# Behind The Game: Implicit Spatio-Temporal Intervention in Inter-personal Remote Physical Interactions on Playing Air Hockey


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**Figure 1: (a) The physical machine allows a remote player to play against a local player. (b) The remote player side. (c) Graphical user interface for the remote player.**


## ABSTRACT

When playing inter-personal sports games remotely, the time lag between user actions and feedback decreases the user's performance and sense of agency. While computational assistance can improve performance, naive intervention independent of the context also compromises the user's sense of agency. We propose a *context-aware assistance* method that retrieves both user performance and sense of agency, and we demonstrate the method using air hockey (a two-dimensional physical game) as a testbed. Our system includes a 2D plotter-like machine that controls the striker on half of the table surface, and a web application interface that enables manipulation of the striker from a remote location. Using our system, a remote player can play against a physical opponent from anywhere through a web browser. We designed the striker control assistance based on the context by computationally predicting the puck's trajectory using a real-time captured video image. With this assistance, the remote player exhibits an improved performance without compromising their sense of agency, and both players can experience the excitement of the game.


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## CCS CONCEPTS

• **Human-centered computing → Interaction devices**; **Web-based interaction**.

## KEYWORDS

Teleoperation; Sense of agency; Human-machine integration

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## 1 INTRODUCTION

Physical sports play an important role in our daily lives, as they can facilitate connecting with others and improve our health. With the advancement of information technology, various activities have become possible beyond the limitations of location. However, it is challenging to play inter-personal sports remotely. One of the problems is the time lag between user actions and feedback, which is caused by systems connecting remote and local areas. The time lag decreases the reaction speed and operation accuracy of action controls and induces various errors. Such a situation can also reduce the remote player's sense of agency, the subjective experience of controlling one's own action, and places them in them an unfavorable position relative to the physical player. This unfair condition reduces both players' motivation to play the game.

This study explores how well-balanced inter-personal games can be achieved between a remote player and a physical (local) player. In general, although the remote player has a disadvantage, their performance can be improved with the assistance of computational intervention. However, a naive intervention that does not rely on the user's intention may also compromise the player's sense of agency. In particular, in interpersonal games the user's intentions can change dynamically depending on the context, which may include other players' action, their's own actions, and changes in the environment. Hence, it is necessary to consider an intervention method optimized for the context rather than focusing only on the user's performance.

In this paper, we propose an intervention method called *context-aware assistance*, in which the computer is aware of the context and intervenes in the user's actions according to it. We demonstrate the method using air hockey, a two-dimensional physical game, as a testbed. Air hockey is a popular inter-personal game that requires temporal and spatial physical control. Players need to predict a puck's trajectory quickly and accurately hit the puck with a striker. Using the puck's movement and the user's behavior, our system estimates two contexts, (1) defense and (2) offense, and provides appropriate individual assistance in response.

The system mainly consists of a 2D plotter-like machine that controls the movements of a striker attached to its end effector (Figure 1 (a)) and a interface in the form of a web application (Figure 1 (b) and (c)). While the remote player controls their striker using the interface, the system detects the puck and striker from the real-time image captured from a video feed and intervenes in the striker motion to prevent missed shots caused by the time lag. Our system, firstly, estimates the context from the puck's movements and the player's behavior. Then, the system dynamically adjusts the striker's position to meet the puck through a method designed for the context. This assists the player to hit the puck as intended, generating the sense of agency.

In our demonstration, the remote participant can use a standard web browser and graphical user interface (GUI) to control the striker and play against a physical opponent in a local.

## 2 RELATED WORK

### 2.1 Teleoperation

Teleoperation systems have a long history, beginning with the master-slave manipulators developed by Goertz [Sheridan 1989]. While teleoperation using master-slave manipulators enables users to perform operation intuitively, noise and delays in signal transmission can hinder performance. In 1967, Ferrel and Sheridan proposed a method called supervisory control, in which a human observer cooperates with an automated machine to complete physical tasks from a remote location [Ferrell and Sheridan 1967]. Supervisory control is a pioneering method of remotely performing tasks. Through it, various methods have been used to perform physical tasks remotely by leveraging automated machine advantages, such as collision avoidance in mobile robots [Takayama et al. 2011] and cancellation of the relative motion between surgical instruments and a beating heart [Bebek and Cavusoglu 2007]. Recently, Rakita et al. proposed a method for intuitively controlling manipulators that have different kinematics from those of the human arm [Rakita et al. 2017]. In this method, the constraints of the mapping, from the position and orientation of the user's hand to those of the manipulator's end effector, are relaxed depending on the motion of the user's arm. This allows the user to feel that they are controlling the manipulator directly, while simultaneously attaining smooth movement and singularity avoidance in the manipulator. While the main goal of these studies was to improve performance, our research focuses on not only performance improvement but also the user's sense of agency as an important factor in achieving a satisfying experience playing sports games remotely.

