Innovative Experimental Methods in Human-Robot Interaction

by
Chinmay Wadgaonkar

A THESIS

submitted to

Oregon State University

Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Electrical and Computer Engineering
(Honors Scholar)

Presented June 5, 2020
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AN ABSTRACT OF THE THESIS OF

Chinmay Wadgaonkar for the degree of Honors Baccalaureate of Science in Electrical and Computer Engineering presented on June 5, 2020. Title: Innovative Experimental Methods in Human-Robot Interaction.

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User studies in human-robot interaction and social robotics in general involve human participants and their reactions, observations and expectations of robots. This thesis presents two innovative experimental methods aimed at gaining access to high-stakes social data not typically collectable with traditional user studies. The Actor Method provides access to data that would not typically be approved by the experimental research board (privacy and data use in human-robot interaction) and the VR Method allows us to collect data about robot physical designs, without actually building all the robot variants. As a methods paper, this thesis presents the utilization of these two methods in two different HRI experiments and highlights the significance of this approach to both the experiments. Not only were both the methods successful at gaining access to the desired data, but they also helped elicit participants' emotions and mental models about the robots and their interactions with the robots. Future work can extend the VR Method to create immersive extended reality story-like experiences that explore human-robot interactions with virtual robots and real-world haptics like water, wind and heat.

Key Words: Human-Robot Interaction, experimental methods, method acting, virtual reality, social robotics, experiment design.

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Honors Baccalaureate of Science in Electrical and Computer Engineering project of Chinmay Wadgaonkar presented on June 5, 2020.

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I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

Chinmay Wadgaonkar, Author

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1 Introduction

Researchers in the field of Social Robotics study the interaction of people and robots, including people's perception and reactions to robot embodiments, behaviors, and social perception capabilities. They use the outputs of such studies to set design objectives for new robot implementations and/or evaluate the effectiveness of such systems around people. Investigating these concepts often involves "user studies" as a data collection method conducted with human participants under controlled conditions, which allow a researcher to analyze and report on people's behaviors and reactions -- in this case, to robots. Thus, this honors thesis seeks to propose two innovative experimental methods at two different stages in user studies to add to the scope and usability of user studies in human-robot interaction research.

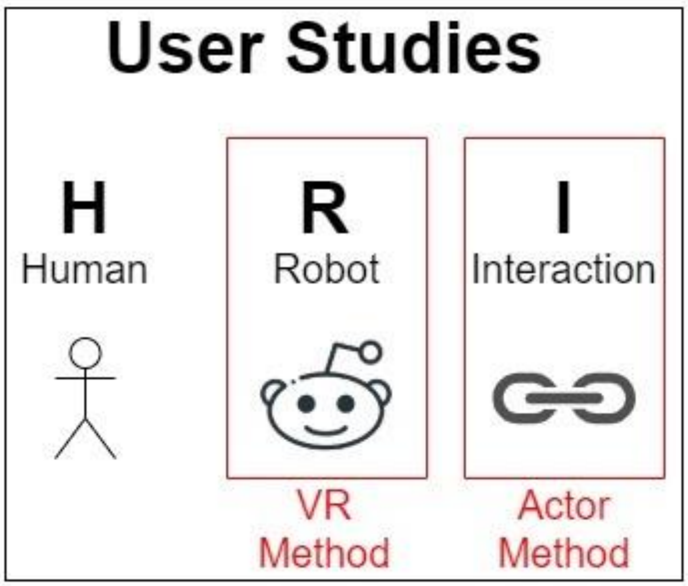

Fig. 1.1: The minimum components of an HRI study: the human participant, a robot and the interaction between the two. The Actor Method innovates user studies at the "Interaction" level, broadening the scope of user studies by enabling data collection in domains where it would usually be prohibited. The VR Method innovates at the "Robot" level by augmenting the materiality/design of the robot, resulting in efficient prototyping.

As shown in Fig. 1.1, user studies in the field of Human Robot Interaction have at least 3 key components: a human participant, a robot (usually prototyped/customized for the experiment) and an interaction between the human and the robot. From this high-level abstract perspective, all user studies in HRI would use some form of this structure to investigate their research questions and hypothesis. We continue this pattern, but instead of recruiting people to observe and interact with programmed robots in a traditional way, this honors thesis reports the development of two innovative protocols for conducting human-robot interaction experiments. The **Actor Method** innovates traditional user study protocols by having a participant act out a condition allowing the research team to explore situations and scenarios (like prior crime records or actual privacy violations) that would otherwise be uncomfortable for the participant. The **VR Method** allows the research team to easily vary the appearance of the same physical robot, allowing us to collect data about people's reactions to various visual variants of the same robot. Both leverage the participant's imagination: one asking them to imagine themselves in a particular scene, the other visualizing the scene and asking them to imagine it is real. Both methods are still user studies, but with a twist applicable to early stage application design, in that they enable us to understand early what should be built and/or programmed.

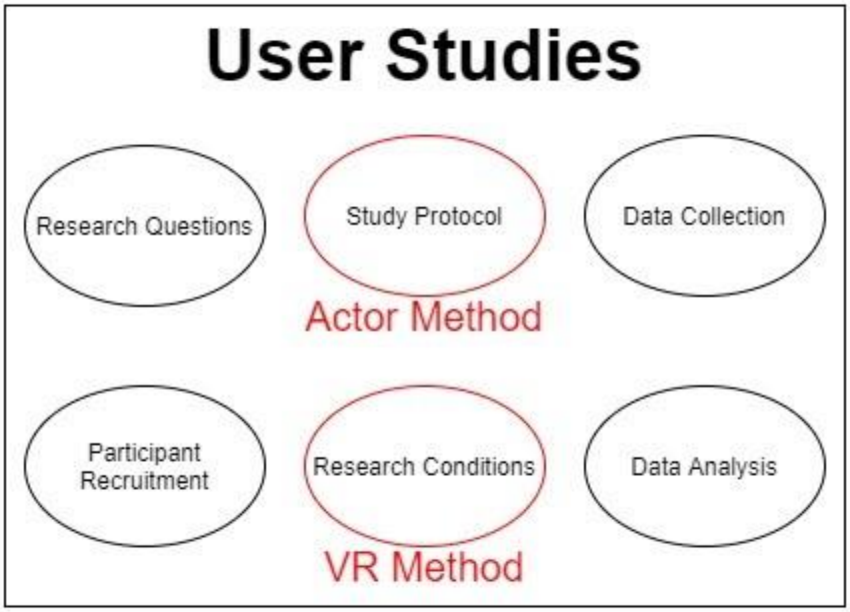

Fig. 1.2: The lifecycle of user studies in HRI from a study planning perspective consist of formulating research questions, recruiting participants, establishing a study protocol, manipulating research conditions, data collection and data analysis. The Actor Method innovates at the Study Protocol stage, leveraging the safety of pretense to allow data collection in high-stakes applications while the VR Method leverages VR to make the manipulation of research conditions during an HRI study easy and efficient.

Fig. 1.2 presents 6 different stages of a typical user study in the field of Human-Robot Interaction. While data collection and data analysis occur during and after running a user study, the other 4 stages typically occur in the early stages of experiment design. After noticing or ideating on interesting phenomena in HRI, researchers will formulate themed research questions. With these research questions in mind, the researcher would develop a study protocol that allows the effects of manipulating research/study conditions to be observable. These two steps paired with pilot studies are usually a part of an iterative process as a researcher clarifies and finalizes the manipulated conditions in a user study. The study protocol development also involves pursuing IRB (Institutional Review Board) approval. IRB safeguards the rights and welfare of human research subjects recruited to participate in research activities. After satisfying IRB guidelines, participants can be recruited to a user study to fulfill the third key component from Fig. 1.1.

