Integrating Robotic and AI Technologies to Support Embodied Collaborative Design

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Background

In this project, we aim at designing robotic systems to support remote design collaborations. Previous research has shown that non-verbal cues, such as proxemics and gestures, are important during collocated design activities. Yet, they are very difficult to be conveyed through common collaboration tools we have now, such as online-sharing documents (Google Docs and Miro board) and video-conferencing platforms (Skype and Zoom). The goal of our project is to study how these physical non-verbal cues can be re-created through a robotic collaboration system during different stages of design activities such as critique, brainstorming, and hardware review.

Activity I: Supporting remote hardware debugging

In the first part of our work, we focus on supporting remote hardware debugging. For example, designers often face challenges to debug hardware prototypes remotely, because it is difficult to grasp where the collaborator's focus is on or what is referred to. To support this type of design interactions, we developed a system where both locations have a robotic embodiment to represent a remote collaborator. This embodiment displays the face expressions of a remote participant and visualizes where their attention is through the kinetic movements. The overall system is shown in Fig. 1. The robotic proxy is controlled by head rotations to eliminate a GUI control which usually adds a cognitive load and disrupts them from concentrating on their design tasks. As shown in Fig. 2 (right), the system includes a feature to remap from the head rotations to the robot in the other space, so that the robot looks at the same area as a remote participant considering different physical configurations.

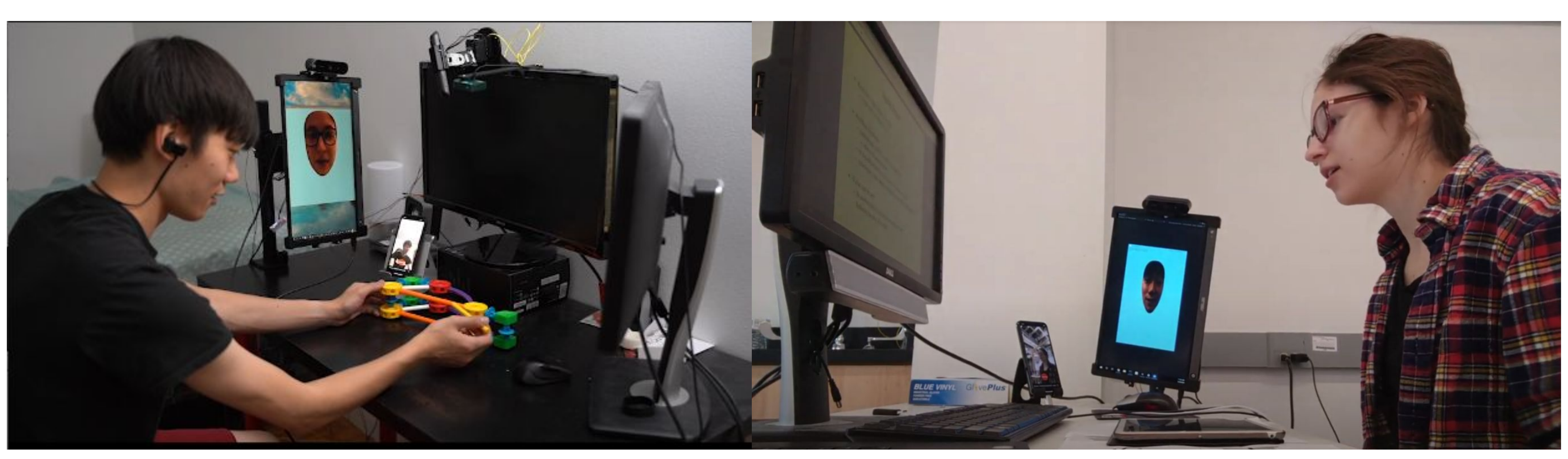

Fig 1. Robotic embodiment system for supporting remote design collaboration using a mobile sensing device. The embodiment has a 2-DOF arm to reproduce head rotations and a monitor to display facial expressions.

