

# Motion Assistance System for Telesports by Seamlessly Blending Manual and Automatic Throwing Controls

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**Abstract**— Telesport, which involves playing sports via avatar robots, has the potential to provide people with physical limitations with the chance to participate in sports, as it allows them to replace their bodies with robots. However, the delay in the teleoperation system makes real-time operation difficult, and it is challenging to operate the agile robot as intended. In this study, we focused on overhand throwing and treated the problem of it being difficult to throw the ball in the intended direction and speed using manual control. In order to accurately realise the agile movements that a user intends, we propose an assistance system that intervenes with automatic control based on the estimated future user's intent for manual control. Furthermore, this assistance system blends manual and automatic control seamlessly to prevent the user from feeling disconnected from the robot due to the intervention of automatic control. The assistance system was evaluated by measuring the direction and speed of the ball thrown overhand, and by assessing whether the user's intent was reflected. As a result, by making the assistance system effective, manual and automatic control were seamlessly blended, and it was confirmed that the throwing motion intended by the user was accurately reflected in the robot.

## I. INTRODUCTION

Participating in sports through avatar robots, referred to as Telesports, is expected to enable people to engage in athletic activities beyond their physical limitations. This technology has the potential to provide opportunities for people who have had difficulty participating in sports due to physical limitations to participate in sports. However, performing the agile movements seen in sports via avatar robots remains a challenging endeavor. This is because teleoperation involves communication and processing delays, which cause a delay before the user can check the robot's movements, and the combination of this delay and the delay in human reaction speed makes real-time operation even more difficult [1]. When performing agile movements, a decrease in the accuracy of task execution, which refers to how precisely the robot achieves the goals intended by the user, becomes a factor that limits the potential of telesports. Improving this accuracy is essential for expanding the possibilities of telesports.

Many studies have been conducted to improve the accuracy of task execution in teleoperation. Among them, operation assistance through automatic control intervention is a promising approach to improve the actions of human-operated robots. For example, assistance in automatically controlling the orientation of the robotic arm's hand is useful for object transport tasks [2]. Other research efforts include

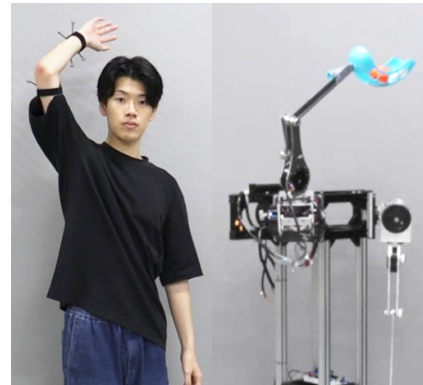


Fig. 1. Throwing in telesports

semi-autonomous control of assistance using visual servo for fine positional control [3] and semi-autonomous impedance control to enable interaction with the environment [4]. There are also several examples of studies in which assistance systems were implemented in teleoperation by setting up tasks with reference to sports scenes. In a study on the subject of air hockey, a context-aware assistance system was proposed [5]. It has also been shown that assistance can even enable an experience called parallel ping-pong, in which one user plays ping-pong with two opponents [6]. Thus, it is suggested that the assistance strategy is effective even when the subject is sports. These examples suggest that the movements need to be enhanced at the meta-level, rather than simply following the human movement trajectory.

However, most of the related research has been conducted using general-purpose industrial robot arms, which have limited agility due to joint angular velocity limitations, and not enough research has been conducted on high-speed movements. As movements become more agile and task execution time shortens, developing an appropriate assistance strategy becomes increasingly challenging. This is because assisting with such tasks requires high instantaneous power during execution. Furthermore, since it is not desirable for the operator to have assistance work in the wrong direction, some studies have integrated a system for estimating user's intent into the assistance system so that assistance can correctly assist the user when there are multiple goals. For example, research is being conducted to estimate the user's intended target based on the direction of mouse movement and peak speed at the mouse point and to support movement [7]. There is also research being conducted on pick-and-place, which provides support for a distribution of user goals when

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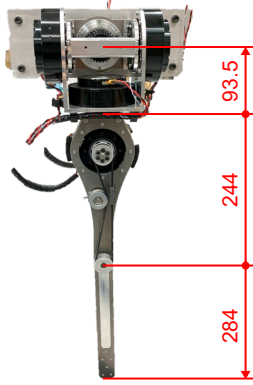


Fig. 2. The agile robotic arm

there are multiple goals [8], or probabilistically estimating goals and providing appropriate assistance [9]. In sports, there are many situations where there are multiple targets, so such a user's intent detection function will be necessary for assistance systems.

