A Time-based Strategy for the Transition of Control in Telepresence Robots

Dante Arroyo and Fumihide Tanaka

***Abstract*—Nowadays, coordinated switching between autonomous and manual operation, according to the demands of the operator and the task, has become a common type of control approach to compensate for the limitations of autonomous systems. This control mode switching, known also as "Transition of Control", is usually referred to the transition from autonomous to manual operation and it could have negative effects on the operator or its surroundings depending on the strategies used. In autonomous cars, an unsuccessful takeover command can potentially risk the safety of the drivers and pedestrians. Remote operators of telepresence robots may not be exposed to such risks, but they are not exempt from the negative effects of the transition, especially when the operator is involved in another activity before taking control of the system. This paper reports the design of an interface for a dual control mode telepresence system, explores the factors implied when switching the operation mode, and finally proposes a time-based strategy for the transition of control from autonomous to manual control.**

I. Introduction

The recent advances in the development of robotic systems have shown a promising potential to greatly augment human capabilities. However, it is still not possible to achieve a degree of autonomy comparable to the human control. For this reason, alternative control strategies have been created, such as shared control and control mode switching[1][2][3], in which the limitations of autonomous systems are compensated with the intervention of local or remote human partners. In the case of mode switching, one of the most common examples of this type of systems are teleoperated robots.

In highly automated vehicles, it is common to have periods of transition in which drivers switch between autonomous and manual operation. However, it is the transition from autonomous driving to manual control that demands a higher level of adjustment by the human operator[4]. This particular scenario, opens a window of negative effects than can lead to accidents. Due to limitations in current autonomous systems, nowadays the transition of control becomes inevitable.

In telepresence robots, the transition of control does not particularly affect the safety of the operator or the interlocutor. However, as in the studies on autonomous cars, there may be psychological impact on the human operators. In Human-Robot interaction contexts it is expected that robotic systems will have a smooth interaction with humans.

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For this reason, telepresence robots with double agency, or in other words, with autonomous or manual control mode of operation, should be designed to achieve this feature. Nevertheless, it is not clear how we should manage the transition of control in this type of systems. In this regard, this document aims to contribute by exploring the dimensions of the transition of control from the operator's perspective, and proposing a time-base switching strategy from autonomous to manual control.

II. Related Works

A. Social Presence in Remote Operated Robots

Systems which support video and audio communication combined with robotic platforms are nowadays known as robotic telepresence systems [5]. This type of tangible communication media can become the avatar of its human operator, transmitting his social presence and allowing him to physically interact with people located in different locations[6], [7]. In the last decade, several researches have conducted exploring the potential of this systems[8],[9],[10].

The transmission of social presence is one of the most valuable features of teleoperated robots. Among the fields of application, one of the most promising is the education sector. A research conducted with school children from different countries showed how equipping a telepresence robot with a gripper hand, controlled by a child operator, helped to overcome social barriers[11]. Current household robots are also able to transmit social presence, such as, Papero[12], developed by NEC, possess conversation functions along with physical interaction by using touch sensors and can be controlled remotely. From commercial robotic platforms, Pepper[13], developed by Softbank Robotics, is nowadays one of the most commercial social robots along with the cleaning robot, Roomba.

B. Double Agency in Telepresence Robots

Many media devices for telepresence purposes have been developed in the recent years, most of them resembling animals or creatures that attract consumers' attention. However, recent researches have stated that physical communication media whose appearance greatly differs from humans can distort the operator's personality perceived by interlocutors[14], [15], [16], [17]. In the last research, the interaction of the interlocutors with different types of media was compared. The results showed that the media that differ mostly from the operator confused the participants about who was controlling the communication media.

Although particular characteristics of robots, such as identity are effective at generating social presence, this risks causing an unwanted distortion of presence in the remote sender[18]. Therefore, the degree of identity of a robot can generate a second agency in the telepresence robot even if it does not possess an autonomous operating function. These above mentioned researches evidence the existence of double agency in most telepresence robots, the agency of the physical communication media (the robot itself), and the agency of the remote operator (through the robot).