The **Actor Method** innovates the *Interaction* (Fig. 1.1) and allows researchers to broaden the scope of their user studies into innovative domains. Typically, user studies have users do actions under certain research conditions. But some actions or research conditions aren't allowed due to the IRB board. For example, any user studies exploring human privacy, the ethical conundrums behind a robot's actions, discrimination by robots in the police force, bias in decisions made in criminal justice systems, robots accessing human medical data, criminal profiling in detection systems and decision making in autonomous driving situations to name a few are studies that cannot be implemented in real life [1]. However, HRI user studies revolving around these sensitive but significant topics often necessitate delving into innovative and high stakes applications and data. Hence, to explore such areas, we propose the innovative **Actor Method** to "test the untestable". The Actor Method involves participants **acting out a script** and **thereby role playing another imagined person**. Inspired by method acting, this helps bypass any situations that may infringe or harm the human participant while also helping the participant empathize and imagine how a real person in that situation may react or feel. As an instantiation of this method, we explored high stakes social privacy data. It is important for robots to have enough data to understand their interaction partners; this enables them to behave intelligently, but **how can we study people's expectations of a robot that uses their data, without violating their data privacy** in the process? Que, the Actor Method. In this experiment using the imagined personality as a proxy meant that instead of violating the actual human's social privacy, the study protocol could be set up such that the robot would violate the imagined person's privacy. Hence, since we weren't actually infringing on the real human participant's data the experiment was approved by the IRB. This method's goal was to evoke parallel emotions in the human participant despite them role playing an imagined person. The Actor Method allowed us to explore a wider variety of ethical themes than would otherwise have been possible and may also be applicable to other areas of high psychological risk.

The **VR Method** innovates the *Robot* (Fig. 1.1) and enables flexible robot prototyping and design. User studies often involve a vast multitude of research conditions. As in Fig. 1.1, in HRI the research conditions being studied often relate to the *Robot*. However, varying the physical appearance of the robot, the robot's personalities, approach styles and behaviors can lead to a large number of combinations. Each type of robot in these categories would need to be built, a time-consuming and costly process. However, these research conditions are central to answering many different types of research questions in HRI. In their paper, Belhassein et. al discuss the utilization of user studies in the field of HRI. While discussing user study design, they mention that the used material (robots) are often expensive and available in limited quantities [2]. Belhassein et. al also bring up another limitation of user studies, the small sample size due to HRI user studies frequently having few participants. For example, about 44% of user studies published in the proceedings of the conference HRI'17 involve fewer than 30 participants [2]. However, with the right methodological development, **Virtual Reality (VR) could act as a valuable prototyping tool for physical human-robot interaction**. Innovating due to the need for inexpensive, efficient and fast robot prototyping, we propose the **VR Method** to enable a greater number of research conditions' (Fig. 1.2) combinations in user studies. Creating an HRI user study in VR can help with varying the materials used for the robot. The Unity Asset Store and other open source resources have a wide array of colors, textures and materials that can be applied to a virtual robot, hence, allowing one prototypable robot to take the place of many robots. VR also allows quick creation and destruction of objects, hence letting us manipulate the shape of the virtual robot. Using a VIVE tracker lets the virtual robot track a physical robot's movements and location in a room. Hence, using this method we can also explore physical properties of the robot in the user study (the user dons the VR headset, rendering them unaware of any texture swaps for the robot that we may incorporate while running the study. As an exemplar of this approach, this thesis presents the VR Method through an experiment exploring the 'impact' of robot shape and materiality on people's sense of safety and companionship with a virtual/physical robot that collides into them. This experimental method involved participants being immersed in VR and observing the robot's appearance and motion in VR. In this specific instance, robot build time and real-world issues with hardware were avoided by using the VR implementation of the virtual robot as a manifestation that tracked the motions of the physical robot. The experiment detailed in this thesis also exposed some of the limitations and strengths of using VR in human-robot interaction research. Some of these limitations take the form of low resolution and imprecise rendering of materials that led to inconsistent recognition of a subset of the materials, like fur. However, the prevalence of pre-existing assets for VR, low-overhead for developing experiments, and the ability to link virtual robots to the motions of actual robots operating in the room support this method as a viable prototyping tool for both robots and human-robot interaction design.

After considering the contributions of these two methods to the two user studies detailed above, we conclude that both methods described in this thesis were successful at gaining access to the desired data. Additionally, the narrative and immersive nature of the methods also elicited emotions and mental models from the participants. By highlighting the benefits of these two methods, this thesis revolves around utilizing innovative experimental methods for social robotics to provide access to high-stakes social data not typically collectible with traditional user studies:

- The Actor Method provides access to data that would not typically be approved by the experimental research board, and
- The VR Method allows us to collect data about robot physical designs, without actually building all of the robot variants.

This honors thesis focuses on the methods used in two of the projects that I have been a part of as an undergraduate researcher in CHARISMA Lab. Apart from these two studies, I have been involved in 3 other HRI user studies. I helped in the early initial stages of the Robot Comedy project where participant recruitment and data collection (Fig. 1.2) were targeted by having a robot perform stand-up comedy with a human co-comedian in front of a medium-sized (15-20 people) audience. The data collected included the audience's feedback and reception of the robot-human comedian pair's jokes, making the whole audience a "participant". Recently, I have also been working on two other user-study related projects. ResolutionBot, a wizard of oz study, is a 3-year long study pertaining to a robot that visits participants at the start of a New Year for a period of 3 weeks, incentivizing healthy activities and helping the participants stick to their New Year's resolutions about being healthy. This variant of a user study contains a wild amalgamation of research questions and data collection about human behavior and the efficacy of a robot as a personal health coach. Finally, a project that is still in development, VR Story, is poised as an expansion of the second innovative method, the VR Method. This project delves further into a human participant's perception of visuals. While the VR method manipulates the user's perception of the robot, this more recent project explores the effects of changing the interaction's backdrop. To this end, we are developing multiple virtual backdrops threaded together with a game-like storyline revolving around the human participant and their robot PoliceBot/friend. As such, this user study innovates the Research Conditions (Fig. 1.2) in user studies while not being limited to solely robot design and prototyping. Working on multiple such user-studies has given me a unique perspective about common parallels between user studies and how variants of these can be expanded and improved to target the different stages of user studies as shown in Fig. 1.2. However, in this honors thesis, I will be emphasizing two innovative experimental methods by drawing on my experiences in 2 of these 5 projects (better described in latter sections).

The following section will detail background work done in HRI user studies, especially with regards to similar variants of user studies. The paper will then explore these two innovative experimental methods by investigating their applicability and contributions in two different experiments. The first experiment leverages the Actor Method while investigating the effects of privacy and data use in social settings. A study investigating social privacy and data use by a robot violating a human participant's privacy would never be approved by the IRB. Hence, this experiment used the Actor Method by asking a participant to take on an imagined scripted role. The robot would then violate this proxy imagined person's privacy while still enabling the participant's reactions and emotions about the robot's behavior. The application of this method, the pertinent results of the study and a discussion of this method will follow the background section. Following a similar format, the next experiment described in this paper leverages the VR Method to explore the effect of a robot's materiality, shape and path on a human-robot interaction. Using this method enabled quick and easy robot prototyping in this experiment and demonstrated some potential for future work in mixed reality with haptics like water, air and heat. This section will contain the applicability of the VR Method while interpreting and discussing the results of the experiment and the contributions of the method. The final sections consist of the conclusion and other possible use cases for these two innovative experimental user study methods.

2 Background and Related Work

This section gives a brief background of the development of user studies in HRI as well as some key guidelines for development of methods based on user studies. The section then dives into background for the Actor Method, related to method acting and the prevalence of such techniques in other fields of study. Lastly, this section provides some background about the current uses of virtual reality in our society as well as how virtual and physical features are mapped together (sometimes called simulated reality) to enhance experiences by utilizing a suspension of disbelief through the physical proxy. We use this ideology to later develop the VR Method for human-robot interaction user studies.

As robots become more and more present in our daily lives, we need to be able to understand the complexities behind interactions between humans and robots in a social context [3]. This necessitates the utilization of user studies to explore the interaction between humans and robots. As outlined by Belhassein, et. al, some recommendations when designing a user study in HRI include: being rigorous with study protocols; making sure an experiment is physically and psychologically safe; making theoretically solid and valid tools that can be publishable to enable user studies among others [2]. Breazeal, a pioneer of the field of social robotics, also makes design recommendations revolving around certain key concepts in HRI user studies: (1) introduce the subject to the experiment and the robot, (2) let the subject attempt any portions of the interaction which may require assistance and allow the subject to become familiarized with the robot, (3) start a video camera to record the interaction, (4) allow the subject to complete the interaction, (5) administer a questionnaire to the subject, (6) complete a recorded interview with the subject, and (7) debrief the subject on the aims of the experiment [3]. A key feature to mention, one of the accepted practices in HRI involves using both simulated and physical robots due to cost and reliability issues for physical robots [4]. The two innovative methods outlined in this paper use these fundamental studies and design recommendations as a backbone for the development and design of their core features.