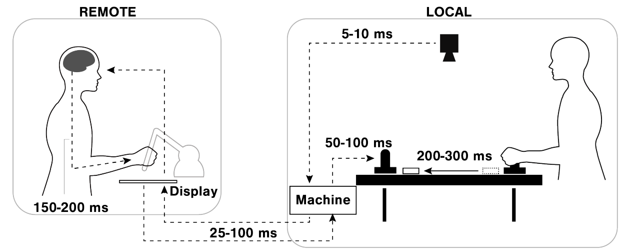


**Figure 2: Overview of the system framework. Communication between remote and local has a time lag of tens to hundreds of milliseconds.**

### 2.2 Human-machine collaboration in motor action

It has been argued that it is important for a system to understand the user context in order to compute effectively [Perera et al. 2013]. However, many studies have focused on sensor data or display of information, and research on understanding the context for the purpose of intervention in the user's physical motor actions is still lacking. Therefore, our research explores important factors for intervention in motor actions in the context of physical sports in a remote environment.

Previous studies have suggested that physical motion assistance can provide an augmented experience. For example, Kasahara et al. proposed a system that uses electrical muscle stimulation to accelerate the user's motion without compromising their sense of agency [Kasahara et al. 2019]. Maekawa et al. reported that a user's performance in throwing with a handheld device can be improved without the user noticing [Maekawa et al. 2020]. These studies built their systems for simplified situations, but we focus on physical sports involving more complex situations.

## 3 SYSTEM OF BEHIND THE GAME

The system consists of an air hockey table, a camera to capture images of the hockey table surface, a physical machine on one side of the table, and a network server (Figure 2). The remote player watches the live video stream and controls the remote striker. On the other side of the table is the physical opponent in a local location.

### 3.1 Physical machine for air hokcey game

We tailored a machine for physical interactions on an air hockey table by its hardware to generate sufficient acceleration and velocity to follow the user's arm motions. The machine has two actuated degrees of freedom driven by DC motors. We adopted a parallel mechanism using a belt and pulley to minimize the mass of end effector and ensure sufficient acceleration and velocity. The end effector is equipped with a striker and can move across half of the two-dimensional plane of the table.

### 3.2 Remote user input and feedback

We built a web application that allows the remote user to control the physicl machine. The application displays the live video stream of the table surface captured by the camera. The movable range of the striker is highlighted with a rectangle overlaid onto the video feed. Inside the rectangle, an indicator corresponding to the striker's position is displayed. The user can control the striker by moving this indicator, which can be manipulated with any familiar peripheral, such as a mouse or touchpad. There is a delay of tens to hundreds of milliseconds both between when the camera captures the image of the physical table and when that image is displayed on the remote application. The same delay also exists between the remote user's input and the physical machine's motion.

## 4 ASSISTANCE DESIGN

The time lag induces various hindrances, such as failing to react the opponent's shot or to meet the puck accurately with the striker. These experiences impede the user's sense of agency. Hence, we designed computational interventions to reduce hitting errors caused by delays. The remainder of this section describes the specifics of our assistance design that we investigated in preliminary experiments.

### 4.1 Context-aware assistance

From the observation of user performance in air hockey, we found that the game can be divided into two main contexts:

(1) Defense: the user reacts to a puck hit by an opponent and blocks or returns the puck.
(2) Offense: the user shoots the puck into the opponent's side.

We also found that the accuracy of horizontal control is critical in air hockey. If the horizontal control accuracy is low, the player may not hit the puck as they intend, or they may not stop the puck hit by the opponent, resulting in a goal being scored against them. Therefore, we designed a system that optimizes the horizontal position in the two contexts of defense and offense.

The assistance in optimizing the horizontal position is triggered only when the system detects two contexts. When assistance is triggered, the horizontal control is given to the computer (Figure 3-a). Even when this intervention is active, the player still has control over the vertical movement. Thus, the player can strategically decide to shoot the puck onto the opponent's side or keep the puck on their side. After the striker hits the puck, the assistance rate gradually attenuates until it is completely back under the player's control (Figure 3-b). This horizontal correction helps the user hit the puck accurately, even under remote control with a time lag. Because the player's goal is to hit the puck, this experience contributes to maintaining a sense of agency.