III. Research Outline

As discussed above, the concept of Transition of Control is not only limited to automated vehicles. In fact, it is also present in social robots that have multiple modes of operations, such as telepresence robots. In the field of Human-Robot Interaction, it is important to maintain a smooth interaction between the agents, especially if one of them, can have more than one control mode.

In this research, we focused on the impact of the transition on human operators. For this reason, we consider the Transition of Control as the switch from autonomous mode to manual mode because this scenario, as in highly automated vehicles, demands a higher adaptation from the operator.

For this work, the following research line was followed:

- Conduct exploratory studies related to a system with multiple control modes and a survey of the dimensions of the Transition of Control.
- Implementation and evaluation of a dual-control Telepresence System.
- Proposal of a mode switching strategy from autonomous to manual control.

IV. Exploratory Studies

A. Telepresence Robot for Childcare Support

This study was our first exploration towards the use of telepresence systems for human support[19]. The results of this exploratory study defined the path of the research.

1) System Description

We aimed to evaluate a scenario in which a parent would perform a housework activity and the robot would replace or complement the childcare task according to the selected mode of operation. In the child's side, the system consisted of a robot with a portable computer attached to its chest to display media, and on the parent' side, a Head Mount Display (HMD) connected to a computer. The purpose of using a HMD was to allow the parent to have multiple visual information on the same screen.

2) Childcare Support Modes

The modes were designed to support the childcare activity according to level of focus that the household chore demands. If the task demand is high, the autonomous mode allows the parent to leave temporarily the childcare to the robot while being able to monitor his child through a sub-screen that shows the robot's view. During a hands-free time, the parent may use the telepresence mode, in which the robot becomes an alter ego of the parent. Lastly, if the task demand is low, the multitasking mode allows the parent to perform housework and make a simple activity with his child at the same time.

(a)

(b)

Figure 1. System from both points of view[19]. a) Parent folding clothes. b) Child listening the narration of the Picture Book

3) Evaluation

The objective was to assess the parent's performance when using the multitasking mode of the childcare support system. The household chore for the father was folding clothes and the activity with his children was the narration of a Picture Book, as shown in Figure 1. A father of 34 years old and his children (a boy and a girl of 8 and 6 years old respectively) participated in the study. A scenario similar to a home environment was recreated in a room of the university which was divided in two sections by a solid curtain as shown in **Error! Reference source not found.**

4) Findings

Overall, the father did not have problems using the interface through the HMD, and the robot could partially transmit the presence of the father and was able to get the attention of the kids. Even though the operation modes for the system were defined, "how" to switch between these modes was not addressed, and became the topic of interest for our research. In the field of autonomous cars, there exists several studies about the transition of control. However, there are no well documented studies corresponding to telepresence robots.

B. Dimensions of Transition of Control

1) Study Description

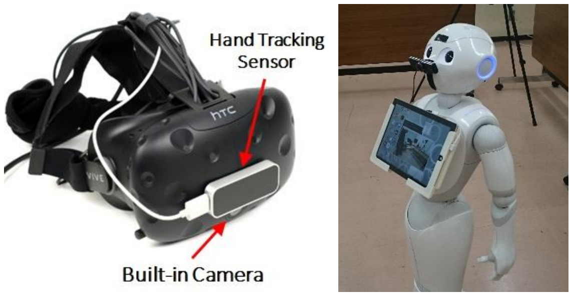
We started with an initial study in order to find what kind of effects had the Transition of control on what people perceive when taking command of a robot. A series of videos were recorded showing different types of mode switching configurations. These videos showed the perspective from a human operator using a HMD. At first, human hands appeared organizing some cubes by color, then a take-over-request appeared and blinked 3 times, a black screen appeared for some seconds and after the view changed to the robot's view which started performing another activity.

