Teleoperation Method by Illusion of Human Intention and Time

Junki Aoki[1], Ryota Yamashina[1], and Ryo Kurazume[2]

Abstract— **Shared control, in which teleoperation and autonomous control are combined to move the robot, is expected to improve the efficiency of the user teleoperation problem. However, a problem exists whereby the user acceptance decreases owing to the conflict of intention between the teleoperation and autonomous control. In this study, we address this problem by providing an illusion to humans. We propose a teleoperation method named the "Illusory Control" that can achieve both mobility efficiency and user acceptance by implementing a cyber-physical system that controls a robot in real space through robot operations in virtual space. Illusory Control has two functions: the "Illusion of Intention," which provides the illusion that the robot is operating according to human intention, and "Illusion of Time," which provides the illusion of time to fill the gap by changing human behavior when the robot positions in the virtual space and real space diverge. Preliminary teleoperation experiments with subjects demonstrated that the system improves the operational efficiency and acceptance of the system compared to conventional teleoperation methods, namely direct teleoperation and shared control.**

I. Introduction

Within the context of the recent labor shortage and increased telecommuting, the use of teleoperation robots, which can be controlled from a distance, has become popular. A teleoperation robot may be, for example, a mobile communication robot that is equipped with interfaces such as cameras and microphones.

When a teleoperation robot is controlled from a remote location, it is generally equipped with a safety system whereby, in addition to human operator control, the robot detects obstacles by using sensors that are mounted on the robot and autonomously avoids or stops them. This mechanism of the efficient completion of mobile tasks while sharing human operator control and robotic autonomy has been studied as shared control and has been used in practical applications; for example, in the double communication robot of Double Robotics[1]. However, when the robot is controlled while observing the camera image, the robot may react to obstacles that the human operator does not notice, and the operator may feel strong stress because the robot does not move according to their commands or it moves in unexpected manners. This is owing to the fact that the motion commands issued by the robot differ from those issued by the human operator, as illustrated in Fig. 1 In previous work, this has been described as the human operator decisions not matching the robot decisions, which causes the operator to be less accepting of the robot (less trusting in the system) [2].

[1]Junki Aoki and Ryota Yamashina are with Ricoh Company, Ltd. junki.aoki@jp.ricoh.com, ryota.yamashina@jp.ricoh.com

[2]Ryo Kurazume is with the Faculty of Information Science and Electrical Engineering, Kyushu University. kurazume@ait.kyushu-u.ac.jp

An ideal solution to the problem of diminishing acceptance would be for the robot to avoid obstacles of which the human operator is unaware automatically, while the operator remains unaware of the avoidance behavior itself and feels that the robot is moving as if it were performing the intended actions. However, provided that the robot has autonomy, this is not possible in practice, because the feeling that the robot is moving on its own will always arise when the human operator command and robot action do not match.

In this study, we attempt to solve this problem by using a method named the "Illusory Control" (derived from the term illusion of control [3] in psychology), which provides the illusion that the robot is being moved according to the human operator intention. To create the illusion, we use a cyber-physical system that includes virtual spaces that are copies of the real space and the robot moves in each space. In the virtual space, the robot autonomy is not considered and the human operator can control the robot according to their preference. Subsequently, the robot in the real space moves autonomously, as if it were chasing a human-operated robot in the virtual space. When moving in the real space, the robot is equipped with a function that automatically avoids obstacles and stops when a collision is predicted, to ensure safety against obstacles and people.

We verify that this approach can be used to ensure task efficiency and acceptance in robot teleoperation.

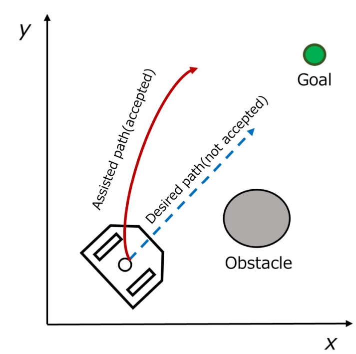

Figure 1. In a shared control system, the human operator intention and trajectory of a robot trying to avoid an obstacle may differ.

