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Alter-Ego X: a soft humanoid robot for the ANA Avatar Xprize

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***Abstract*— Alter-Ego X is a modular, lightweight, two-wheeled humanoid robot equipped with variable stiffness actuators and soft anthropomorphic hands. The robot can be operated both in autonomous and immersive teleoperation mode with easy-to-use, wearable motion control and haptic interfaces. Among the main objectives of the system are the possibility to operate in a home environment thanks to its agile mobile base, reduced footprint and contained dimensions, and at the same time the ease of use to enable the use of the robot also to non-expert users. Alter-Ego X has been adapted to the requirements of the ANA Avatar Xprize competition under many aspects that are described and discussed in this work. Alter-Ego X reached ninth place in the final ranking of the competition. At the ICRA2023 conference, the Alterego team will host a "be the bot" experience at the SoftBots booth.**

I. Introduction

The humanoid robotics research field focuses on creating robots that, inspired by human capabilities, can simultaneously perform balancing and loco-manipulation tasks. This capability leads to the employment of these platforms in multiple real-world applications, like individual help, instruction, search and rescue, healthcare, space investigation, and others [1]. The specific application in which the humanoid robot influences not only the design of these platforms, from the locomotion system to the single robotic head, but also how this kind of robot operates. Indeed, humanoid robots can perform loco-manipulation tasks autonomously or in teleoperation, sharing their control with a human operator that uses the robot as an avatar.

The development of humanoid robots and teleoperation systems that allow using these robots as avatars was accelerated in the latter years by the investment of large companies and funding agencies in scientific competitions and the awarding of prizes. Two famous examples are the 2015 DARPA Robotics Challenge[1] and the recent All Nippon Airways (ANA) Avatar Xprize (US$ 10 million prize)[2].

This presentation will show the Alter-Ego X, the two-wheeled humanoid robot developed for the ANA Avatar Xprize competition by the team Alterego, from Soft Robotics for Human Cooperation and Rehabilitation Lab. of the Italian Institute of Technology, in cooperation with the "E. Piaggio" Research Center at the University of Pisa. This robot is an improved version of Alter-Ego, presented in [2]. Below, we first introduce in Sec. II the platform Alter-Ego, already presented in [2], and all the updates that led to Alter-Ego X. Then, in Sec. III, we provide the results obtained during the competition. Attendees of ICRA2023 conference will have the possibility to live the "be the bot" experience at SoftBots booth, by diving into the robot and trying to perform some of the tasks of the competition.

Fig. 1: Alter-Ego Platform: Alter-Ego (on the left), Alter-Ego X (on the right) and the pilot station (in the middle).

II. From Alter-Ego to Alter-Ego X

The Alter-Ego robot [2], in Fig. 1 (on the left), features a two-wheeled-inverted-pendulum-type mobile base designed to achieve faster and more efficient locomotion at the cost of passive stability. The Inertial Measurement Unit (IMU) sensors and wheel encoders on the base feed into stability control and robot pose estimation. Its upper body is anthropomorphic in terms of form factor and interaction behavior. Indeed, it features two 5 Degrees-of-Freedom (DoFs) arms, where each joint is actuated by a Variable Stiffness Actuator (VSA) [3] able to reproduce the elastic behavior of the human muscles and change online the output shaft stiffness profile. Each arm mounts the Pisa/IIT SoftHand [4], an anthropomorphic (5 fingers, 19 DoFs) synergistic (1 Degree of Actuation) artificial hand. Alter-Ego's head, with two more VSA DoFs (Pan and Tilt), hosts a double stereoscopic vision system (a ZED stereo camera[3]) to have good vision both indoors and outdoors. Two mini-PCs (with Linux) integrated directly into the body of Alter-Ego manage all its functionalities. One of these PCs is connected to a touch screen integrated into the back of the robot, which allows the robot to be quickly activated via a graphic interface. This makes Alter-Ego easy to use even by non-experts.

All these features are also presented in Alter-Ego X. Some updates in the design of the robot were necessary to meet some of the requirements for the ANA Avatar Xprize competition and to improve the performance in terms of safety

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[1]https://www.darpa.mil/about-us/timeline/darpa-robotics-challenge

[2]https://avatar.xprize.org/prizes/avatar

[3]https://www.stereolabs.com/zed/

and manipulability. On the safety side, the system presented in [5] is incorporated in the robot to prevent permanent damages in case of failure during the race test course and also to make the robot able to stand up alone without human intervention. This safety system deeply integrates a passive layer and an active one. The passive layer consists of two passive kickstands, one on the back and one on the front. In case of failure, the passive layer engages while the active one turns off the control, reducing the reaction forces generated by the fall. Then, when the robot is stable in this condition, the active layer turns on the control, and the robot recovers the upward position. For the competition, the active layer is substituted by the power button.