2) Manipulated Factors

The first manipulated factor was the use of a black screen which can reduce the burden of transition by relaxing the eyes. The second factor was time, for this factor we considered 3 fixed times corresponding to Fast, Normal, and Slow. A total of 6 conditions were designed.

3) Evaluation

A total of 21 university students (17 male, average age 25) participated in this study. Each participant evaluated 3 videos by watching them in a random order. After each video, they were asked open-ended questions to describe how they felt and which adjectives they would use to define the experience.



(a) (b)

Figure 2. a) Head Mount Display HTC Vive with Hand Tracking Sensor attached. b) Robot Pepper with camera and portable computer attached.

4) *Findings*

Participants had many different impressions from the videos. However, as participants experience was limited, we only focused on identifying the dimensions involved in the transition. For this purpose, word counts for each question were computed and then clustered into equivalence classes for an easier analysis. The most common adjectives to describe the transition were slow and fast which formed the "Competence" cluster. Other common adjectives were smooth, predictable and natural, forming the "Natural" cluster. Other adjectives, such as confusing, strange and dizzy formed the "Awareness" cluster. These three dimensions were chosen to later evaluate the experiments on Transition of Control.

V. HYPOTHESES

From the observations and results of the initial study, we identified the need of creating a strategy for the transition from autonomous to manual mode. However, it was necessary to start by conducting a deeper study in which participants would be able to fully experience the transition of control by operating the robot.

For the experiments on Transition of Control, it was our objective to explore the negative effects of the Transition of Control and the possibility to reduce those effects by using a flexible switching strategy.

H1. A flexible switching strategy can reduce the burden of the Transition of Control in contrast to a fixed switching strategy.

H2. A flexible switching strategy can increase the awareness of the operator before taking control of the telepresence robot.

VI. SYSTEM DESIGN

For the initial exploratory studies, the robot motion was achieved by using predefined movements activated by voice, along with the Wizard of Oz technique. However, for the experiments on Transition of Control, it was necessary to fully implement the operator's interface, and make modification so the robot could be controlled.

A. *Operator's Interface*

For the Human Operator's Interface, it was necessary to use a device that could display different types of visual media according to the mode of operation, and perform head and hands motion tracking in order to control the robot's body.

Figure 3. Operator's View from the HMD Frontal Camera

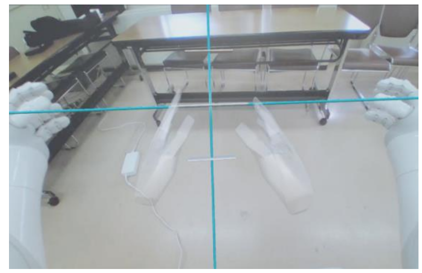


Figure 4. Robot's View from the attached Camera.

1) *Head Mount Display*

Commercial HMD (Head Mount display) offer the possibility to show different types of media. For our application, the limitation is that these devices cover the eyes completely as they are targeted to display virtual environments. However, we selected the HTC Vive which provides a built-in front camera that allows the development of Augmented Reality applications.

For the control of the robot's head, we retrieved the position and rotation information from the HMD. As for the hands tracking, we use the Leap Motion [20], an infrared sensor attached to the HMD as seen in Figure 2. These devices were integrated using Unity[21], which provides a robust support for the HTC Vive and the Leap Motion Sensor.

B. *Telepresence Robot*

For this research we used SoftBank Robotics' humanoid robot Pepper[13], which in comparison to other commercial robotics platforms, such as Baxter[22], Jibo[23] and iCub[24], has a big size and a high mobility. However, as it is not a robot for telepresence purposes, we attached a 120° wide angle view camera to the head, along with a portable computer for video streaming attached to the chest. Finally, these devices were integrated using the Software Unity. The components are shown in Figure 2.