II. Related Works

Numerous studies have been conducted to support teleoperation, and some success has been achieved in improving the efficiency of user operation. However, shared control systems have yielded mixed results compared to direct teleoperation systems in terms of whether or not human operators prefer such a system [4]-[6]. In the study of Roy et al., it was asserted that users prefer manual control over a control method with an assistive controller [6]. In response to these studies, Brooks et al. attempted to ensure human acceptance in the assistive controller by clarifying the intentions and trajectories of the assistive controller through augmented reality visualization [7]. Although this may increase the acceptance of the system, conflicts of intent between humans and agents can occur in that they share and manipulate a single control object. Therefore, cases may exist in which acceptance cannot be ensured.

The control method whereby a human and a robot cooperate with one another to control an object is generally referred to as “supervisory control” [8]. Within this context, the term "traded control" refers to the control of a single object by a human and a robot while exchanging control authority, whereas "shared control" refers to the control of a single object by a human and a robot while combining the control commands. Traded control includes directing robot behavior through trajectory sketching [9], delegating control to experts based on inference uncertainty [10], and supporting human intervention for disaster rescue [11]. Shared control encompasses the use of probabilistic approaches to estimate goals [12], human-in-the-loop reinforcement learning to obtain human-assisted policies [13], and brain signals to obtain control assistance [14]. Other methods vary widely, such as those that extend human capabilities without requiring goal estimation [15]. In both traded control and shared control, the agent and the human control the same object, so it is expected that the agent may delegate control authority to the human at unexpected times, or the robot may perform actions that differ from the intention of the human. Therefore, the problem of a mismatch between the human and the agent intentions is unavoidable. Although the system in this research is based on the latter concept of shared control, the proposed Illusory Control is a new method in which a human (virtual space) and an agent (real space) each control a different object. Humans can feel that they can control the robot according to their intention, which is expected to increase the acceptance of the system.

Moreover, this research is related to the field of virtual reality (VR)-based teleoperation. In recent years, an inexpensive VR environment for human operator training purposes has been proposed [16]. Omarali et al. [17], Sebastian et al. [18], and Whitney et al. [19] used multiple cameras to sense the work environment and to transfer the point cloud information to the VR environment, thereby enabling the remote control of a realistic robot while viewing virtual images in real time. These conventional works assumed that the system can accurately perceive the scene and reflect the user operation in its behavior. Therefore, safety concerns remain, such as erroneous operations owing to the inability of humans to perceive the environment accurately. In this research, the motions of the human and robot do not necessarily need to match. We attempt to ensure both human operability and safety by enabling the robot to act to compensate for the problems of the human in the virtual space, or allowing the human in the virtual space to act to compensate for the problems of the robot in the real space.

III. ILLUSORY CONTROL

As noted in Section I, the operators may feel stress when they perceive that the teleoperation robot is not moving according to their commands. To address this issue, we devised two methods: (A) not allowing the operator to feel that the robot is not working as expected, and (B) changing the operator commands themselves without the operator noticing.

First, we propose a function named the "Illusion of Intention" to prevent the operator from feeling that the robot is not moving as expected. Even if the robot automatically avoids obstacles and at times comes to a standstill, if the operator is not informed of this, they will think that the robot is moving smoothly and as expected. That is, the real robot automatically avoids obstacles or stands still, but the operator is not shown the images of the environment in which the robot is located; thus, the operator may feel that the robot is moving according to their intention.

Subsequently, we propose a function named the "Illusion of Time" as a means to change the operator command itself without the operator noticing. The problem of the Illusion of Intention is that, over time, a difference will exist between the positions of the human-operated robot and the robot that is actually moving. Therefore, to reduce the difference in positions, the operator commands need to be guided unconsciously to fit the system needs over time. The solution to this problem is to hijack the operator thoughts by changing the operator commands and the environment that the operator perceives without the operator noticing. This can cause the operator to believe that they are controlling the robot by their own intention, even though they are actually issuing commands that match the intentions of the system (robot).