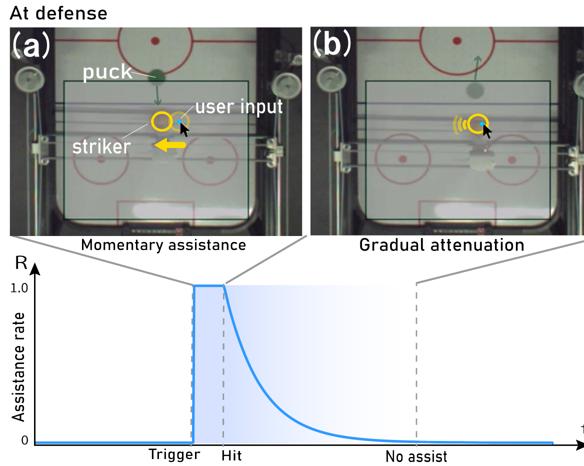


**Figure 3: The system estimates the context from the movements of the puck and striker. (a) When the system detects the context, assistance is momentarily activated. (b) After the striker hits the puck, the assistance rate attenuates gradually until the striker is entirely back under the player's control.**

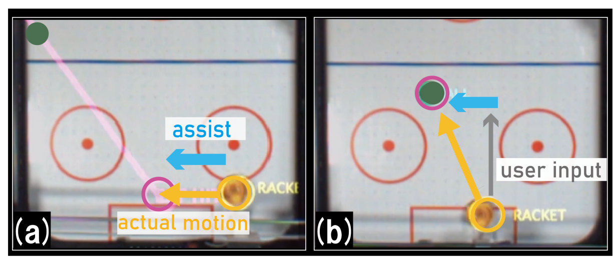


**Figure 4: Context-aware assistance. (a) Defense: the striker's position is adjusted to match the estimated contact point according to the puck's trajectory. (b) Offense: the striker's position is adjusted to match the position of the puck.**

*4.1.1 Defense.* The defense context is estimated when the puck approaches towards the remote player's side above a certain speed. In this case, the system adjusts the striker's horizontal position to match the intersection between the predicted trajectory of the puck and the horizontal line through the striker's current location (Figure 4 (a)). In the defense context, the intervention is triggered independently of the player's input. This is because the player's reaction based on a delayed video prevents them from hitting the puck on time. We found that in many cases, the player felt more agency than when they move the striker by themselves because of the apparent congruency between action and feedback.

*4.1.2 Offense.* The offense context is estimated when the puck stays below a certain speed on the remote player's side, and the system detects the player is moving the striker to hit the puck. In this case, the system adjusts the striker's horizontal position to match the position of the puck detected by the camera (Figure 4 (b)).

## 4.2 Haptic feedback

We also implemented haptic feedback as an optional feature. This feature includes two types of haptic feedback: collision feedback between the puck and the striker, spring force feedback to navigate to the corrected striker position. Because haptic sensation is one of the essential factors in motor learning, we believe it can contribute to becoming proficient in manipulating the system. However, this feature can also make the presence of interventions apparent.

## 4.3 Two-dimensional assistance

To design more performative intervention, we implemented a prototype system that intervenes for vertical and horizontal control. In this implementation, the system estimates the contact point in front of the current striker position and achieves accurate shooting. In preliminary experiments, we confirmed that this implementation enabled the puck to be shot with more power than the horizontal assistance. However, some test users reported that their sense of agency was lower than it was when only horizontal assistance was activated. This may have been because the intervention generated movements and timings that were different from the player's intentions, which may have been caused by an inaccurate estimation of the context. However, we will achieve this two-dimensional assistance without compromising user agency by implementing another context estimation method. Specifically, by properly switching between horizontal and two-dimensional assistance based on the user's input, the two-dimensional assistance may be able to be incorporated into the system without compromising agency.

# 5 USER EXPERIENCES

We will demonstrate our Behind The Game system at the SIGGRAPH 2021 Emerging Technology exhibition Our system allows remote users to control the striker and play against a physical opponent at our demo location. Our demonstration can be achieved fully online manner. The attendees can join our exhibition over the web browser with their mouse. The context-aware assistance we designed increases the user's performance and sense of agency, even in teleoperation, in which there is a time lag between the user's action and feedback. Thus, the user is able to play fairly with a physical opponent. Even if there is no haptic feedback, it will allow remote participants to experience the concept.

If attendees can physically visit our demonstration, they can experience the optional haptic feedback and play against remote attendees. Playing against remote opponents who cooperate with a machine will also provides a new experience for the physical players.

# 6 LIMITATION AND FUTURE WORKS

Because the time lag varies depending on network conditions, there is a possibility that we will need to adjust the intervention parameters for different networks.

We are planning on conducting a detailed user study. One of our goals is to clarify how to adjust the parameters to maximize the user's sense of agency. Eventually, we hope to provide design guidelines for solving physical constraints in teleoperation using a psychological approach.

We aim to develop this project not only as a solution to teleoperation problems, but also as research on human-machine interactions in motor actions. For instance, we are interested in what behavioral changes are generated when the intervention is gradually increased or decreased, and when the user learns a machine-human mutual motor model.

# 7 CONCLUSIONS

We demonstrated a computational intervention method for teleoperation of an remote air hockey that retrieves the remote user's performance and sense of agency, even with a time lag. With context-aware assistance, in which the system is aware of the context and intervenes according to it, the remote player exhibits in improved performance without compromising their sense of agency, and both players can experience the excitement of the game. We believe that the experience of human-machine collaborative actions achieved in this study provides new insights in the research field of human-machine integration that are beyond the solution framework for time lags in teleoperation.


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