C. *System's Points of View*

The Telepresence System's Interface, through the content displayed in the HMD, could offer two points of view according to the mode of control. The Operator's View, through the frontal camera, as shown in Figure 3. , and the Robot's view, through the camera attached to the robot's head, which is depicted in Figure 4. The field of view of the external camera significantly limited the robot's view. However, by attaching the camera to the HMD, the field of view could be increased by encouraging users to move their head when they lost view of the robot's hands. Latter, a horizontal and vertical line were included to mark the reference of the robot direction.

VII. System Evaluation

A. Experiment design

The objective of this experiment was to evaluate if the designed Telepresence System was suitable for conducting further experiments on Transition of Control. For this purpose, a measure of transmitted presence, along with a workload assessment was performed.

1) Collaborative Task

We selected a collaborative task of joint movement which demanded the operator's focus and movement coordination: a leader-follower imitation game. The participants had to mirror the hands' movement of a person by using the two modes of operation of the robot:

- Operator's Mode: The operator had to interact with the person in front of him, by moving his own hands, as shown in Figure 5. .
- Telepresence Mode: The operator had to interact with the person located in front of the robot by controlling the robot's hands, depicted in Figure 6.

For this experiment, 11 participants of the initial exploratory study were recruited again (7 male, average age 24), and were explained that they will fully experience the Transition of Control by using the robot. For this purpose, a training session was included for participants to get used to the system and get a common baseline. They were instructed how to control the robot, which included the movement of the robot head and control of hands, along with an explanation of the interface and the workspace limitations. In order to get a proper degree of familiarity with the system, participants were given a training time of approximately 1 hour. At the end of the session, all participants stated that they could use the system without problems.

After the training session, participants were evaluated by performing a collaborative joint task in which they had to mirror the hands movement of a person. As mentioned above, two conditions were evaluated: by using the operator's mode and the telepresence mode. The activity for each condition lasted approximately 2 minutes.

2) Dependent Measures

The Nasa Task Load Index[25] and the Temple Presence Inventory (TPI)[26] were used to measure the mental demand and the transmitted presence in both modes of the system. The results corresponding to the operator's mode and telepresence mode are shown in the graphs as operator's view and robot's view respectively.

B. Analysis

1) Measure of Presence

The results of the evaluation using the TPI, presented in Figure 7. , showed that the *Engagement* factor remained almost constant during the two conditions. As for the *Spatial Presence* and *Social Richness* factors, there was a slight decrease, but not significant difference between the two system's modes. From the evaluation of this factor the telepresence mode of the system could effectively transmit the presence of the operator.

Figure 5. Interacting by using the Operator's Mode

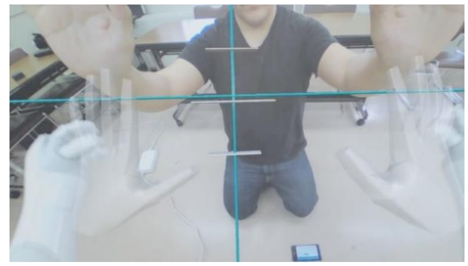


Figure 6. Interacting by using the Telepresence Mode

2) Workload Assessment

Results from the Task Load Index in the Telepresence condition, presented in Figure 7. , showed a significant increase in some parameters of the workload. However, participants did not have major problems performing the collaborative task using the HMD. The *Performance* parameter was the highest of all and the *Frustration* parameter, the lowest in both system's modes.

When using the telepresence mode there was a significant increase in the *Mental Demand, Effort and Frustration* parameters. As for the *Physical Demand*, there was a slight increase as some participants had some struggle controlling the robot hands at the beginning. The *Performance* parameter was lower. Nevertheless, at the end of the experiment participants were satisfied with their overall performance.