In this study, we implemented the Illusion of Intention and Illusion of Time based on the above concept. In the following, we describe each implementation in detail.

A. *Illusion of Intention*

For the proposed system, we constructed a real space and a virtual space, which was a 3D model of the real space. Moreover, we implemented a set of modules to control the robot in the virtual space and a set of modules to control the real space. The system was implemented using the robot operating system (ROS). The concept of the system and the system architecture are depicted in Fig. 2.

First, the operator sends control commands to the robot in the virtual space to cause it to move. While the robot in the virtual space is being moved by the operator, the system estimates the current robot position sequentially. Thereafter, the estimated current position information of the robot in the virtual space is transmitted to a group of modules in the real space.

Subsequently, the modules in the real space perform navigation, using the current position information received from the virtual space as the goal. The navigation is implemented using the Navigation Stack in ROS. Given a goal position, the navigation stack conducts path planning based on Dijkstra's

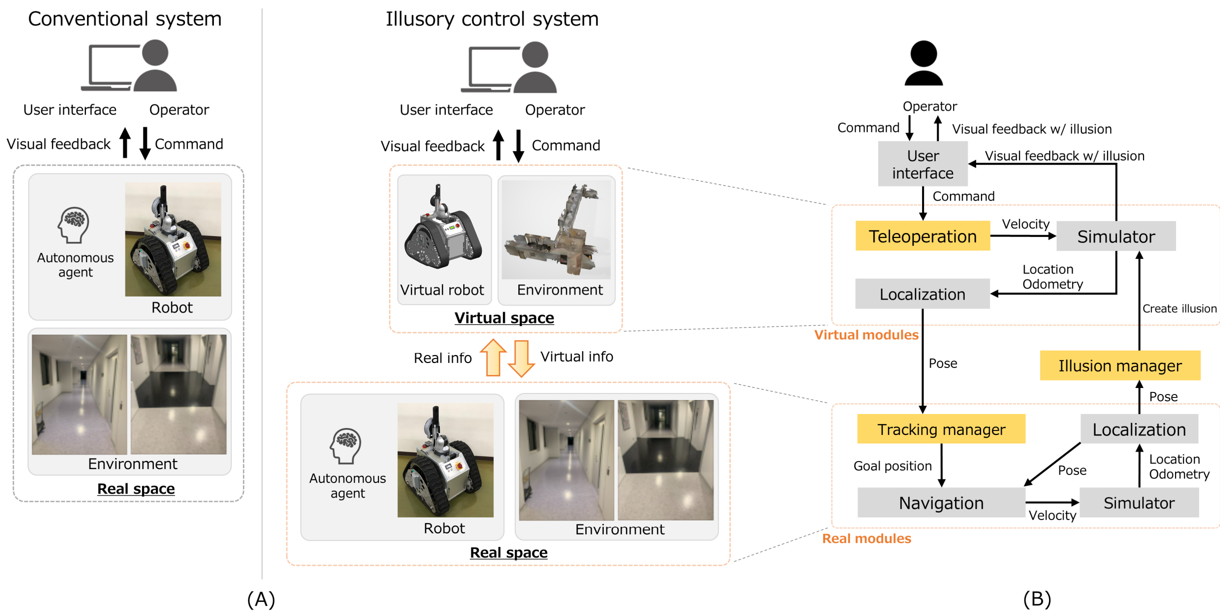

Figure 2. (A) In conventional systems, an operator and an autonomous agent control the same robot. In the Illusory Control system, the operator controls the robot in the virtual space and the autonomous robot moves in the real space. The robot moves while interacting with the virtual space and real space. (B) System architecture of Illusory Control. Navigation is performed so that the real-world robot approaches the position of the virtual robot that is directly controlled by the operator. When the positions of the virtual robot and real-world robot diverge, the Illusion of Time function is activated.

algorithm and autonomous movement is achieved while avoiding obstacles using the dynamic window approach. While the robot is navigating in the real space, the current robot position in the virtual space changes constantly owing to the continuous teleoperation of the virtual space by the operator. Therefore, based on the amount of robot movement in the virtual space, the new current position is transmitted to the modules in the real space once the robot has moved beyond a certain threshold from the previously estimated position. When the modules in the real space are provided with the position information from the modules in the virtual space, they update the goal point and resume navigation with a new path plan.

