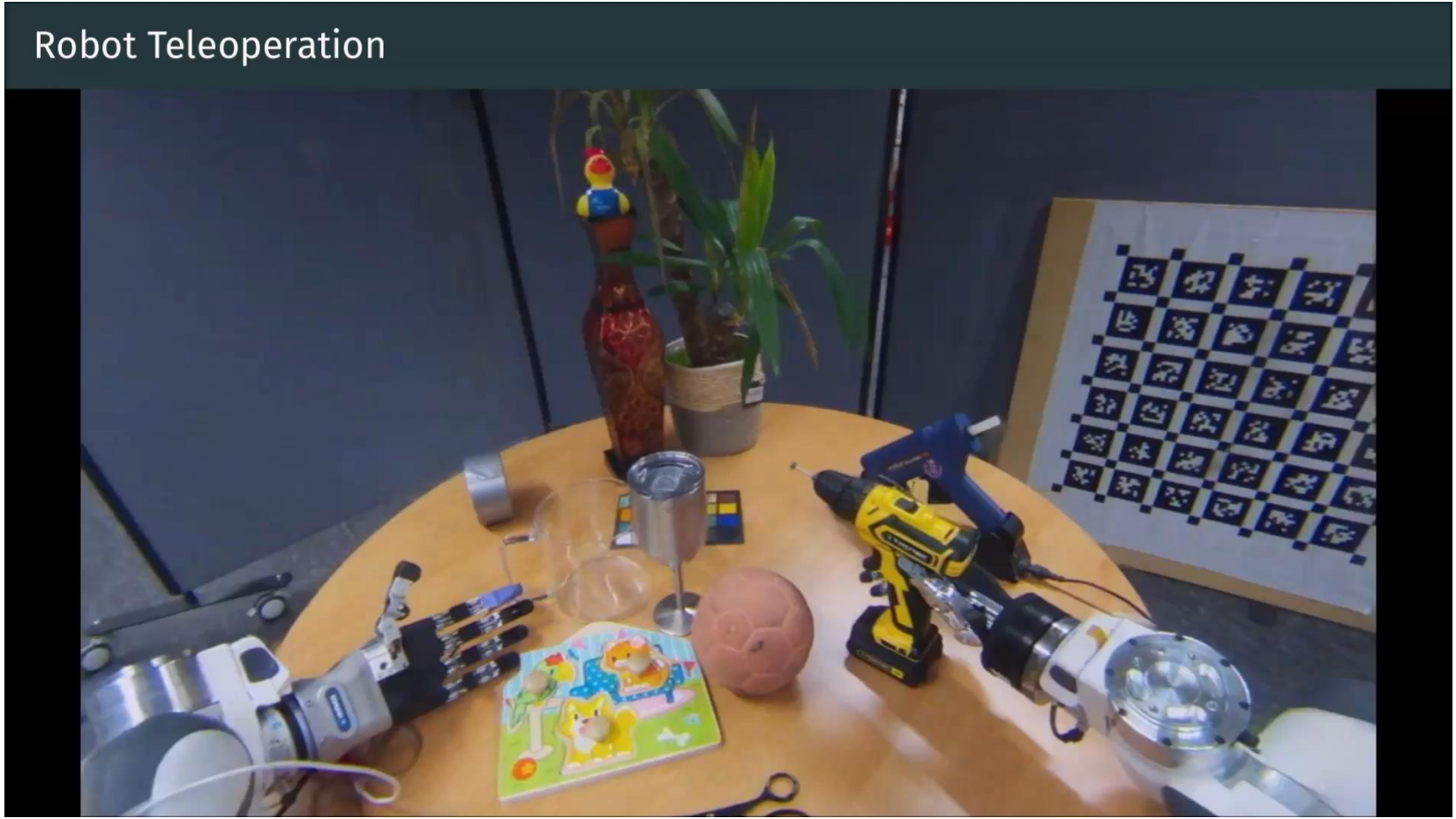
- Two input views
- Generate novel view from different pose
- Does not require depth
- Handles occlusions, transparency, reflectance, moving objects, …





[Rochow et al. RSS 2022]

FaDIV-Syn: Fast Depth-Independent View Synthesis



[Rochow et al. RSS 2022]

Questions?