Method acting is a technique used in theatre by actors to create realistic emotions for their performances by drawing on their own personal experiences. This technique can help actors immerse themselves into their characters and roles, imagining the world through their character's eyes. Interactive Digital Storytelling (IDS) is a field that usually enhances the effects of a story by allowing the recipient some autonomy in choosing the path followed by a story. Research based on method acting has shown that rather than requiring a participant to be in an improvisational scene, IDS can leverage an interactor as an actor in a scripted drama to achieve a certain transformative pleasure where the interactor becomes a character and experiences that character's emotions and desires instead of her own [5]. The specific instantiation of the Actor Method in this document points to a study that investigated social attitudes towards robot data use [6]. Previous methods exploring sensitive topics like people's privacy expectations of a robot are often at a distance from the privacy-violation (survey, video studies [7]); conservative (user study), or at a danger of putting the participant at risk (live deployment).

Before running any HRI user study, the actual robot that interacts with the participant often needs to be built. If not built from scratch, the robot at least must be prototyped to fit the needs of the experiment. Rapid robot prototyping has been a topic of research across years [8] [9], however switching out robot materiality from a human-perception perspective is fairly novel. Previous experimental methods and systems have imagined such experimentation with materiality in human-robot interaction research by using the web for mass participant recruitment [10]. Switching materials and shapes, however, can be as easy as the touch of a button when attempted in a virtual environment. Virtual Prototyping Environments are also being used for prototyping and have been shown to be a key contributor towards fulfilling business requirements embodied in a short time-to-market, in cost-effective and high-quality manufacturing, and in easy support and maintenance [11]. Virtual design has been also used for both customer-facing and engineering prototyping purposes. Customers can now design their own living rooms before ordering furniture [12] in both graphical and virtual tools. Leveraging physical interactions, researchers have made use of a participant's physical surroundings to augment their experience in a virtual space. For example, in substitutional reality, every physical object and architectural feature in a room is replaced and mapped in a virtual environment [13]. On a smaller scale this can be done with something like cup handles to explore the effect of such passive haptics [14]. Taken together, this virtual environment may offer benefits to the human-robot design process, blending creativity, physical awareness, and interaction principles. Previous studies have explored the use of such a virtual space for human-robot interaction via a participant manipulating a robot arm [15]. However, most previous research has focused on collaboration between a virtual robotic machine and the human participant, rather than utilizing VRs potential to manifest a whole separate virtual robot that interacts with the participant.

We hope to use and promote the following methods to delve into such relevant research areas.

3 The Two Innovations

This section forms the bulk of the innovations proposed in this document. First, we consider the **Actor Method** and its instantiation and usage in an experiment revolving around social privacy and data use in human-robot interaction [6]. The Methodology section discusses how this method was applied to the experiment to help understand humans' expectations of a robot barista and how it uses the possibly private data. This subsection discussed how an online study was used to narrow down research condition possibilities following which the Actor Method was used as inspiration for an in-person study setup. The Results section provides a brief summary of finds of the experiment.

Second, we discuss the **VR Method** through its instantiation for an experiment revolving around understanding the effect of materiality, path and shape on human-robot interactions that involve the robot colliding into a human participant [16]. The Methodology section first presents how the system in the VR method is designed, how this design correlates with the specific study setup (especially with the research manipulations) and finally the multiple input streams that the VR Method allows for participant data collection. The Results section then talks about the direct results of the experiment.

3.1 The Actor Method

To bypass the high stakes psychological risk of exposing private social information, the Actor Method involves the participant acting out the role of an imagined person. The imagined person has certain private data about their social interactions. However, a robot being able to access this information would not result in a violation of the actual participant's privacy since this is the privacy of a role that the participant is acting out, rather than the participant's own privacy. Multiple measures were undertaken to enable this variant of an experimental design. This section will develop the Actor Method and its methodology, through an example of using it in a research experiment. The section also compares results from two similar parts of the experiment, one part run online and another run in-person using the Actor Method. The results of this study highlight how the Actor Method could be used in studies investigating similar research areas containing sensitive information.

3.1.1 Methodology

A research question that a user study might try to investigate can often be controversial or sensitive. HRI, by its nature, encompasses a robot's involvement in the social issues that plague humanity. Multiple subject areas like criminal justice systems, discrimination faced at the hands of police offers, subconscious criminal profiling, equal opportunities for work for all different demographics, decisions in autonomous driving cars and other ethical conundrums though sensitive, need to be investigated. Technology has permeated into such issues with instances like Amazon's facial recognition containing bias for gender and race but still being used and sold for law enforcement [17] [18]. With the rampant amalgamation of robots and our own human lives, investigating and exploring such sensitive areas can often be a hurdle. First, a researcher must receive IRB approval for their user study. Exposing participants to such sensitive issues based on their own identities can be scarring to a participant and wouldn't usually be approved by an experimental board. Discussions about autonomous vehicle adoption often highlight the classic Trolley problem [19]. How should an AI decide whom or what to strike when a collision seems unavoidable? What decision would most people prefer the AI make? User studies could be conducted to answer such questions, but as researchers we could hardly force a participant to make such a decision in real life with consequences. Rather than using a real context, a user study implemented with the Actor Method provides participants the safety of pretending these complicated social behaviors. The Actor Method adds to the field of HRI by broadening the scope of user studies and allowing researchers to investigate complex socially sensitive questions.

As shown in Fig. 1.1, the Actor Method augments a typical user study by innovating the *Interaction* aspect of an HRI user study. This section will detail some of the core features of the Actor Method and how they enable collecting data in domains where data collection is prohibited. In the following subsections, we will also describe how this method was applied to a research study revolving around social privacy and data use in human-robot interaction [6].

3.1.1.1 Study Setup

The key component of the Actor Method lies in the participant being provided an imagined persona, like a proxy. The participant is asked to act, by reading a script, as though they are the imagined persona; hence enabling them to vicariously experience what the persona experiences. This study protocol is inspired by method acting, a technique or type of acting in which an actor aspires to encourage sincere and emotionally expressive performances by fully inhabiting the role of the character. Applying this technique, often used in theatre, to user studies allows a participant to experience a certain situation through this proxy while still being safe from either exposing their own identity or data or the dangers of a situation that the imagined persona/proxy might be undergoing. The effectiveness of this method hence probably lies in how immersed the participant can be in the imagined persona and the imagined persona's scenario. We will now detail an experiment that we ran using the Actor Method's study protocol.

The goal of this experiment was to explore the impact of a robot barista's comment to two coffee shop customers after the two customers have had a brief conversation. To perform the role of the robot barista, we selected a NAO robot as it had an anthropomorphic face to relate to customers, and arms that could be used to make the coffee. Humanoid robots are commonly used in customer service roles, from giving directions in a mall to checking someone in at a hotel. The NAO acts as a proxy for such robots, not to be confused with the proxy needed for the Actor Method. This imagined persona, on the other hand, was built into the Study Protocol by asking the participant to act out a script.

To explore the effect of the robot's comment there were 4 different variable types as shown in Table 1. The Robot Comment variables included the comment's *valence*, the comment's *data type*, and the comment's *addressee*. There were 24 robot comments overall. Valence is whether the robot said something that was positive, neutral, or negative. Data type corresponds to the way the robot would have inferred information it used conversationally, e.g., overhearing the meeting was about a job. Addressee was a category we added after the data came in, as participants scored the robot differently depending on which customer the robot addressed.

The robot made these comments during different *Meeting Types*, e.g., between potential romantic partners, potential roommates, or job colleagues, and for different *Meeting Valences*, i.e., the meeting might be going well or going badly. The full set of experimental variables are summarized in Table 1.

Comment Valence	**Robot's Data Use**
Positive Comment	Body Language Analysis
Negative Comment	Conversation Analysis
Neutral Comment	Database Search
	Control
Robot's Addressee	**Base Script Variants**
To One Person	Meeting Type
To One About the Other	Meeting Valence
To Both	

Table 1: A Summary of the Experiment Variables

One positive/negative valence comment pair was *"You guys look happy!"* versus *"You guys look upset!"*, which was also in the data type category called Body Language Analysis. Other data type categories included comments like, *"She has a clean criminal record, I think you should go for it!"* (Database Search), or *"Did you bring a stamp card?"* (Control). The Control comments are the ones expected in any normal cafe conversation and were intended to act as control conditions. Conversation Analysis most often related to the Meeting Type: Job Interview, Roommate search, or Romance (first date); for example, the robot might comment, *"I am also in need of a place to stay."* for the *roommate* Meeting Type.