This architecture enables the operator to move autonomously in real space safely, while providing the illusion that the robot is operating according to their intention in virtual space.

B. *Illusion of Time*

In the teleoperation using the Illusion of Intention described in (A), the problem of the difference between the positions of the robot in the virtual space and real space occurs. One possible solution is to force the operator to stop. However, this may cause strong stress for the operator. Another solution is to guide the operator unconsciously so that this difference becomes smaller over time. The Illusion of Time function is activated based on the current distance of the robot in the virtual space and that in the real space. When the distance between the robots in the virtual space and real space exceeds a certain threshold, the Illusion of Time function is activated. In this study, we devised three methods for realizing the Illusion of Time function and conducted comparison experiments. The methods are described in detail as follows:

1) Deceleration: This is a method of gradually slowing down the robot movement in the virtual space according to the distance between the robot in the virtual space and the robot in the real space. Decelerating the movement speed of the robot in the virtual space has the effect of waiting for the robot in the real space to approach the robot in the virtual space.

2) Blur: In this method, as the distance between the robot in the virtual space and that in the real space increases, it becomes substantially more difficult for the operator to perceive the environment in the virtual space. The operator perceives the virtual environment through the operation user interface (UI) and controls it remotely. When blurring the image of the virtual space and making it difficult for the operator to perceive the space, it becomes difficult for the operator to navigate between obstacles and to perceive the goal ahead. As a result, the operator can expect the effect of decelerating the teleoperation of the robot in the virtual space by their own will, and thus, adjust the time until the distance between the virtual space and real space is reduced.

3) Obstacle: This method presents an obstacle in front of the robot that is controlled by the operator in the virtual space when the distance between the robot in the virtual space and that in the real space exceeds a certain threshold. When an obstacle is created in front of the operator, the operator must take steps to avoid the obstacle with their own intention. While taking the steps to avoid this obstacle, the effect is waiting for the robot in the real space to approach the position of the robot in the virtual space.

To verify the functional concept of Illusory Control, we constructed both the real space and virtual space on Gazebo to implement a prototype. Figure 3 presents the activation of each function of the Illusory Control described above.