To improve the manipulability performance and make Alter-Ego X able to manipulate objects on top of a table, its height is increased by 30 cm, the wrist flexion-extension DoF is added to the arm, and two new modalities are implemented: the *boost mode* and the *anchor mode*. The first increases the stiffness of the VSAs that equipped Alter-Ego X arms at the maximum, allowing the robot to manipulate heavier objects with greater precision. Instead, the anchor mode exploits the passive layer of the safety system described above to switch from the unstable two-wheeled mobile base to the stable three-wheeled one, improving the stability during manipulation tasks. Moreover, force-torque sensors are integrated into the middle of the arms to estimate the weight of the objects that Alter-Ego X is manipulating. This data is used to improve the balancing during the loco-manipulation tasks when the anchor mode is not active.

Alter-Ego X can operate in interactive scenarios either autonomously or in teleoperation, sharing its control with an operator. For safety reasons, balancing is always managed autonomously by the robot in the background independently from the operation mode. Instead, depending on the intended operation mode, Alter-Ego X manipulation and locomotion tasks can be designed by the users directly, passing specific commands to the onboard computers or through a pilot station from which a person can dive into the Alter-Ego and control it remotely (see [2]). In particular, this pilot station comprises one laptop, a dedicated wireless router, a VR headset (such as those used for Oculus Rift), and two joysticks (Fig. 1). The streaming coming from the ZED camera is elaborated on the laptop and reproduced on the VR headset obtaining, in this way, an immersive visual representation of the world in which the robot is operating. Through the joysticks, the users can provide the references for the robot's mobile base and arms motion and, through the buttons on the joysticks, they can open and close hands. Different haptic feedback devices are integrated to deliver different haptic stimuli, for example impacts and surface roughness [6].

Finally, to enable the operator to talk to the people interacting with Alter-Ego X, the robot is equipped with a microphone in the torso and a speaker in the head. Communication with people also improved thanks to the new face, designed to replicate the emotions the user wants to express. The new face comprises a 7x16 RGB LED matrix as the Alter-Ego's mouth and two servo motors for the eyebrows. Combining the image on the LED matrix replicating mouth expressions with eyebrow movements makes possible to imitate a defined set of emotions that the user can choose from a list.

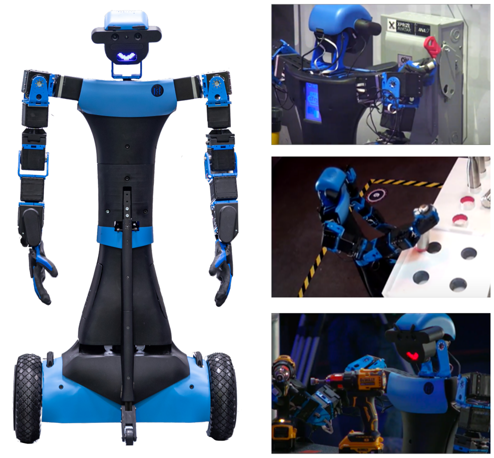

Fig. 2: On the left side Alter-Ego X and on the right one some snapshots of the final test course.

III. Competition

After the semi-finals in March 2022, our team was selected among the 99 teams participating in the competition as one of the 17 finalists. The final test course took place in Los Angeles in November 2022 and required the robot, teleoperated by one of the challenge judges, to complete ten different tasks in 25 minutes maximum. For each successful task, one point was awarded to the team. On the first day of the competition, our team collected 10.5 scores, 6 for the task and 4.5 for the judges' experience, thus placing 9th in the provisional ranking. On the last day, the second judge completed eight tasks with the Avatar (some snapshots are reported in Fig. 2), and we again collected 4.5 scores for the judges' experience. Finally, we ended the competition with a score of 12.5 and 9th place, tied with the team SNU (8th), in the final ranking.

To summarize, we collected approximately the maximum of the scores on the avatar usability all day: 2.5 on 3 for the operator experience and 2 on 2 for the recipient one. On the task side, the two modalities that we introduced improve the robot's performance. Future works will focus on the arms design to increase the payload that can be applied on the hands without damaging the robot, as in the last run.

IV. Conclusion

In this work, we introduce Alter-Ego X, the two-wheeled humanoid robot that we developed for the ANA Avatar Xprize. Our robot presents the advantages of being modular and lightweight. Moreover, the VSAs that equipped its arm allow the robot to interact safely with people and the environment. To use Alter-Ego as an avatar, we create a simple, reliable, easy-to-use, and wearable piloting interface in which different haptic feedback devices are integrated modularly. All these features allowed our team, the team Alterego, to rank 9th out of 99 teams from all over the world at the competition. Future work will be devoted to improving robot balancing, particularly when the robot is manipulating heavier objects.

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