To achieve this, we first implemented a pipeline to render a facial mesh in realtime using a mobile device. The facial mesh consists of dynamic 1220 vertices and texture of an actual user captured by a phone camera. This is used to always render the frontal face on a robotic proxy (Fig. 2 left). Then, we developed a prototype of a 2-DOF robot that's synchronized with the head rotations of a remote participant. We calculated a homography matrix for each area after calibration and manipulated the robotic proxy based on the remapping feature. We also implemented a laser pointer for a remote participant to be able to refer to a certain object in the task space. We set up a server application in a way that users can get connected to the system far apart from each other. Using our system, remote collaborators can conduct a hardware prototyping session with clear understanding of where the collaborators are focusing their attention.

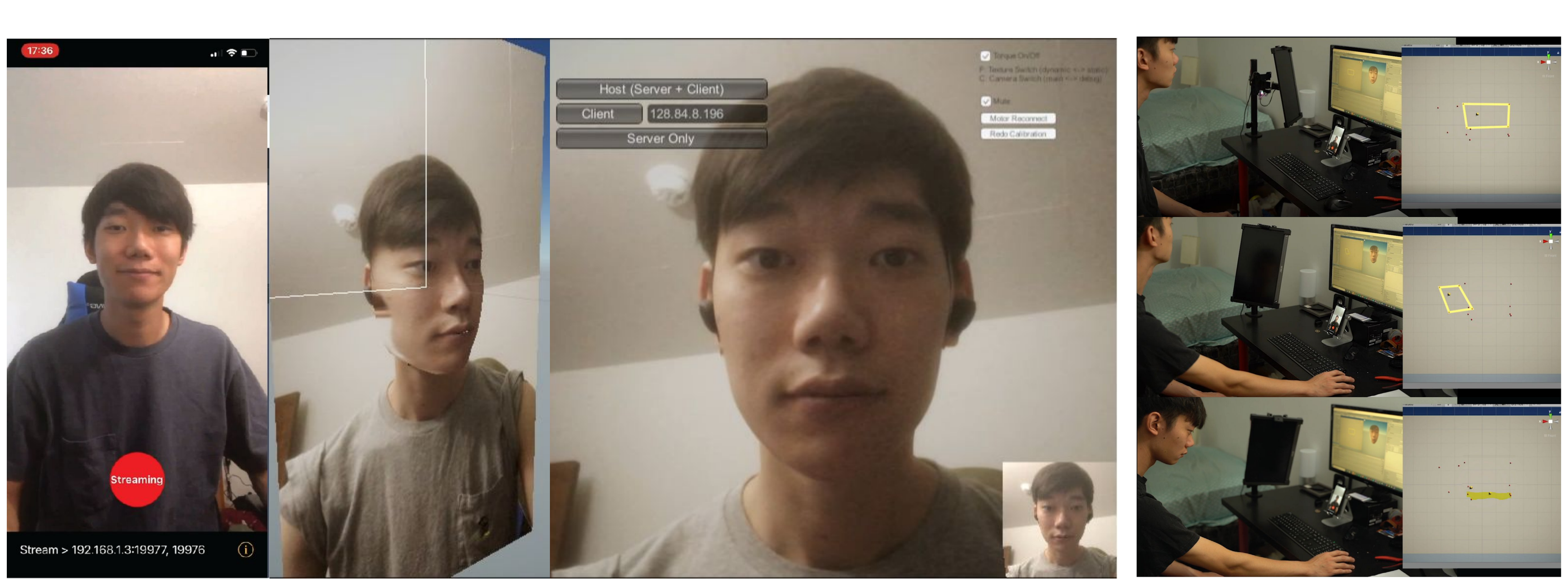

Fig 2. (left) face rendering pipeline using TrueDepth camera on an iPhone to show a frontal face, (right) three homography matrices to remap from head rotations to the robot movements

Activity II: Embodiment of Robotic Collaboration System

In the second part of our work, we explore remote brainstorming scenario using a telepresence robot to represent a remote user in a local space. A key challenge in designing the robotic system to interact with people is the enormous complexity of hardware and software makes it difficult to quickly explore and evaluate possible designs and converge to a successful solution. We developed and leveraged a novel interactive simulation system to enable a wide-range of design variations, such as configurations of robotic platforms, without the need to build the complex hardware systems as shown Fig 4. With the interactive simulation, we were able to quickly visualize different setups and implement different collaborative tasks, for example, pictionary and tic-tac-toe in Fig 4. Our system can be quickly deployed on a web browser and make it easier to recruit participants to remotely experience and evaluate the robotic system. With feedback and insight we collected, we were able to further our understanding of the pros and cons of different setups and look into the implementation of non-verbal cues, such as proxemics. Results show that people changed their position in relation to the posture and position of the robot.

