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Team Northeastern: Reliable Telepresence at the ANA XPRIZE Avatar Final Testing

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***Abstract*— This paper reports on Team Northeastern's Avatar system for telepresence. The system features a dual-arm configuration with a hydraulically actuated glove-gripper pair for haptic force feedback, bi-directional audiovisual communication, and an omnidirectional mobile base. Our proposed Avatar system was evaluated in the ANA Avatar XPRIZE Finals and completed all 10 tasks, scored 14.5 points out of 15.0, and received the 3rd Place Award. We provide a systematic review of our system in manipulation, perception, locomotion, tetherless design, and teleoperation control scheme. Both hardware and software implementations are covered.**

I. Introduction

In November 2022, the ANA Avatar XPRIZE Finals testing event was held, where 17 teams participated in testing their telepresence systems under 10 different tasks. Our participating team, Team Northeastern, was awarded 3rd place overall. We were one of only four teams capable of completing all ten tasks within the time limit. Two distinguishing traits of our system are that it was the only one to use hydraulic-actuated grippers and complete all ten tasks without the aid of a VR headset. A typical telepresence system consists of two main components: a set of instruments for the operator to administer control and perceive sensory feedback; and the robot that acts as an embodied avatar for the operator to explore the remote environment. For example, the Avatar robot presented in this work is shown in Fig. 1.

While we could not finish all the tasks on Day 1, we were able to modify the mechanical design and network configuration for Day 2 due to our system's highly configurable properties. As a result, our system completed all the tasks on Day 2, making our team one of the three teams that had improved performance during their second day's run.

In this workshop paper, we first present our novel Avatar system and any notable improvements over its predecessor [1] in response to the new challenges proposed for the ANA Avatar XPRIZE Finals.

II. Avatar Generation 2 overview

In this section, we review the improvements of our second-generation Avatar system over its predecessor in five major aspects. For more details, interested readers are recommended to refer to [2].

A. Manipulation

Our new Avatar robot features bi-manual manipulation capabilities by having two 7-DoF Franka Emika Panda arms

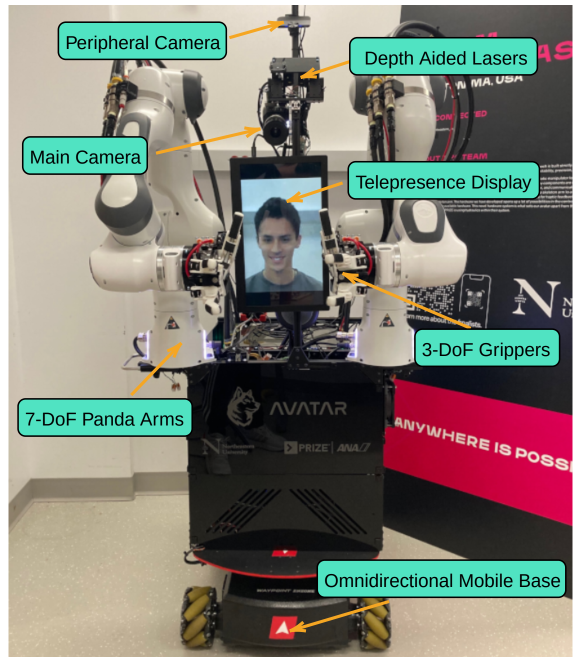

Fig. 1: The Avatar robot as part of our second generation Avatar telepresence system.

to allow for more range of motion and avoid singularity configurations. To track the operator's hand position and orientation, new operator exoskeleton arms were developed that added translational force feedback in 3 degrees of freedom. The end-effector of the arm is a 3-DoF anthropomorphic gripper that was fully invented by Team Northeastern. It has the features of hydraulic actuation, back-drivability, light weight and high customizability. The operator can control the gripper and receive force feedback by wearing a 3 DoF glove that corresponds to the gripper's configuration. Fig. 3a illustrates this setup.

B. Perception

We redesigned the display setup in the operator suite as shown in Fig. 2. The vertically displaced human-size 72 inches TV as the main interaction display provides an immersive experience and ample vertical coverage for both bimanual object manipulation and human-to-human interaction. The bottom ultra-wide monitor provides an auxiliary view with a 180° camera view stitched from three cameras to provide environmental awareness for the operator. Our non-VR design achieved a trade-off between immersiveness and situational awareness around the operator's surroundings. It

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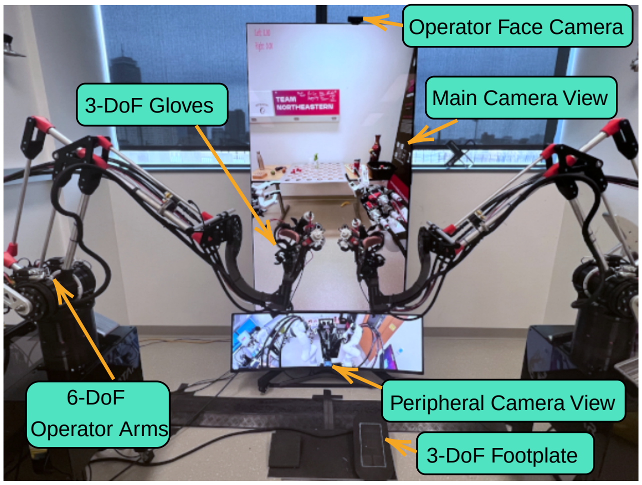


Fig. 2: The new operator suite as part of our second generation Avatar telepresence system.

