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

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Autonomous Intelligent Systems
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
Mobile Manipulation Robot Momaro

- 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

At the DARPA Robotics Challenge, Momaro demonstrated driving a car.

[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]
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

- 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]
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

[Rochow et al. IROS 2022]
NimbRo Avatar: Operator Face Animation

Gaze Direction

Output

Mouth Cam

[Rochow et al. IROS 2022]
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
performed 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

Robot Teleoperation

[Rochow et al. RSS 2022]
Questions?