The purpose of this study is to improve the accuracy of task execution by providing an assistance system with automatic control intervention for a manipulator that excels in agile movements. This study focused on the throwing motion, especially the overhand throwing motion, which is one of the basic sports movements and requires agility. Figure 1 shows the experiment in this study, in which the user is operating the robot arm to throw the ball. We propose an assistance system that estimates the user's intended goal based on data from tracking the user's arm movements, and an automatic control intervenes to achieve this operational goal. Finally, we conduct an experiment using a robot to confirm that the operation intent is accurately reflected in the throwing by the assistance.

## II. TELEOPERATION SYSTEM

### A. Hardware: Agile Robotic Arm

The manipulator used in this study, hereafter referred to as the agile robotic arm, is shown in Fig. 2. It is an original manipulator that excels in agile movement. It weighs approximately 4.1 kg, has a total length of 621.5 mm with a forearm measuring 284 mm and an upper arm measuring 337.5 mm, and features 4-DoFs, including 3 at the shoulder joint and 1 at the elbow joint. The actuators of each joint are servo motors with low gear ratio, AK80-6 and AK80-9 of T-motor, which enable agile motion.

### B. Manual Control

The green frame in Fig. 3 is a teleoperation system configuration diagram for manual control. The agile robotic arm follows the posture of the user's arm. A marker base consisting of infrared reflective markers is wrapped around each of the operator's arms, covering both the forearm and upper arm, to enable motion tracking using an optical motion capture system, specifically the OptiTrack Motive operating at 240 Hz. The joint angles of the manipulator

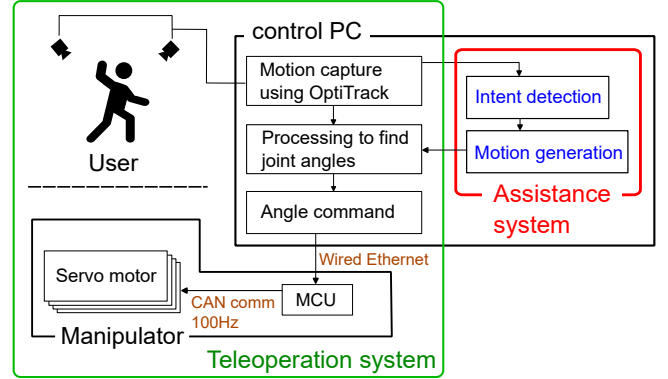


Fig. 3. System overview

are calculated from the difference in the posture of the forearm and upper arm relative to the gravity down position of the arm, and these angular angles are commanded to the motors. Angle commands to the motors are sent from the control PC to the microcontroller via wired Ethernet and then from the microcontroller to each servo motor using CAN communication at 100 Hz.

## III. ASSISTANCE SYSTEM

The red frame in Fig. 3 indicates the assistance system, which is integrated into the teleoperation system. The intent detection block in the diagram has the function of estimating the user's intents, and the motion generation block has the function of generating automatic control movements to achieve the estimated intents. The assist system intervenes in the manual control of the teleoperation system with the generated movements.

### A. User's Intent Detection

As soon as the start of the user's throwing motion is detected, the direction and velocity of the user's intended throw are estimated. The detection of the start of the throwing motion is based on the tracking data of the user's arm, and is realized by a judgement condition devised from the characteristic motions in throwing. Specifically, a throwing motion is judged to have started when all of the following four conditions are met simultaneously. Here, the coordinate system is the right-hand coordinate system, with the frontal direction in the positive direction of the x-axis and the height direction in the positive direction of the z-axis.

- (1) The user's hand position is moving in the frontal direction; the tip velocity along the x-axis is positive.
- (2) The user's hand are moving at a certain speed; the velocity of the hand exceeds a pre-defined threshold.
- (3) The user is in the posture of ready to throw; the x-coordinate of the hand position is smaller than the x-coordinate of the elbow position.
- (4) The user's hand is raised; the z-coordinate of the hand position exceeds a pre-defined threshold.

The judgement conditions for the end of a throwing motion are as follows, and when all of these conditions are met simultaneously, the throwing motion is judged to be over.