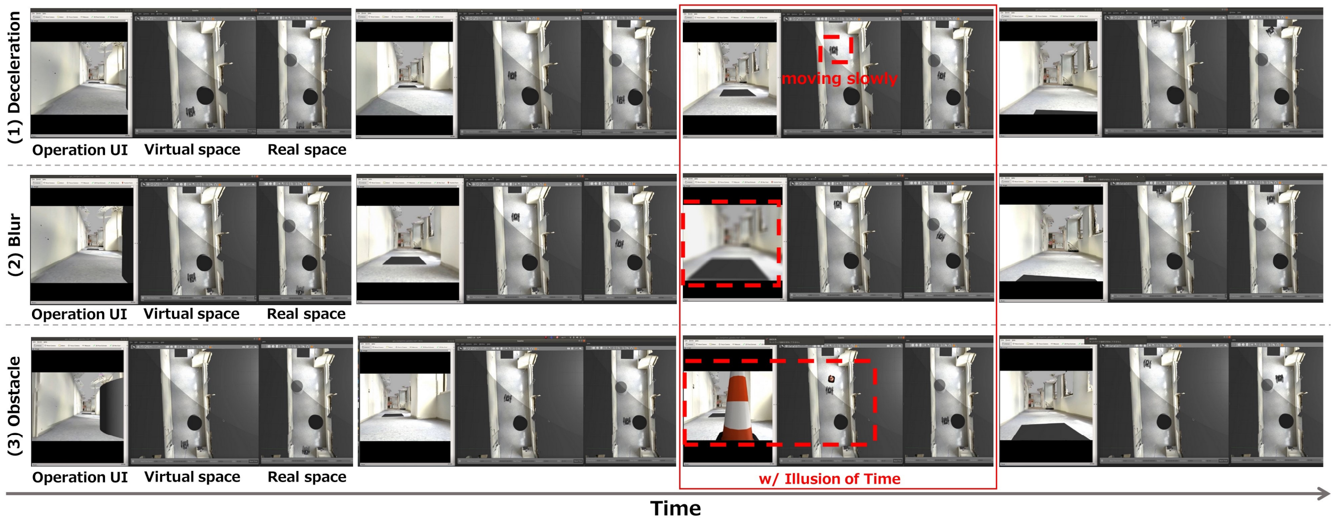

Figure 3. Illusion of Intention: In (1) to (3), the robot in the real space moves to follow the robot operated in the virtual space. The operator perceives the environment of the virtual space through the operation UI. Illusion of Time: (1) By decelerating the speed, the time required for the real-world robot to catch up with the virtual space can be controlled. (2) The operator operation UI gradually becomes blurred, making it difficult to perceive the environment of the virtual space. (3) An obstacle is appeared in front of the robot in the virtual space.

IV. Preliminary Experiments

We verified the usefulness of the proposed method through a user study in which we compared it with conventional teleoperation methods. We aim to answer the following three questions:

- Can Illusory Control improve task efficiency as well as shared control?
- Can Illusory Control improve system acceptance better than conventional methods?
- Which of the three methods using the Illusion of Time is more acceptable?

A total of nine participants were used as subjects (six men and three women). Moreover, we divided the subjects into two groups: those who understood the function of Illusory Control (five subjects) and those who did not (four subjects). This was to verify whether the operation time and impression of the system differed depending on the level of understanding. The tasks to be performed and questionnaire items were the same in both groups. The difference was whether or not the function of Illusory Control was explained to the subject beforehand. In this experiment, the subjects were asked to control a mobile robot remotely and to perform a task according to five control methods.

The five methods were direct teleoperation, shared control, Illusory Control (deceleration), Illusory Control (blur), and Illusory Control (obstacle).

Conventional methods are based on direct teleoperation and shared control. In direct teleoperation, the robot moves according to the directional input from the operator. In shared control, the directional keys of the operator and the local cost map are used as the input, and the local planner of the ROS is used to calculate a path to avoid obstacles and turn the robot in a direction that is free from obstacles.

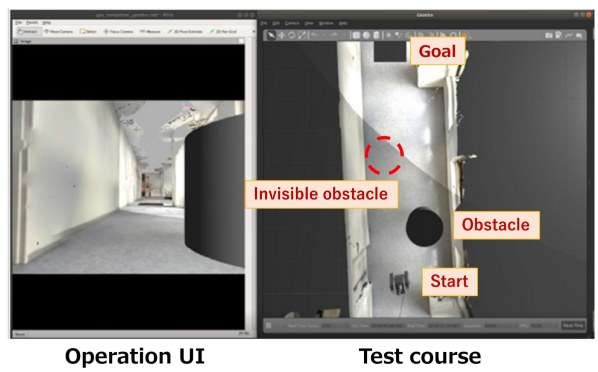

Figure 4. Experimental environment.

A. Experiment Setup

The subjects were asked to operate the robot with a PlayStation controller while viewing the operation UI. The robot started from the start point indicated in Fig. 4 and aimed at the goal point while avoiding obstacles. The task was performed once per method. To eliminate order effects, the order in which the five methods were performed was randomized for each subject. Furthermore, the subjects could become accustomed to the course as they attempted the five methods. For this reason, we randomly applied two different courses with varying obstacle locations. Moreover, we considered it to be a problem that the robot behavior would change for obstacles that the operator could not perceive without knowing the reason for the change. Therefore, we placed one obstacle that the subject could not see and required them to avoid it. The proposed method, Illusory Control, is based on the assumption that the operator controls the virtual space. Therefore, it is possible to pass through obstacles during the operation of Illusory Control.