Here is an example script in which the robot comment has *valence* = "Neutral", *data use* = "Database Search", and *addressee* = "To One About Other":

Person 1: "Are you the person looking for a room on Craigslist?"
Person 2: "Yes, I am!"
Person 1: {to the robot} "Two coffees, please."
Person 1: {to Person 2} "Just so you know, I think we're going to be perfect roommates."
Robot: "Scanning face. This is your fifth visit this week!"

In the above example, "Scanning face. This is your fifth visit this week." was the robot comment, "Are you the person looking for a room?" indicated the script is in the *roommate* Meeting Type condition, and "I think your application looked really great" signified a *positive* Meeting Valence.

Inspired also by [20], we use ranges of terms such as polite, considerate, appropriate and data-violating/data-respecting to explore conceptualizations of privacy. Nissenbaum [21] defines context as a structured social setting characterized by roles, relationships, power structures, norms and internal values that are central to the acontextual integrity which she proposes to be the benchmark for privacy. The use of these words was intended to capture participant attitudes toward robot data use within these norms.

Utilizing these terms, we hoped to capture nuanced aspects of social violation and consideration. For example, "Politeness" may reveal whether the robot follows societal rules. "Considerate" may indicate whether the robot appears to be respecting someone's individual needs. "Appropriate" is an adjective used in many previous social robotics studies. And finally, privacy-respecting is used to validate the overall coherence of these results.

The statistical results relate script variables to participant ratings of the robot. For example, would participants rate the robot response differently if the clients were on a date versus looking for a job? Or if the robot comment used a database search versus reading the customer's body language?

3.1.1.2 Online Study and its Relevance to the Actor Method

Before conducting an in-person study using the Actor method, we used an online survey to narrow down the set of possible variable combinations. This was done so that the Actor Method could be used to home in on significant predictor relationships. The online survey was administered on Amazon Mechanical Turk (mturk.com), a website where one can hire human workers to complete tasks online. The survey page included a video of an interaction between two human customers and the robot barista, followed by a question about the video (Fig. 2). Participants were required to have an approval rating above 97% from previously performed tasks on Mturk and were required to be located in the United States, to increase response quality and cultural consistency.

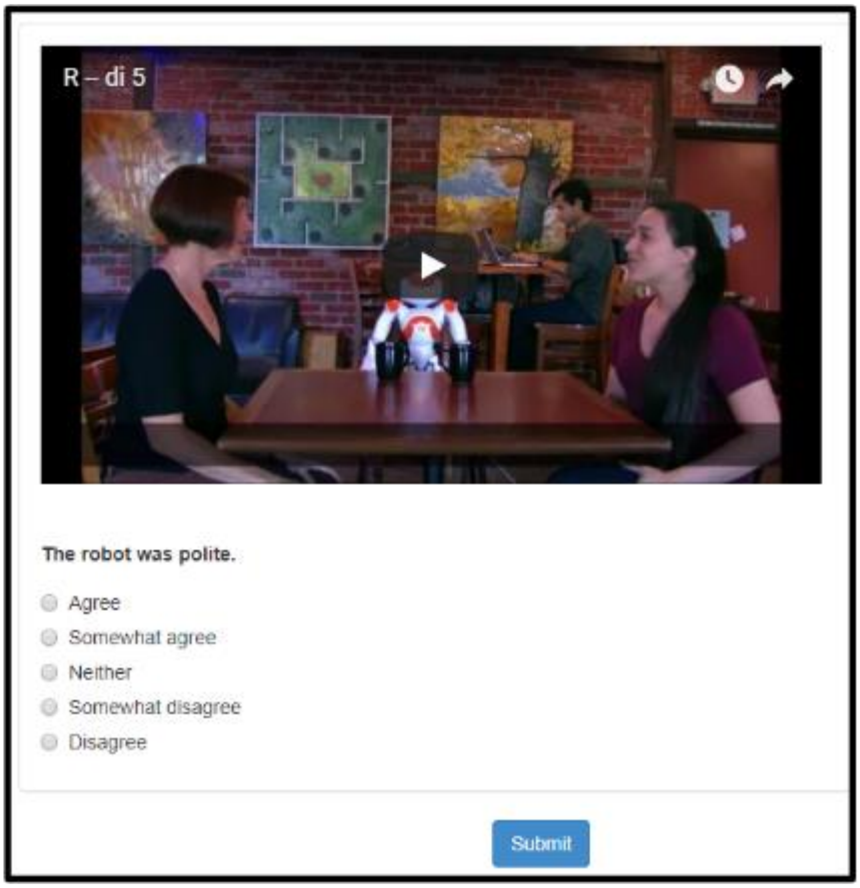

Fig. 2: A screenshot of what the online survey would look like to participants.

The dataset consisted of survey responses to 288 videos, which comprised the full set of experimental variable combinations from the previous subsection. For each video, responses were collected for the following 5-point Likert scale prompts:

- The robot is {impolite, polite}
- The robot is {inappropriate, appropriate}
- The robot is {inconsiderate, considerate}
- The robot {respected, violated} customer privacy.

Even though this part of the study did not involve the participant assuming the role of one of the robot barista's customers, the online survey enabled pruning the set of possible variable combinations. This allowed the Actor Method (in the next subsection) to further explore relationships that were found to be significant among the independent and dependent variables from this online study.

3.1.1.3 In-Person Study and its Application to the Actor Method

The in-person study followed up on the Online Study, this time in a within-participant study (Table 2). This part of the study used identical meeting scripts as the online study. This time, the participant was an actor in the scene, specifically *Person 2* (Fig. 3). Embodying the Actor Method, the participant would read from a provided script, to enact the scene with a professional actor and the robot. This method allowed participants to experience a robot violating their character's privacy without being at risk themselves. The Actor Method allowed us to explore a wider variety of ethical themes than wouldn't otherwise have been possible; and may also be applicable to other areas of HRI in studies related to high psychological risk.

Meeting Type	Data Type	Addressee
Romance	Data-Romance	Whom-Romance
Interview	Data-Job	Whom-Job

Table 2: The variations in Meeting Type, Data Type and Addressee chosen for the In-Person Study.

For the in-person study we used a smaller population of 20 participants. All our participants were either students or lived in the vicinity of the university.

Fig. 3: A picture of the in-person study's room and participant setup.

The participant was first guided through a neutral practice script with the actor in which the robot did not comment. After this the participant went through the following loop for 6 trials in total.

- The participant receives a script and is told to sit at the table (Fig. 3).

- The participant performs the scene with a human actor and a NAO robot.
- As soon as the robot delivers its comment, the participant moves to a desk where they fill out a 6-question survey.

After the 6 trials, the experimenter would sit with the participant and ask them further open-ended questions about their general experience during the study. The aforementioned survey consisted of three 5-point anchored Likert scales (similar to the online study), and three open-ended questions (unique to the in-person study):

- The robot is {impolite, polite}
- The robot is {inappropriate, appropriate}
- The robot is {inconsiderate, considerate}

The open-ended questions were used to further explore themes discovered in the online study. Additionally, the responses to these questions could also be used to delve into the reasons behind some of the quantitative results. The Actor Method hence enabled this further investigation into the reasons behind the results of the online study. Since the participants took on the role/character that was assigned to them, they were able to introspect and posit reasons for their internal thoughts and emotions. The experimenter was able to ask questions about any interesting events that might have occurred over the course of the 6 trials. The additional open-ended questions specific to this experiment were:

- What do you think about the robot's data use?
- What do you think about whom and how the robot addressed?
- Any reactions or observations about the scene?
- What did you think of the robot barista?
- What did you think of the other person?
- Did you have any emotional reaction to what the robot said?
- Would a real barista in a real coffee shop do/say things like what the robot barista did/said?

Adding on an interview section to an implementation of the Actor Method allows further exploration into what a participant might have felt or experienced. Specific to this experiment, during each trial, the robot made ambient barista-inspired motions and gestures, such as cleaning, checking the phone, and handling the coffee machine when the order was placed. The robot also used its arms to emphasize whom the robot was addressing. The robot also used head nods to reinforce its sentences. The researchers believe that incorporating any small details that can add to the immersiveness of the experience (for the participant) can help with the efficacy of the Actor Method.