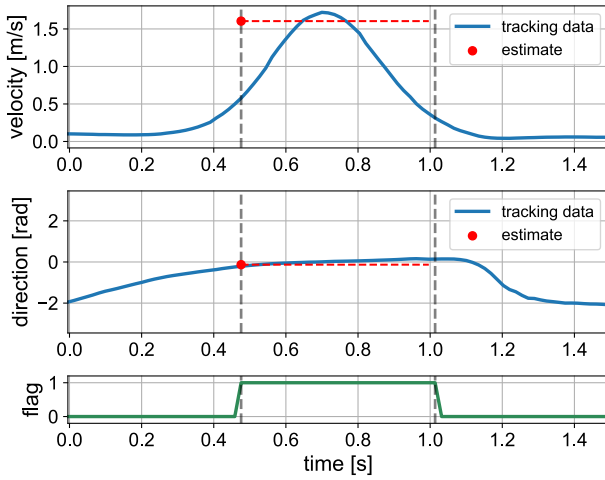


Fig. 4. Estimation of user's intent and motion detection

- (1) The throwing operation is in progress.
- (2) The user's arm is in an extended position; there is sufficient distance between the hand position and the elbow position projected on the xy plane.
- (3) The user's hand is moving slowly; the velocity of the hand is less than the pre-defined threshold.

The direction of the user's intended throw and its velocity are assumed to correspond to the direction of movement and peak velocity of the user's hand when throwing. However, we usually cannot determine these values until the user has completed the throwing motion. Therefore, by predicting the user's motion in real time, the intention to throw can be estimated at the same time the throwing motion begins. Prediction of the user's motion is based on the minimum jerk model [10], which predicts motion up to 300 ms ahead and estimates peak velocity and throwing motion direction.

Figure 4 shows time series data on user's intent detection. The blue line shows the data measured by OptiTrack, and the red circles show the estimated peak velocity and direction of movement, which correspond to the estimated user's intents derived from the time series data shown by the blue line. The section where the swing velocity change of the user's arm is the section where the user is actually performing the throwing motion. From the time series data of the throwing motion flag, it can be seen that the flag is activated at the start of the throwing motion and is deactivated at the end of the throwing motion by applying the judgement conditions just described. The user's swing speed and throwing direction are estimated at the beginning of the throwing motion, and when these are compared with the actual tracking data, it can be seen that the discrepancies are small.

### B. Motion Generation for Automatic Control

Automatic control is intervened to achieve the estimated user's goal. To achieve seamless transition between manual and automatic control, the motion generation for automatic control is performed immediately after the user's intent detection is completed. The throwing motion is generated

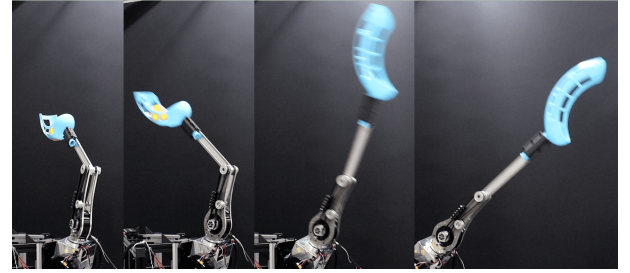


Fig. 5. Throwing motion

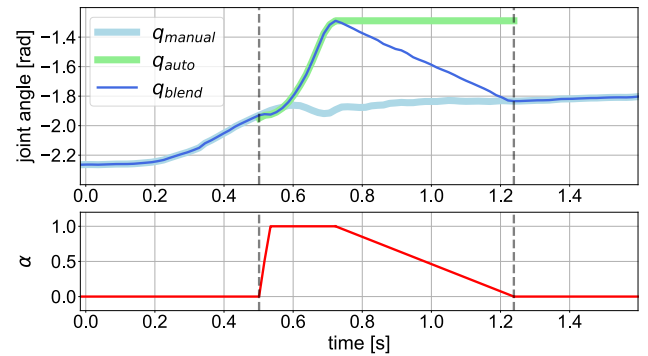


Fig. 6. Seamless blending

based on the estimated throwing direction and velocity as the user's goal, and the user's pose at the time of generating the motion. First, the estimated throwing direction and the user's pose determine the posture at the time of throwing the ball. The robot pose at the start of motion generation is used as the initial pose of automatic control. The direction of the manipulator's fingertip and the target throwing direction are controlled to match before the throwing motion is completed. Second, the estimated throwing velocity determines the throwing motion time. Here, the parameters of this conversion can be adjusted to determine the motion time so that the motion accurately reflects the user's intent, or the throwing motion can be enhanced by making the throwing motion more agile.

Figure 5 shows a demonstration of the generated throwing motion. In this figure, some frames are clipped from the video recording and arranged in time order from left to right. The leftmost frame is the posture before throwing, from which the robotic arm swings and throws the ball. By controlling the direction of throwing during this period, it is possible to throw the ball in the desired direction.