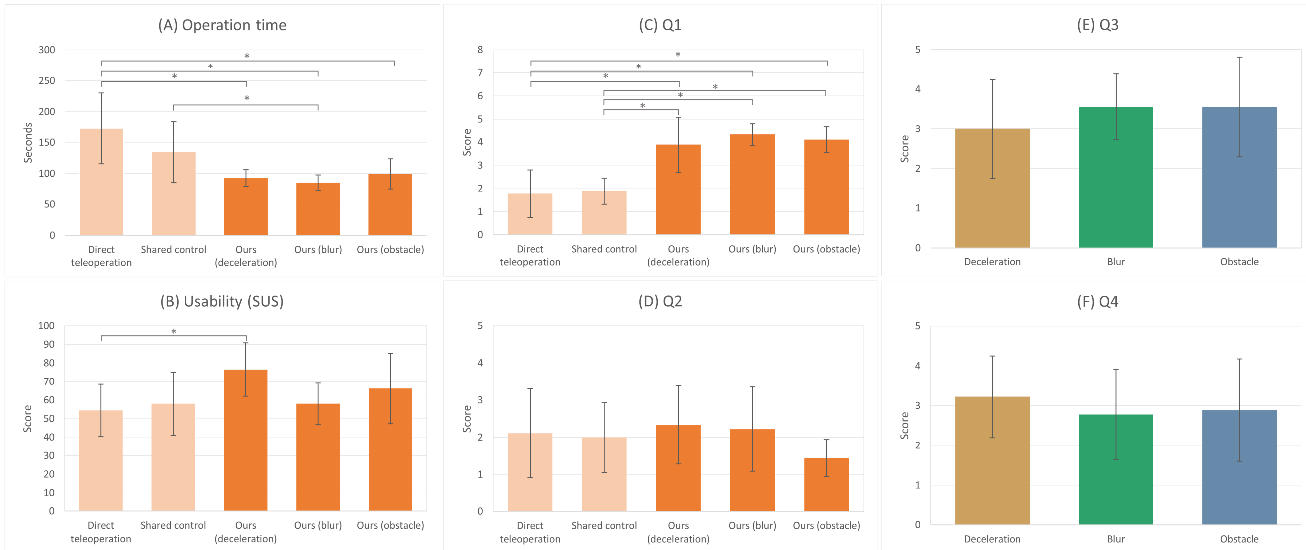

Figure 5. (A) The proposed method resulted in a shorter operation time compared to the conventional method. (B) A significant difference was observed only when the deceleration method was compared with direct teleoperation. (C) The proposed method improved the acceptance compared to the conventional method. (D) There was no difference in the attention to obstacles between the conventional and proposed methods. (E) and (F) There was no difference between the three Illusion of Time methods.

An overview of the functions was provided prior to starting the experiment. We did not explain the Illusion of Time function, such as the presentation of obstacles along the way or the difficulty of perception, to the group that did not understand Illusory Control. To evaluate the pure impression of the Illusion of Time function when it was activated, the subjects were asked to operate it with no prerequisite knowledge.

B. *Measure*

Both objective and subjective metrics were used to evaluate the usefulness of the proposed method.

We used the operation time from the start to the goal as an objective measure to evaluate the improvement in the operation efficiency. In Illusory Control, there is a virtual space in which operators operate and a real space in which robots move autonomously, but in this experiment, we focused only on the operation time in the virtual space.

As a subjective evaluation, we asked the subjects to answer a questionnaire after using each method. This enabled us to evaluate the impressions of the system. First, the System Usability Scale (SUS) [20] was used to evaluate the system usability. Thereafter, the subject impressions of the system were evaluated using four questionnaire items with a five-point Likert scale. Among the four items, the two items in Table I were common to all five methods and were used to evaluate the acceptance of the methods. The other two questionnaire items in Table II were used to test the acceptance of the three Illusion of Time methods.