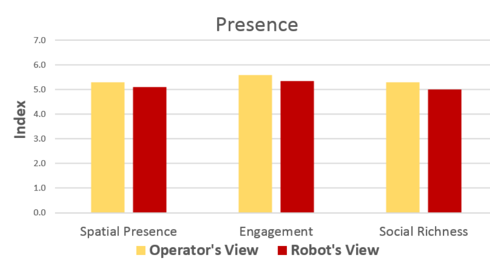


Figure 7. Measure of Presence for each system's modes. Scale (0-7)

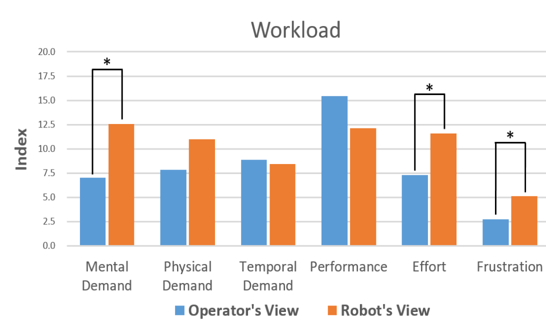


Figure 8. Measure of Workload for each system's modes. Scale (0-20)

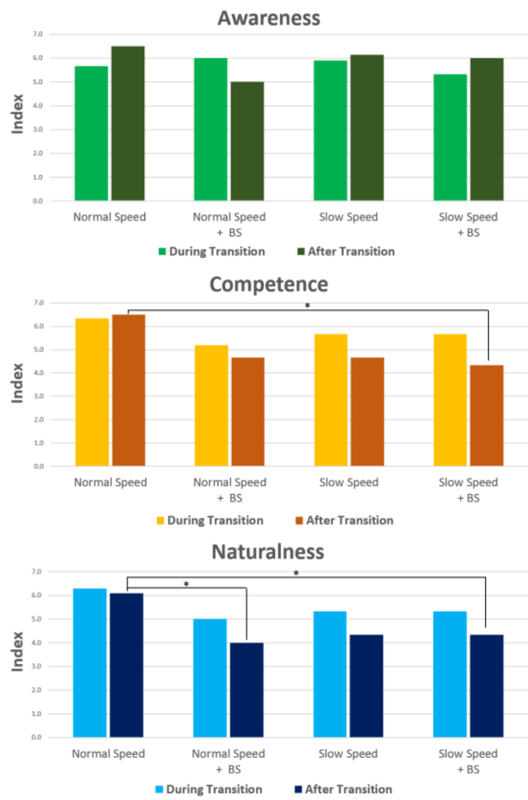


Figure 9. Factors of the Transition of Control. Scale(0-7)

VIII. Experiments on Transition of Control.

A. *Description*

The purpose of this set of experiments was to analyze the impact of the transition of control in participants which were familiar with the telepresence system described above. The variables to measure were retrieved from the results of the exploratory study: Awareness, Naturalness and Competence.

B. *Methodology*

Six conditions were defined. The user would be asked to perform a task and randomly a "Take over Control" will appear. The conditions were designed according to 2 factors. Speed, which could be *Slow*, *Normal* and *Fast* (0.5, 2 and 6 seconds respectively), and the appearance or not of a Black Screen. For the evaluation the 3 dimensions of the transition of control were measured using a 7 point Likert scale. Additionally, in order to get subjective comments from the participants, there was a short interview after each experience. The question was open-ended, and participants were told to describe their experience.

C. *Analysis and Results*

The *Fast* and *Normal* results were similar and therefore, the data from the *Fast* condition was ignored. Results are shown in Figure 9.

Awareness. Despite the factors of *Speed* or the *Black Screen* display, the "Awareness" factor remained the same among the conditions. However, the participants who started the experiment with the *Slow Speed* factor mentioned that this prolonged time helped to get used for the next transitions.

Competence. There was a significant decrease of "Competence" when participants had the *Slow Speed* and *Black Screen* condition compared to the *Normal Speed* transition. Users mentioned the prolonged time of the black screen was like a "hole" and a "gap" in the task.

Naturalness. For both *Normal* and *Slow Speed* conditions without showing the *Black Screen*, the "Naturalness" factor remained almost the same during and after the transition. However, in the after transition scenario, for both *Normal* and *Slow Speed* there was a significant decrease of "Naturalness".