3.1.2 Comparing the online study and the Actor Method’s Results

Though not central to this thesis, the results obtained in the online study and the results obtained in the in-person study while using the Actor Method are juxtaposed in this section. Comparing these results demonstrates the parallelism of the two different approaches for data collection, thereby speaking to the efficacy of the Actor method.

The design of the online study (4x3x24) used 288 videos to create all possible conditions and was run with 4608 participants. Such an immense sample size was possible due to us using Amazon Mechanical Turk to recruit participants. The online study found that Comment Valence (that is, whether the robot made a positive comment or a negative comment) to be a significant predictor of the robot's politeness, considerateness and appropriateness. All significant differences were found using Multi-ANOVA analyses as well as the non-parametric Kruskal Wallis Test. For polite, $F(2, 1149) = 42.12$, **$p < .001$****; for considerate, $F(2, 1149) = 39.16$, **$p < .001$****, and for appropriate, $F(2, 1149) = 16.70$, **$p < .001$****. Similarly, the in-person study that used the Actor Method found Comment Valence to be a significant predictor of the robot's comment being considered polite, considerate and appropriate. The statistical results for these effects were: for polite $F(2, 110) = 12.87$, **$p < .001$****, considerate $F(2, 110) = 10.82$, **$p < .001$**** and for appropriate $F(2, 110) = 7.38$, **$p < .001$****. Both these studies showed that negative robot comments like "*You guys are not cute*" and "*She is my least favorite*" were rated negatively by the participants.

In a similar fashion, both the online study and the Actor method study found the Data Type, that is, the source of the robot's comment to be a statistically significant predictor of the robot being considered polite by the participant. For the online study, $F(3, 1148) = 8.64$, **$p < .001$**** and for the Actor method study, $F(2, 55) = 6.70$, **$p = .003$****. In both types of studies, Database Search and Conversation Analysis were considered impolite for the robot to perform while Body Analysis was the most innocuous channel for data collection. Both the studies also found Comment Addressee to be significant predictors for how polite the robot was considered. For the online study, $F(2, 1149) = 9.07$, **$p < .001$**** and for the Actor method study, $F(3, 109) = 2.73$, **$p = .020$***. Participants considered the robot addressing them to be more polite than the robot addressing both the participant and the actor (thereby, talking about the character that the participant was playing to the actor). The similar results obtained in both the studies point towards the usability of the Actor Method in investigating matters related to social privacy and data use without violating this privacy in the course of the research study.

3.2 The VR Method

To enable faster robot prototyping and reduce physical robot build time, the VR Method involves the user study participant being immersed and running through the study in virtual reality. Often, robot designers need to be able to explore many different materials, textures and colors. Robot interaction designers and the HRI community often need a higher level of testability due to the need for investigating the effect of different robot visuals, like material, path and shape on interactions with humans. For example, robot approach styles are often evaluated for purposes such as recruitment, carrying out tasks and other ways of initiating interactions [22] [23]. Investigating such robots and robot interactions can be limited by resources in laboratories and the time taken for such endeavors [7]. This section will discuss how the VR Method can be used to enable rapid and inexpensive prototyping of the *Robot* (Fig. 1.1). First this section will develop the VR Method and its methodology by presenting how the VR system is set up to enable multiple permutations of robot designs. This will include measures taken to increase the immersiveness of the participant's experience. Next, we present a research experiment conducted using the VR Method as well as the contributions of this method in enabling multiple variants of 3 different research conditions (Fig. 1.2) namely, material, shape and path.

3.2.1 Methodology

As described above, a user study can often have an immense number of research conditions. Designing robots for HRI user studies need to be able to prototype robot designs to investigate the effect of such conditions on interaction parameters. Multiple subject areas like the effect of robot texture [24], user trust across different robots [25], the effect of a robots' physical features (e.g. faces or lights) [26] [27] require the use of multiple robots and robot bodies. However, due to cost and time this can often be a hurdle and research laboratories sometimes need to compromise by either using fewer variant types than they would like or by conducting mass online surveys that might miss out on data that can be gained from an in-person interaction. Rather than having to limit user studies, the VR Method adds tools to allow manipulating a robot in HRI user studies in an inexpensive and fast manner. An immersive technology, virtual reality allows such prototyping without taking away from the visuals that a person would experience in real life. Additionally, we propose a VR Method which allows physical interactions with a robot (hence enabling research area investigations around tactile features like textures and collisions) by having the virtual robot track a physical robot. The virtual robot can alternate between visual variants and the physical robot can be used for any tactile interactions with the user study participant.

As shown in Fig. 1.1, the VR Method augments a typical user study by innovating the *Robot* aspect of an HRI user study. This section will detail some of the core features of the VR Method and how they enable enacting multiple research conditions (Fig 1.2). This includes how the VR System is designed and set up to enable the study. We will then delve into how this system contributed to exploring the effect of robot material, path and shape on a participant's perception of a participant-robot collision [16].

3.2.1.1 System Design

In the VR Method, the system is set up in multiple parts that all interact together to give the participant the experience of interacting with multiple robots that have different appearances. This is achieved by having (1) a virtual representation of the robot that can have various apparent shape and material conditions, (2) mechanical toppers of shapes that mirror the VR shape conditions, and (3) physical robots controllable with a remote control.

The virtual representation of the robot tracks to the real robot as it changes position and rotation. If the real robot changes rotation in any axis the virtual robot will match this, allowing the person to touch the real robot tracked to the virtual robot. This virtual robot is inside of the VR system and therefore is tracked in the virtual reality system. This tracking is done by using the VR controller positioned on top of the real robot in a holder as shown in Fig. 4.

Fig. 4: This project utilized a freely available Solidworks model [28] *that we 3D printed to hold the HTC Vive Controller. We printed two holders, one integrated into the cube topper, and another integrated into the cylinder topper.*

The tracking system first went through a calibration step to calibrate the system to a specific user. This was done by marking 4 points equidistant from each other on the object with the controller's trigger. The tracking system was coded to save these 4 points. The controller was then placed in the holder shown in Fig. 4 which was 3D printed from an online open source resource [29]. Once the controller was successfully mounted on the topper in real life, the controller's button could be pressed to allow the tracking system to use the 4 points to find the offset for the position and rotation for the object. This process can be seen in Fig. 5. This tracking offset can be used for the cube and cylinder and does not need to be calculated during the transitions in the study as the math from the previous calibration can be used [30].

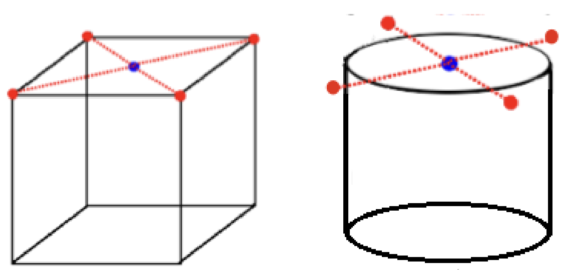

Fig. 5: Topper Shapes and Calibration: After installing a hand controller at the top of the physical robot (blue dot), a second controller was used to click four points (red dots) around the periphery of the physical object. This calibrated the virtual robot to the size and location of the real robot.

The only flaw with this tracking system is that because of slight errors in the VR tracking, the object does not always become aligned correctly with the physical object. This can mean that the object is slightly off in the real world compared to the virtual one. This is often fine for virtual reality as your brain cannot actually tell slight differences, but to ensure that the object was properly tracked in this project there were also buttons that the operator running the laptop could use to make slight adjustments to the position, rotation, and size of the object. This was done during the calibration process of the procedure.