TABLE I. QUESTIONS FOR ACCEPTANCE OF THE SYSTEM

No	***Question***
Q1	I felt that the robot was working according to my will.
Q2	I took great care not to let the robot collide with any obstacles.

TABLE II. QUESTIONS FOR ACCEPTANCE OF ILLUSION OF TIME

No	***Question***
Q3	Before and after the change by Illusion of Time, I felt that I was able to move the robot according to my will.
Q4	After the change by Illusion of Time, I felt inconvenient to operate the robot.

V. ANALYSIS AND RESULTS

The experiment was completed by all subjects, who were able to reach the goal point from the starting point for all methods. The scores of the experimental results are depicted in Fig. 5. Although we grouped the subjects according to whether or not they understood the function of the Illusory Control, no significant difference was exhibited. Therefore, the graph in Fig. 5 summarizes the results for all subjects.

The number of subjects in the preliminary experiments was small. As a result, some of the measurement results were not normalized or equivariant. Therefore, one-way analysis of variance was conducted for those with normality and equality of variance, and multiple comparisons were drawn using the Dunnett test as a post hoc test, considering the conventional method as the control group and the three proposed methods as the experimental group. The Kruskal–Wallis test was used for items without normality or equal variance. For items that were compared to the baseline, the Steel test was used as a post hoc test, and for those that were not, the Steel–Dwass test was used to determine whether there was a significant difference.

The operation time results demonstrate that the proposed method was more effective than direct teleoperation in the scenario with obstacles that the operator could not observe from the camera. In the direct teleoperation process, the subjects searched for obstacles and attempted to avoid them by trial and error. Furthermore, the proposed method allowed the subject to move through obstacles even when obstacles existed. Therefore, they did not need to be distracted by the obstacles and the operation time differed.

In terms of usability, a significant difference was observed only when direct teleoperation and Illusory Control (deceleration) were compared. This may be owing to the fact that the subjects were less confused than in the other Illusion of Time methods, because no change occurred in the appearance of the environment. This phenomenon can also be attributed to the fact that certain subjects did not decelerate as much as others. In Illusory Control (obstacle) and Illusory Control (blur), the subjects could not understand the reason for the appearance of the obstacles or blurred vision, which suggests that there was no difference from the conventional method.

For Q1, there was a clear difference between the conventional and proposed methods. The reason for this is that in the conventional method, the subject could not operate the robot as desired, because the robot stopped moving when it bumped into an obstacle without understanding the reason or changed its movement direction when it detected an obstacle.

For Q2, there was no difference from the conventional method. In this experiment, we used a simulator for both the virtual space and real space. Therefore, the subject operated the robot in the virtual space for all of the methods. It is desirable to design experiments so that the subject operates the conventional methods in the real space. If a difference exists between the operation in the virtual space with the Illusory Control system and that in the real space with the conventional method, the degree to which the subject is concerned about obstacles is expected to differ.

For Q3 and Q4, no difference was observed among the three methods. In all three methods, the subjects noticed the change in the environment caused by the Illusion of Time; thus, they were surprised by the sudden change and found it difficult or inconvenient to move the robot as they intended. Therefore, by applying a method of environmental change that the subject does not notice, it is expected that differences will appear in the results. Further improvement of the method in addition to the three Illusion of Time functions described in this paper will be necessary in the future.

VI. Conclusion

To improve the efficiency of mobile tasks and user acceptance of teleoperated robots, we have proposed a new control method named the Illusory Control, and conducted experiments on subjects using the system. According to the experimental results, a significant difference in the operation time compared to that of direct teleoperation was observed in the scenario with obstacles that the user could not see from the camera. Furthermore, there was a significant difference between the conventional and proposed methods in terms of whether the user could operate the system as desired. In summary, we have demonstrated that Illusory Control offers the potential to increase the efficiency of user operation as much as the shared control and to improve the acceptance of the system more than direct teleoperation and shared control. However, no significant difference was observed in the impression of the Illusion of Time function.