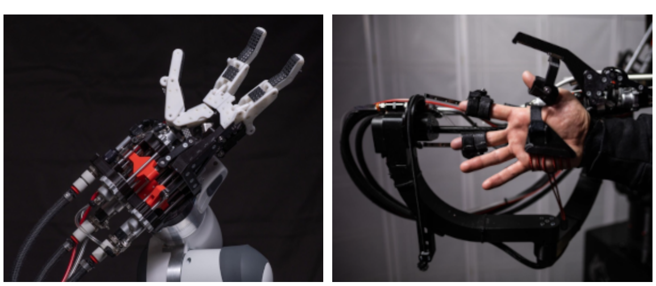
is also more user friendly to operators who struggle with VR experience. Aural feedback was also considered as an important channel for human sensing, therefore a stereo audio system was set up by attaching two microphones on the wrist links of two arms. It provided spatial audio and amplified the fingertip-touching sound to augment the tactile sensation. The operator judge gave positive feedback on this design as the integration of auditory and haptic feedback facilitated the last competition task when the vision was obstructed. An actuated laser system was designed to assist depth sensing. Two laser lines followed the robotic hands' motion and were adjusted with two servo motors.

C. Omnidirectional Locomotion

The mobile base of our new Avatar robot was switched from the differential drive Clearpath Husky to an omnidirectional Waypoint Vector. As the operator's both arms are wearing exoskeleton arms, we designed a 3-DoF footplate for the operator to control the base with the right foot as shown in Fig. 4.

D. Tetherless Power and Network System

The Avatar system was required to be fully untethered in the Final, which presented significant challenges in both power and network designs. The Avatar robot is powered



(a) The 3-DoF gripper. (b) The operator glove.

Fig. 3: A closer look at the new 3-DoF anthropomorphic design gripper and 3-DoF operator glove.

Fig. 4: Top view and side view of the 3D footplate. The red arrows denote the possible control direction. The yellow boxes denote the locations of the underneath pressure sensors.

by the battery of the mobile base Vector, which can last 3 to 4 hours of tetherless operation. To accommodate new challenges presented by the Wi-Fi network, UDPROS was used for the low latency control network while NDI|HX was used for the high bandwidth video communication. The bandwidth of video communication could be adjusted from 40 Mbit/s to 150 Mbit/s to accomodate different network conditions. Two networks were running independently on two onboard NUCs with independent wireless adapters.

E. Controller Algorithm

We adopted a Cartesian impedance controller for the 7-DoF Panda arm:

$$M(q)\ddot{q} = J^T(q)(K(x_d - x) + B(\dot{x}_d - \dot{x}) - F_e),$$

where q represents joint positions, $M(q)$ represents inertia matrix, $J(q)$ represents Jacobian matrix, K and B represent coupling stiffness and damping, x_d and $\dot{x}_d$ represent desired position and velocity derived from communication channel, F_e is the reaction force from environment. The Coriolis force and gravity force are compensated and not shown in the equation. The 7-DoF Panda arm was coupled with the 6-DoF exoskeleton arm in Cartesian coordinates under the base frame such that the operator could always feel the weight of objects in the global z direction regardless of wrist angle.

In addition to the main impedance controller, we designed two more secondary controllers: a nullspace controller and a virtual wall. These controllers were designed to prevent self-collision and violation of joint constraints during teleoperation.

The same wave variable method [3] as in our previous system [1] was updated to transmit the bi-directional control signals for the dual arms.

III. Conclusions

In this workshop paper, we presented the major improvements of Team Northeastern's new Avatar systems that helped award us 3rd place in the ANA Avatar XPRIZE Final. Five aspects of the systems improvements were discussed in detail, including manipulation, perception, locomotion, power/network, and controller design.

REFERENCES

[1] R. Luo, C. Wang, E. Schwarm, C. Keil, E. Mendoza, P. Kaveti, S. Alt, H. Singh, T. Padir, and J. P. Whitney, "Towards robot avatars: Systems and methods for teleinteraction at avatar xprize semi-finals," in *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2022, pp. 7726–7733.

[2] R. Luo, C. Wang, C. Keil, D. Nguyen, H. Mayne, S. Alt, E. Schwarm, E. Mendoza, T. Padır, and J. P. Whitney, "Team northeastern's approach to ana xprize avatar final testing: A holistic approach to telepresence and lessons learned," 2023.

[3] G. Niemeyer and J.-J. E. Slotine, "Telemanipulation with time delays," *The International Journal of Robotics Research*, vol. 23, no. 9, pp. 873–890, 2004.