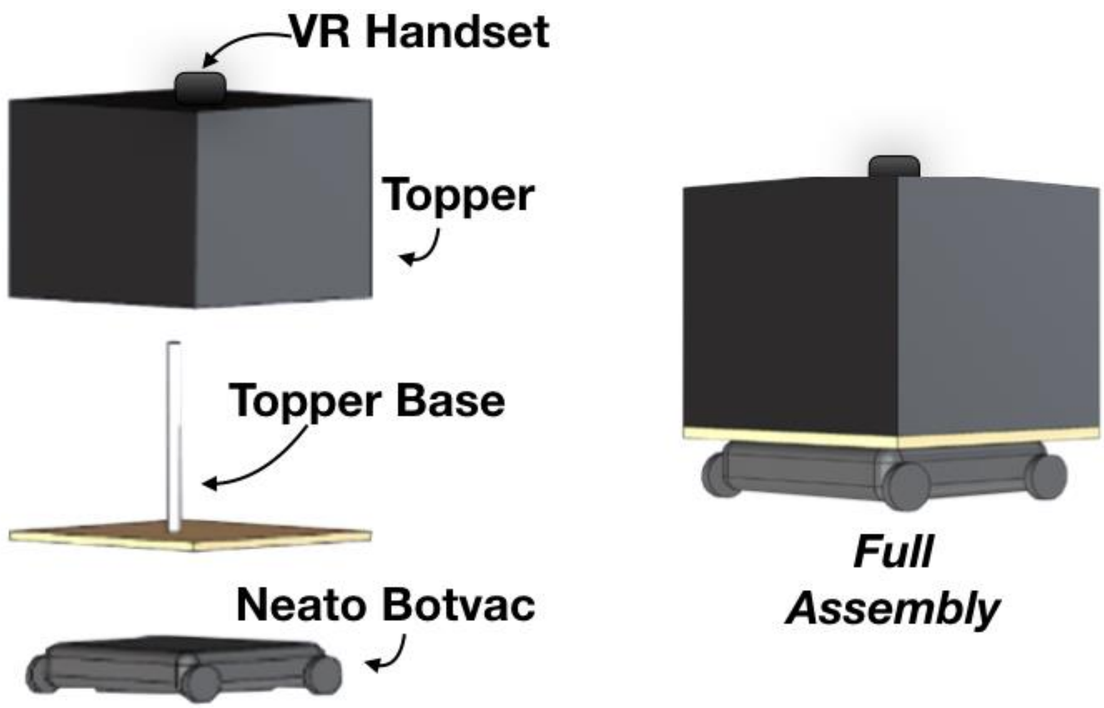

Fig. 6: Breakout view of the VR Prototyping System Components: Robot Motion Via Neato Botvac. The Topper Base allows for easy switching out of Robot Topper Shapes (cube displayed here), and an HTC VIVE Controller is mounted at top center for best tracking from all angles.

The physical robot used in this experiment was a Neato. To enable prototyping, an object is attached on top of the robot so that it can take the shape of a cube or a robot, rather than the Neato. This can be seen in Fig. 6. Having a topper allows the user to actually touch the object mapped to the VR. The topper for this robot is attached using 4 bolts that are connected through the chassis. This topper is a square piece of plywood that sits slightly larger than the robot itself. This prevents the participant from accidentally hitting the robot and only interacting with the topper. This piece of wood then has a hollow cube, made of cardboard, connected to the top of it to give the shape of the topper without adding unnecessary weight. Inside of this cardboard cube, sits a pipe that goes up to the top of the cube and has a 3D printed holder for the controller (Fig. 4). This allows the controller to be held securely allowing for accurate tracking.

A Raspberry Pi was connected to the Neato to act as a relay to be able to drive the robot. This works by taking commands wirelessly from a laptop and relaying them to the Neato. Since the Raspberry Pi needs power, a portable battery is included in this compartment. The connected laptop can send commands to the Raspberry Pi to relay to the Neato. Connecting a PlayStation controller to the laptop and running a ROS program to interpret and send messages based on button presses allows for remote control using a PlayStation controller connected to the laptop using Bluetooth.

To ensure consistency in the motions and to reduce any chances of human errors when moving the robots while controlling remotely, ROS Bags were used to record the key motions and paths that the robot would take during the experiment. These motions were then mapped to specific buttons on the PlayStation. The ROS Bag contained information about the coordinates for the path. A hard-coded speed was used to keep the motion consistent among participants. In testing, we observed that the speed and motion were affected by the decrease in the battery level of the robot. As the battery level decreased, the speed reduced. To counter this, we ran studies in batches of 2 and charged the battery whenever the robot wasn't moving during and between studies. The ROS Bag recorded motions were used as often as possible, but the robot sometimes needed to be manually controlled for consistent trials.

3.2.1.2 Study Setup

The study was conducted in an experiment room on a university campus over multiple days. There was one study conductor and one technology wrangler to help with the study. The study conductor guided the participant through the trials and asked the survey questions for data collection in addition to controlling the robot's motion. The technology wrangler controlled the virtual reality as seen by the participant in addition to recording the participant's comments and answers to the study questions. One external camera was used to record the interaction between the robot and the participant. The HTC Vive recorded the participant’s experience in VR and its internal microphone was used to record the participant’s comments while in the study.

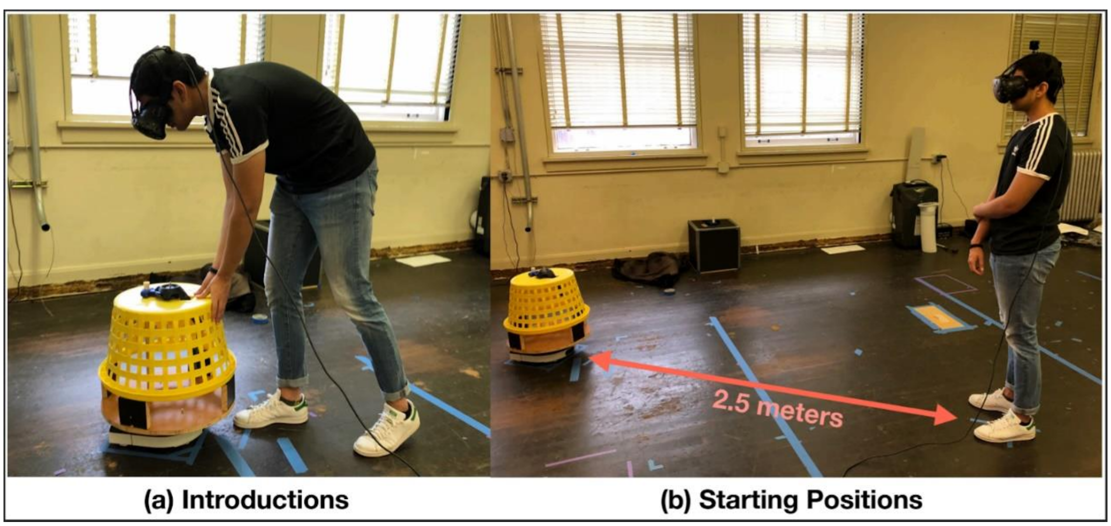

Fig. 7: Images of experiment room and cylindrical topper. (a) Toppers were stored under a sheet when participants entered the room. Once in the headset, however, participants were encouraged to touch the robot to confirm that the calibration was correct, and to orient them to the mixed reality. (b) Next, the participant and the robot would go to their starting positions.

The study was conducted with 16 participants and each interaction lasted about 45 minutes. After a quick introduction to VR, the participant was asked to don the VR headset. First, the participant oriented themselves to the virtual environment, an abstract room structure that is empty except for the robot (Fig. 7). Next, the participant was introduced to the robot. They are asked to touch the robot (in the physical world) and comment whether the appearance of the robot in VR maps to what they feel in the physical world. This step was also used to calibrate the robot (as described in the System Design section above). Next, they were guided to stand on the X in the center of the room and the robot was driven to its starting position by the study conductor (Fig. 8). Since the participant is in VR, they cannot see the study conductor and the technology wrangler controlling the robot and the VR. The essence of this method lies in the participant being immersed in the VR to mimic their reactions and emotions in the real physical world for the same conditions.