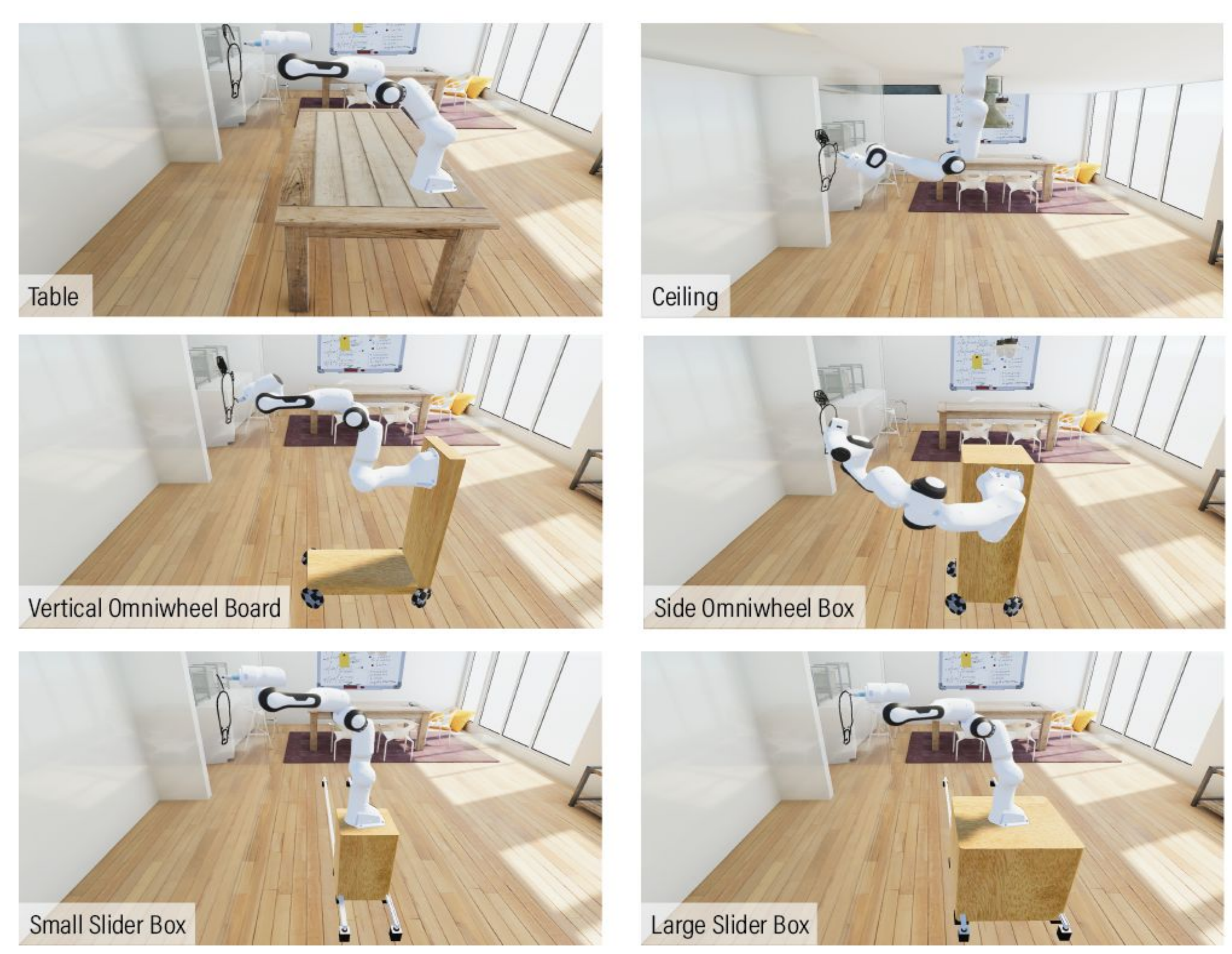

Fig 3. Rapid iterations with the interactive simulation: the interactive simulation we developed with the use of Unity has allowed us to implement, envision, and explore a wide range of design variations, such as configurations of robotic platforms.