### C. Seamless Blending

Angle commands from manual control and automatic control are combined by the following equation.

$$q_{\text{blend}} = (1 - \alpha) \cdot q_{\text{manual}} + \alpha \cdot q_{\text{auto}}$$

where  $q_{\text{manual}}$  is the joint angles of manual control,  $q_{\text{auto}}$  is the joint angles of movements generated by automatic control,  $q_{\text{blend}}$  is the synthesized joint angles, and  $\alpha$  is the ratio of synthesis, taking a value between 0 and 1.

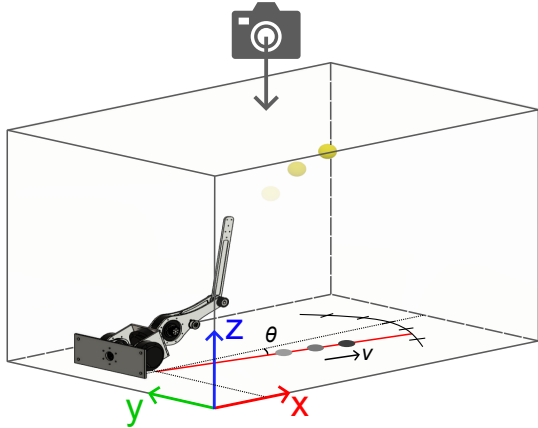


Fig. 7. Coordinate system in the experiment

Figure 6 shows the behavior of the joint angle (shoulder pitch) and  $\alpha$  when the throwing motion is actually performed. The value of  $\alpha$  is usually 0, and the robot is controlled manually using the teleoperation system with OptiTrack, but when it detects the intention to throw,  $\alpha$  immediately increases. At this point, if the value of  $\alpha$  is set to 1, the robot arm will throw the ball using fully automatic control. In other words, the movement generated by the assistance system will be reflected in the robot. On the other hand, it is also possible to set the value of  $\alpha$  to 1 and throw the ball using fully automatic control, but it is also possible to choose to set a lower value and reflect your own detailed operation. When the throwing action is completed,  $\alpha$  gradually drops to 0 and seamlessly returns to manual control. The switch between manual and automatic control should be smooth in order for the user not to strongly feel the intervention of the assistance. Seamless blending can be achieved by continuously changing  $\alpha$ .

#### IV. EXPERIMENTS

##### A. Method

To verify the effect of the assistance, we compared manual mode and assistance mode, the direction of the thrown ball, and its velocity. The manual mode refers to the manual control only, which means that  $\alpha$  is always 0. On the other hand, assistance mode is the mode in which the proposed assistance system is effective. When a throwing motion is detected,  $\alpha$  is set to 1 and automatic control intervenes.

Figure 1 shows the situation during the experiment. We conducted a throwing experiment, comparing throwing in manual and assistance mode. We had three trials of the experiment. In one trial, we used the same user input for both manual and assistance mode. We attached a commercially available simple lacrosse head to the manipulator's fingertip, to hold the ball during throwing.

Figure 7 shows the coordinate system at the time of the experiment. The user made a control input to throw in the front direction, which means in the direction of  $\theta = 0^\circ$ . A thrown rubber ball, yellow, 68mm diameter, was filmed at 140FPS using two cameras. After shooting, the ball