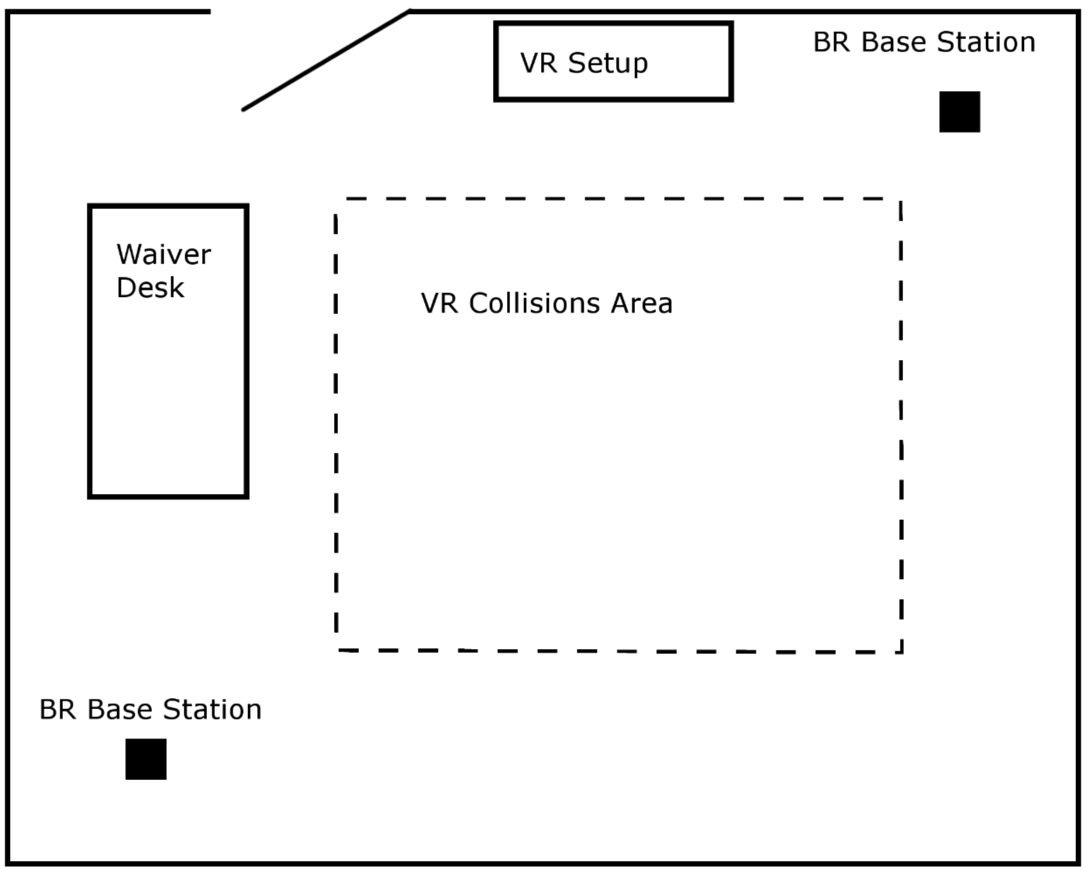

Fig. 8: The Study Room Layout included the Vive Base Stations for tracking, and the desks for the study conductor and technology wrangler. The participant stood on the X on the floor (mapped in VR), while the robot began each trial in the taped out square.

Each trial began with the participant facing the robot. Fig. 9 shows what the room and the robot looked like to the participant in one specific trial. The robot (i.e. the cube in Fig. 9 in this specific trial) then approached the participant in a direct or indirect path and collided with the participant. After the collision, the robot would retreat a couple inches and stop. The participant was asked survey and follow-up questions trying to confirm their provided first impression. The robot would then move back to its starting position, the participant would turn away from the robot toward the study conductor at the front desk, and that would conclude the trial.

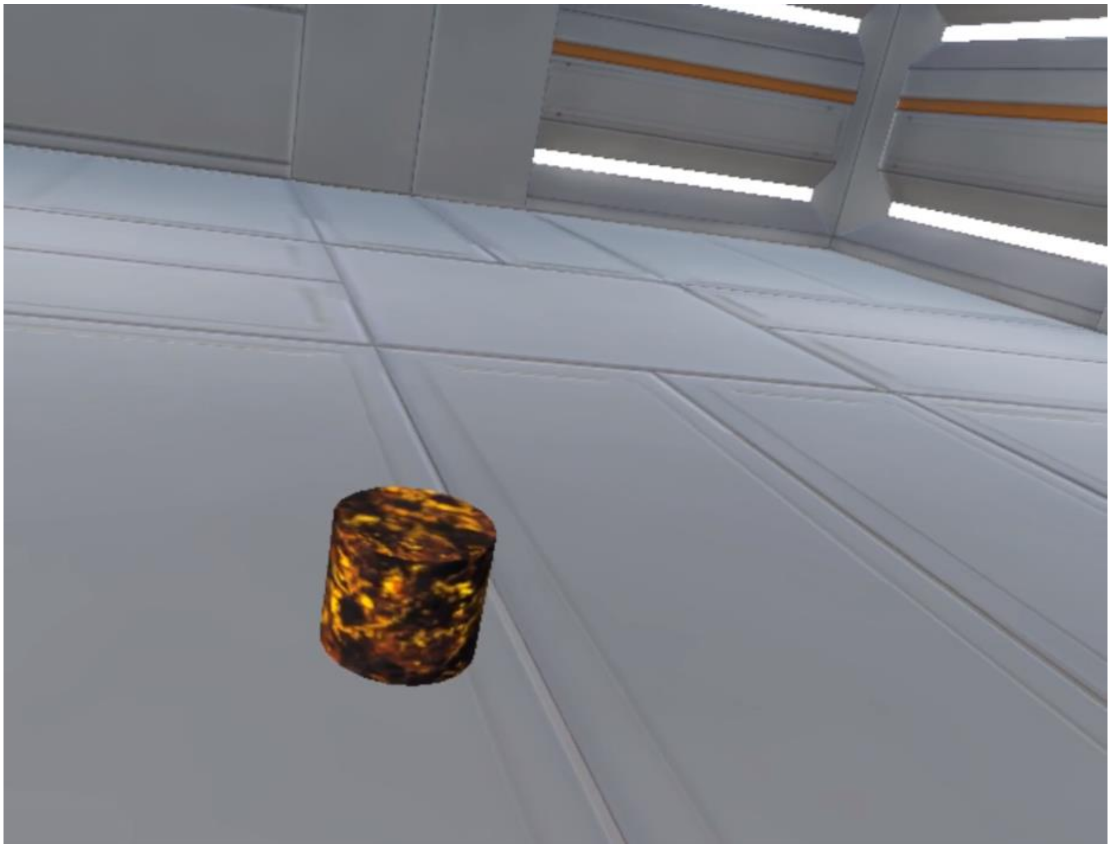

Fig. 9: Participant's View in VR: This is a still from a participant's video recording. The robot texture depicted in this picture is Lava.

Six such trials were conducted with one robot shape (cube or cylinder), while varying the texture and the path of approach. There was a short break before the next six trials in which the participant stayed in VR, but the physical topper of the robot was switched to another shape and re-calibrated. This is followed by 6 more trials with varying textures and path of approach. Between the trials, the facing of the participant toward the desk allowed us to avoid sudden changes of material or shape as seen by the participant. After the completion of all the 12 trials, the participants were asked several open-ended questions based on their previous responses and that concluded a participant's experience in the study.

3.2.1.3 Manipulations in VR and their reflections in the physical world

The research manipulations involved in analyzing this experimental approach to human robot interaction in VR spanned apparent material (VR only), topper shape (VR + physical matched), and robot approach path (VR + physical matched).