In this study, we have constructed a simulator environment that assumes a real space to verify the robot operation. In future work, we plan to operate the actual robot in real space and to include a large number of subjects to verify the operation. Furthermore, in this experiment, we used a special scenario in which we placed obstacles that were difficult for the subjects to perceive. In future studies, we will conduct experiments on scenarios with perceivable obstacles and scenarios in which obstacles are placed chaotically.

References

[1] Double Robotics, “Double 3,” https://www.doublerobotics.com/.

[2] H. Tokushige *et al.*, “Trust Lengthens Decision Time on Unexpected Recommendations in Human-agent Interaction,” *Proceedings of 5th International Conference on Human Agent Interaction (HAI)*, pp. 245-252, 2017.

[3] Langer. E. J, “The Illusion of Control,” *Journal of Personality and Social Psychology*, vol. 32, no. 2, pp. 311-328, 1975.

[4] A. D. Dragan *et al.*, “A Policy-Blending Formalism for Shared Control,” *The International Journal of Robotics Research*, vol. 32, no. 7, pp. 790-805, 2013.

[5] S. Javdani *et al.*, “Shared autonomy via hindsight optimization,” *Robotics: science and systems: online proceedings*, vol. 2015, 2015.

[6] Q. Roy *et al.*, “Automation Accuracy Is Good, but High Controllability May Be Better,” *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI)*, no. 520, pp. 1-8, 2019.

[7] C. Brooks *et al.*, “Visualization of Intended Assistance for Acceptance of Shared Control,” *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 11425-11430, 2020.

[8] T. B. Sheridan, “Telerobotics, automation, and human supervisory control,” *MIT Press*, 1992.

[9] K. Lee *et al.*, “Development of the Human Interactive Autonomy for the Shared Teleoperation of Mobile Robots,” *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 1524-1529, 2016.

[10] Y. Cui *et al.*, “Uncertainty-Aware Data Aggregation for Deep Imitation Learning,” *2019 International Conference on Robotics and Automation (ICRA)*, pp. 761-767, 2019.

[11] B. Doroodgar *et al.*, “A Hierarchical Reinforcement Learning Based Control Architecture for Semi-Autonomous Rescue Robots in Cluttered Environments,” *2010 IEEE International Conference on Automation Science and Engineering (CASE)*, pp. 948-953, 2010.

[12] S. Gholami *et al.*, “A Probabilistic Shared-Control Framework for Mobile Robots,” *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 11473-11480, 2020.

[13] S. Reddy *et al.*, “Shared Autonomy via Deep Reinforcement Learning,” *Robotics: Science and Systems: online proceedings*, vol. 2018, 2018.

[14] J. Philips *et al.*, “Adaptive Shared Control of a Brain-Actuated Simulated Wheelchair,” *2007 IEEE 10th International Conference on Rehabilitation Robotics (ICORR)*, pp. 408-414, 2007.

[15] Y. Du *et al.*, “AvE: Assistance via Empowerment,” *Neural Information Processing Systems (NeurIPS)*, 2020.

[16] L. Pérez *et al.*, “Industrial Robot Control and Operator Training Using Virtual Reality Interfaces,” *Computers in Industry*, vol. 109, pp. 114-120, 2019.

[17] B. Omarali *et al.*, “Virtual Reality Based Telerobotics Framework With Depth Cameras,” *2020 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, pp. 1217-1222, 2020.

[18] S. Kohn *et al.*, “Towards a Real-Time Environment Reconstruction for VR-Based Teleoperation Through Model Segmentation,” *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 6305-6310, 2018.

[19] D. Whitney *et al.*, “ROS Reality: A virtual reality framework using consumer-grade Hardware for ROS-enabled robots,” 2018 *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 5018-5025, *2018.*

[20] J. Brooke, “SUS: A Quick and Dirty Usability Scale,” Usability evaluation in industry, *CRC Press*, 1996.