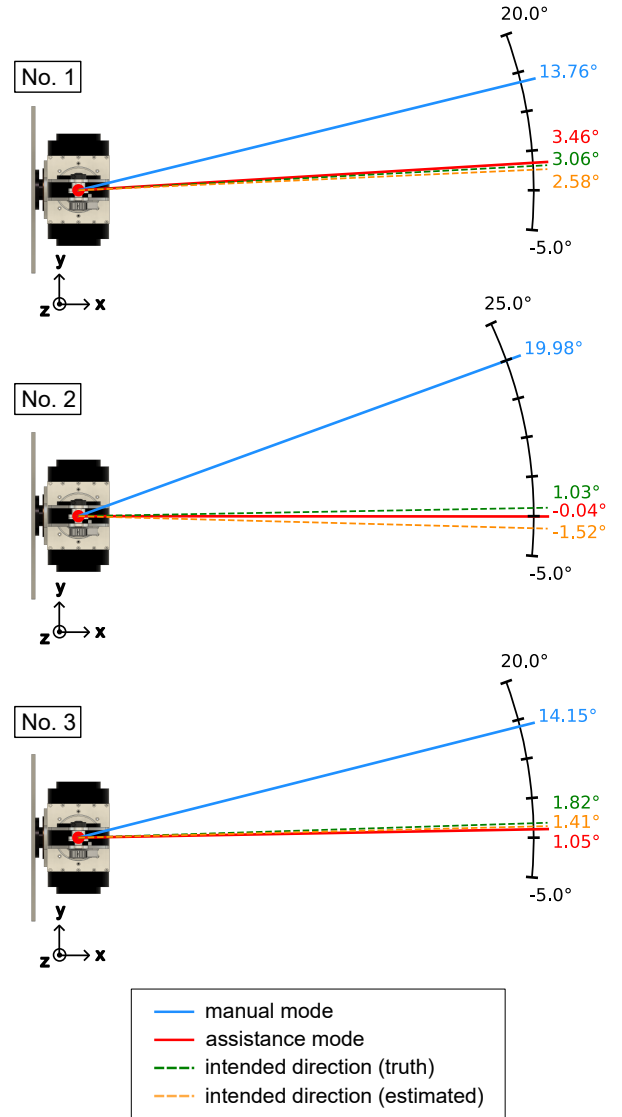


Fig. 8. Results of throwing experiment: direction

position is obtained by color tracking the thrown ball and triangulating its 3D position. The throwing direction and the velocity of the ball thrown are then calculated from the position data during the ball's flight. The throwing direction is obtained from the slope of the ball trajectory projected onto the xy-plane and approximated by a linear equation using the least squares method. The velocity of the ball thrown was determined as the average velocity from the start of the ball throw to the time the ball fell.

##### B. Results and Discussion

Figure 8 shows the results of the throwing direction in the throwing experiment. The dashed line indicates the direction of throwing intended by the user, and the solid line indicates the trajectory of the ball. The throwing experiment consisted of three trials, with No. 1 to No. 3 representing the number of trials. Here, the same person teleoperated the robot throughout the experiment. Assuming that the throwing

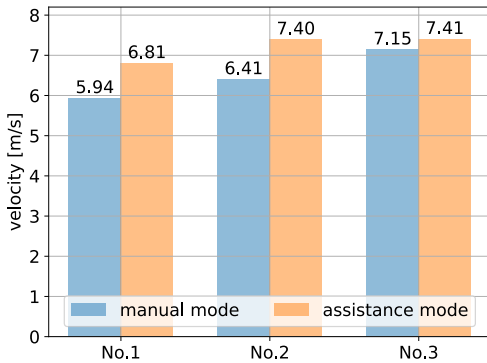


Fig. 9. Results of throwing experiment: velocity

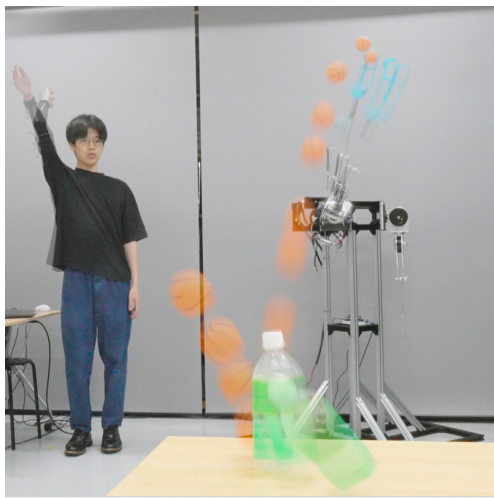


Fig. 10. Demonstration: task to hit a target by throwing a ball

direction obtained from the motion capture time series data is the true value of the user's intent, it can be seen that the manual mode does not accurately reflect the user's intent. This is because it is difficult for the robot to throw the ball in the same direction as the user's intent due to a mapping problem between the robot and the user's body. On the other hand, when the assistance mode is enabled, the robot is able to estimate the user's intent well from the initial motion alone, without seeing the entire time series of arm swing. The robot can throw the ball in the direction of the user's intent by compensating for the deviation from the manual control.

Figure 9 compares the velocity of the balls thrown in the manual mode and the assistance mode. No. 1 to No. 3 correspond to the experiment numbers in Fig. 8. In terms of the velocity of the ball, the assistance mode exceeded the manual mode in all cases. In addition, the order of velocity of the ball in manual mode and assistance mode was the same in No. 1 to No. 3. This indicates that the assistance system provides appropriate assistance based on an estimation of the user's intended throwing velocity. The above results confirm that the system can accurately estimate the user's intended throwing velocity and then assist the user in enhancing throwing motion. In addition, the blend

of automatic and manual control was so seamless that it appeared difficult for the user to notice the transition between the two.