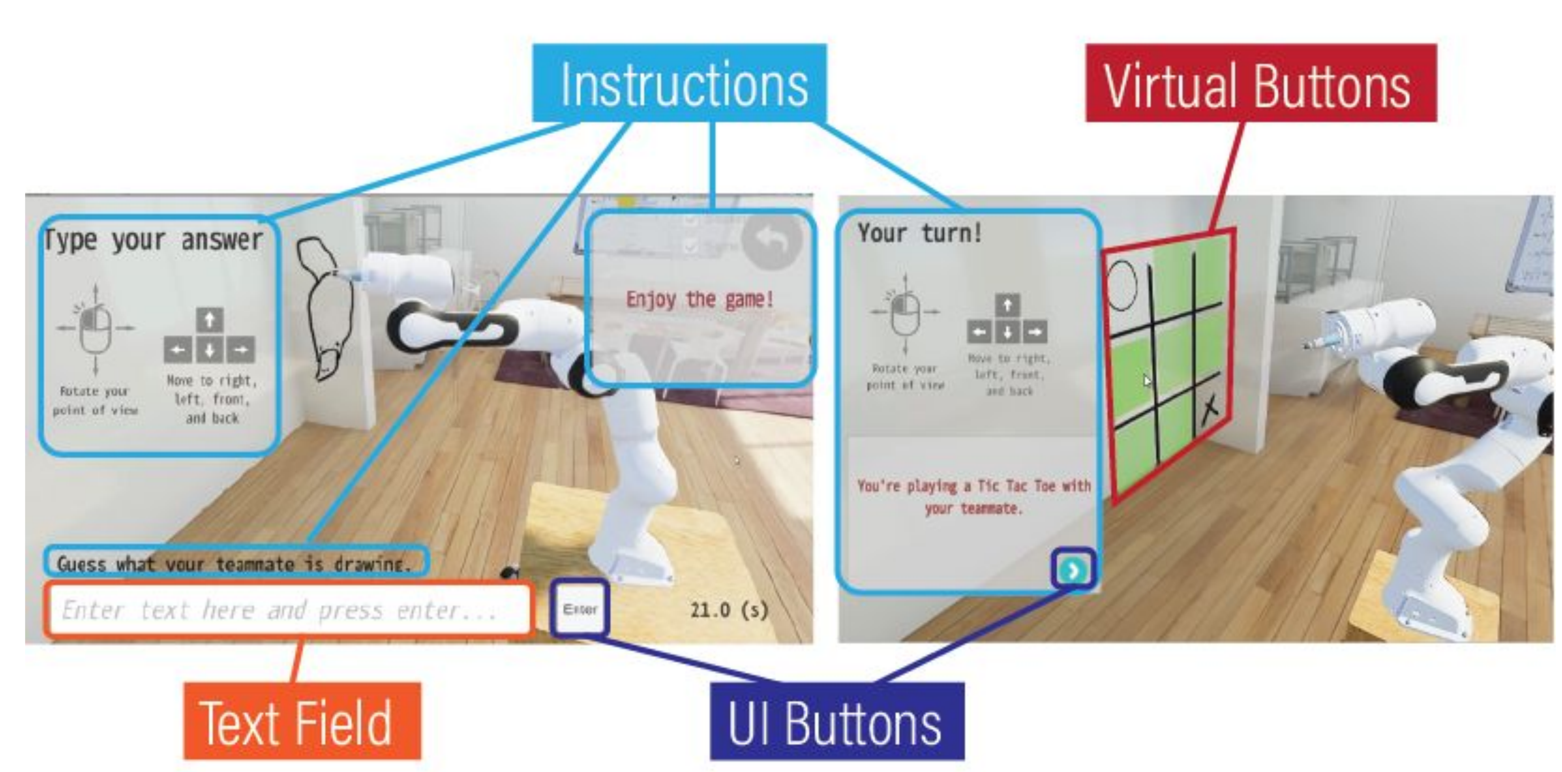

Fig 4. Implementation of Pictionary and Tic-Tac-Toe games with the interactive simulation.

Future Work

We are now planning to run in-person study to evaluate the system and further understand how robotic and AI technologies can better support remote embodied collaborative design.In the future, we will implement hardware prototypes explored in the interactive simulation and integrate the embodied robot into a VR system.

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