Results showed that the "Awareness" parameter was independent from the *time speed* and *black screen* factor. However, the prolonged use of a black screen resulted in a decrease of "Competence" and "Naturalness". From the after-experiment discussion with the participants, it was highlighted the importance of using a "black screen" at the beginning as it helped them to get prepared. However, participants mentioned that in the long term the *Normal* speed would be the most suitable. The findings evidenced that the time of transition had to be personalized according to each subject's performance.

IX. Mode Switching Strategy

From the findings in the experiments of the transition of control we recognized two important factors: The time and the frequency of transitions. In order to define a strategy for the transition of control it was necessary to design a function that could contemplate these two variables. For this reason we defined a time-based switching strategy according to the following requirements:

- A Long Fixed time for the first transition
- Time of transition should be selected according to previous time of transition
- Short and long times of transition for high and low frequencies of transition respectively.
- Maintain a long fixed time of transition if there were not transition's request for a period of time.

TABLE I. Transtion Time's Parameters

T_I	Minimum time of Transition.
T_F	Maximum time of Transition.
t_w	Window Time
ζ	Dumping Factor

The y-axis represents the T_{Trans} (Time of Transition) in seconds which is constrained by the minimum value T_I and the maximum value T_F. The x-axis represents the time after the *previous* transition in minutes, and t_w represents the period of time in which T_{Trans} reaches its maximum value T_F. From that moment $T_{Trans} = T_F$. The value of t_w directly affects the speed of change from T_F *to* T_M and the ζ parameter corresponds to the Dumping Factor which is initially set to 1. The function presented below was based on the time response of second order systems (step response) as the parameters suited our requirements. The corresponding variables are shown in Table 1.

$$T_{Trans} = (T_F - T_I) \,.\left(1 - e^{-\left(\frac{\zeta}{10\,.t_w}\right).\,t} . \left(1 + \frac{\zeta}{10\,.\,t_w} .\, t\right)\right) + T_I$$

For $T_I = 1$secs, $T_F = 6$secs, $t_w = 5\ min,$ and $\zeta = 1$

For this example, the first transition is set to T_F. From that moment the duration of the next transition time starts from T_I and increases to T_F as long as there is not a request for transition. By using these parameters, the evolution of T_{Trans} over time is shown in Figure 10.

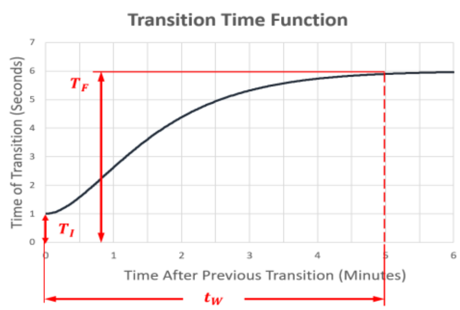


Figure 10. Plotted Function

X. Conclusion

Despite that transition of control has been extensively performed in other fields, such as highly automated vehicles, the exploration of these parameters in telepresence robots has not been clearly documented. This documents shows an initial analysis of the dimensions of the transition of control on Telepresence Robots and proposes a time-based strategy for managing the time of the transition of control.

The results of the experiments showed that there does not exist an ideal fixed time for the Transition of Control. Even though the duration of the transition does not affect parameters such as "Awareness", it does impact the "Competence" and "Naturalness" parameters. Many participants agreed that a larger time of transition at the beginning (6 seconds) would be the most suitable in order to reduce the workload and get used to the transition. However, for the next transitions, a short period (1-2 seconds) would the most suitable.

Even though participants recognized the importance of having different periods of time, a crucial parameter emerged during the development of the experiments, the frequency of the transition. The proposed time-based strategy targets to contemplate the effect of these 2 parameter based on the results of the experiments conducted. However, in order to fully understand the effects of the Transition of Control we will perform a deeper research with longer periods of interaction.

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