Finally, as one of the examples of demonstrations using the assistance system, the user tried a task to hit a target by throwing a ball, which is shown in the Fig. 10. Assistance was provided to reflect the user's intent in the robot's throwing motion, and the robot was able to hit the target.

## V. CONCLUSIONS

We proposed the assistance system that supports the overhand throwing of a ball using the agile robotic arm, allowing the user to throw the ball at the velocity and direction they intend. Specifically, we improved the accuracy of task execution by intervening with automatic control based on the estimated user's intents in manual control using a teleoperation system. The experimental results confirm that the assistance system enables the user's intent in throwing the ball compared to the case of manual control only. Furthermore, the blend of automatic and manual control was seamless, suggesting that the user may be able to operate the system naturally without strongly feeling the intervention of assistance.

Future work includes introducing a function that automatically adjusts parameters to accommodate individual differences and conducting evaluation experiments with a larger number of users. By developing an assistance system that can be applied to other sports movements and tasks, we can expect to further expand the potential of teleports.

## ACKNOWLEDGMENT

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## REFERENCES

- [1] L. Penco, J.-B. Mouret, and S. Ivaldi, "Prescient Teleoperation of Humanoid Robots," in 2023 IEEE-RAS 22nd International Conference on Humanoid Robots (Humanoids), Feb. 2023, pp. 1–8. doi: 10.1109/Humanoids57100.2023.10375166.
- [2] M. Selvaggio, J. Cacace, C. Pacchierotti, F. Ruggiero, and P. R. Giordano, "A Shared-Control Teleoperation Architecture for Nonprehensile Object Transportation," *IEEE Transactions on Robotics*, vol. 38, no. 1, pp. 569–583, 2022.
- [3] C. P. Quintero, R. T. Fomena, A. Shademan, O. Ramirez, and M. Jagersand, "Interactive Teleoperation Interface for Semi-autonomous Control of Robot Arms," in 2014 Canadian Conference on Computer and Robot Vision, Montreal, QC, Canada: IEEE, May 2014, pp. 357–363. doi: 10.1109/CRV.2014.55.
- [4] L. Muratore et al., "Enhanced Tele-interaction in Unknown Environments Using Semi-Autonomous Motion and Impedance Regulation Principles," in 2018 IEEE International Conference on Robotics and Automation (ICRA), May 2018, pp. 5813–5820. doi: 10.1109/ICRA.2018.8460559.
- [5] A. Maekawa, H. Saito, N. Okazaki, S. Kasahara, and M. Inami, "Behind The Game: Implicit Spatio-Temporal Intervention in Interpersonal Remote Physical Interactions on Playing Air Hockey," in Special Interest Group on Computer Graphics and Interactive Techniques Conference Emerging Technologies, Virtual Event USA: ACM, Aug. 2021, pp. 1–4. doi: 10.1145/3450550.3465348.
- [6] K. Takada et al., "Parallel Ping-Pong: Exploring Parallel Embodiment through Multiple Bodies by a Single User," in *Augmented Humans 2022*, Kashiwa, Chiba Japan: ACM, Mar. 2022, pp. 121–130. doi: 10.1145/3519391.3519408.

- [7] T. Asano, E. Sharlin, Y. Kitamura, K. Takashima, and F. Kishino, "Predictive interaction using the delphian desktop," in Proceedings of the 18th annual ACM symposium on User interface software and technology, Seattle WA USA: ACM, Oct. 2005, pp. 133–141. doi: 10.1145/1095034.1095058.
- [8] S. Javdani, H. Admoni, S. Pellegrinelli, S. S. Srinivasa, and J. A. Bagnell, "Shared autonomy via hindsight optimization for teleoperation and teaming," *The International Journal of Robotics Research*, vol. 37, no. 7, pp. 717–742, Jun. 2018, doi: 10.1177/0278364918776060.
- [9] S. Jain and B. Argall, "Probabilistic Human Intent Recognition for Shared Autonomy in Assistive Robotics," *J. Hum.-Robot Interact.*, vol. 9, no. 1, pp. 1–23, Mar. 2020, doi: 10.1145/3359614.
- [10] T. Flash and N. Hogan. 1985. The coordination of arm movements: an experimentally confirmed mathematical model. *Journal of Neuroscience* 5, 7 (1985), 1688–1703. doi: 10.1523/JNEUROSCI.05-07-01688.1985