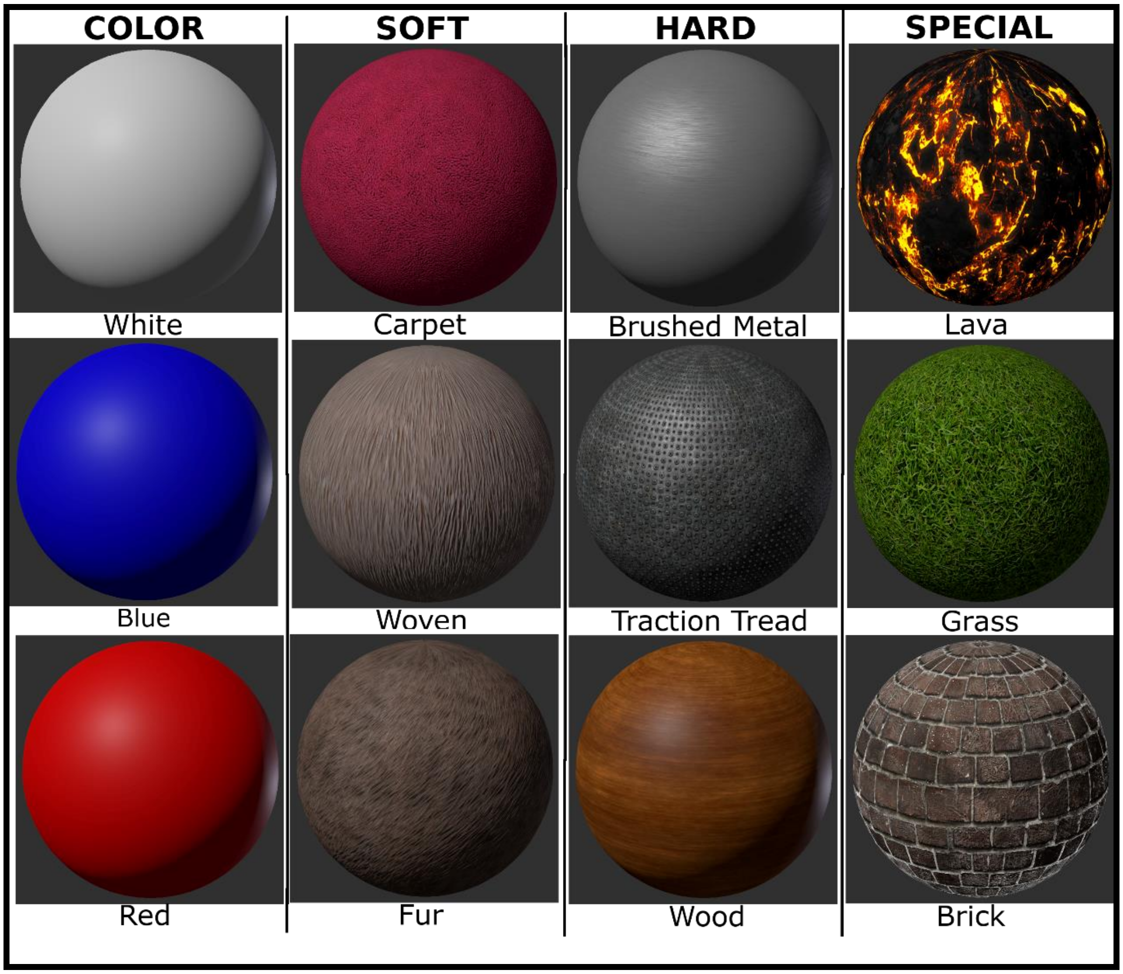

Fig. 10: The 12 VR Materials: three colors, three materials associated with soft, three materials associated with hard, and three odd materials, uniquely available to VR.

Material: The apparent material of the robot was an integral manipulation, as it emphasized how easily a robot's physical appearance can be changed in VR. We included 12 different materials depicted in Fig. 10. These materials were intended to explore soft and hard materials, but also included flat colors as a baseline, and special VR materials as an exploration of the VR-material space.

Shape: The robot as seen by the participant in VR was counterbalanced between two shapes, namely *cylinder* and *cube* as seen in Fig. 5. The shape of the physical robot was also changed to the same shape as the one in VR so that the participant could see and feel the same structure of the robot. These shapes were chosen due to quick build time in order to validate the VR method. The research team also believed these shapes to be easier to associate to different real time objects that the participants may encounter daily. This reflects the method's central theme of maintaining similarity between the virtual and physical world that a participant experiences in the study.

Approach Path: The robot approaching the participant took two different paths that were counterbalanced across the trials. These two paths result in two types of collisions. The first path is *direct*, where the robot approaches the participant in a straight line and results in a direct collection with the participant along the path of approach. The second path is *indirect*, where the robot approaches the participant in an arc and collides indirectly into the side of the participant (Fig. 11).

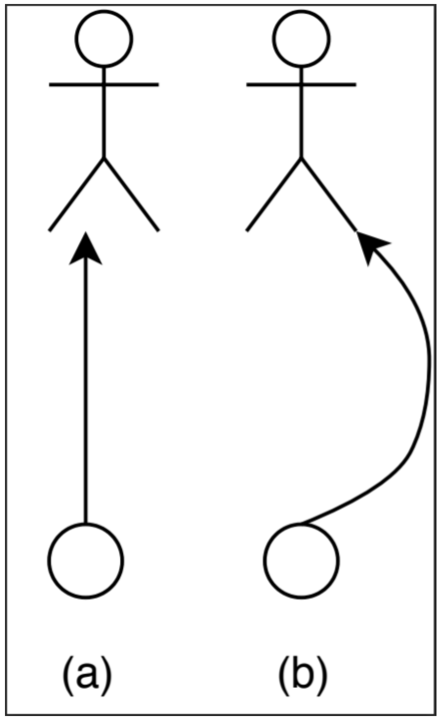

Fig. 11: Robot Approach Paths: (a) Direct proceeded in a straight line and forward collision with the feed, while (b)Indirect curved sideways and generally impacted the side of the participant's leg or foot.

3.2.1.4 Data Collection enabled by VR

This implementation of the VR Method leverages the SteamVR system. SteamVR provides a lot of tools that can help record the experience and log data while running the trial. For instance, SteamVR when paired with a screen recorder like OBS Studio can record the virtual environment as it is being experienced by the participant. Additionally, the internal microphone in the VR headset can be used to record the participant's comments during the study. This was especially important due to the Think Aloud (explained further in the following paragraphs) protocol that the participant was instructed to follow to enable qualitative data collection. Pairing the participant's VR feed with a video from a GoPro showing the participants motions in the actual physical world can also help elucidate and log interaction effects from the VR and collisions in the actual world.

As described in the Study Setup section, the participant experienced VR for 12 trials each having an interaction with some combination of variables. After each trial, the participant was asked a set of questions which they answered based on a 5-point Likert scale. Recording all this information is slightly difficult in VR since the participant taking off the headset to fill out a survey after each interaction would break the flow of the experiment.

Taking off the VR headset would also break the illusion of there being multiple robots approaching the participant since they would be able to see the physical robot. Hence, as a part of the VR method, the participants were asked to answer these questions verbally. For example, if the participant were asked, "*The robot was friendly*", they would answer either {*strongly agree, agree, neutral, disagree or strongly disagree*}. To enforce this question answer format, the participant was walked through with a couple examples at the start of the study. For example, "*The grass is green*" or "*The sky is blue*".

Additionally, we also wanted to collect general data about what the participant was experiencing and feeling to learn more about how they would describe the virtual robot's material, shape and the robot's path while they were in VR. To collect this kind of data using the VR method, participants were encouraged to follow the Think Aloud protocol. This meant asking participants to speak out about any experience or emotions they might be feeling, any thoughts that might be entering their head or any objects or memories that certain VR materials, shapes, paths or a mix of all 3 might be eliciting. This helped us collect qualitative data about the experiment as well as the VR system as an effective method for prototyping robots.

3.2.2 Interplay of VR and the physical world in HRI results

A Kruskal-Wallis H test showed that while robot material was a significant predictor of robot aggression ratings (χ= 24.819, **p = 0.01****), it did not statistically significantly predict robot friendliness (χ= 17.159, p = 0.103). Numerically, the friendliest robot materials included wood, metal (`gray'), fur and white. Considering participants interpreting the metal material as a grey that matched the VR room environment (Fig. 9) in Table 3, perhaps this robot seemed friendly to the participants since it fit into the virtual environment. Coordinating robots to their environmental context is a possible avenue for further exploration that can be explored using the VR method. The metal texture was also rated as one of the least aggressive, just a little more aggressive than the white material and the wood material.

Additionally, the VR method revealed some more fascinating qualitative results aside from the quantitative results of the experiment. If wood is considered a nonaggressive and friendly material, perhaps more roboticists should consider integrating it into real world robot designs. The organic texture was highly recognizable in VR, beating out even the best categorized soft material (carpet) which was rated only neutrally friendly and moderately nonaggressive. The next section also describes the mental models that participants developed about the various robots, one of which was furniture. The realm of robotic furniture could be further enriched with furniture robots that actually look like they are made out of wood, rather than metal or some other material. Consequently, this same VR system could be used to prototype such robots in specific environments. The white-colored robot also bodes well for many of the companion robot designs currently popular, as its mean was the least aggressive of all the different materials.

Alluding to the comments made in the Material Legibility section about the metal ('gray') material, numerically, participants seem to have found a material that matched the environment to be safer and less scary.

The brick material as shown in Fig. 10 numerically ranked the lowest in the participants' feeling safe. Participants' prior experiences with brick walls as an obstacle or something that can hurt them could have influenced this low score for safety. The brick material also stands out sorely in the environment, which has been rendered to be plain and metal-like. Since brick is considered to be such a scary and non-safe material, roboticists probably shouldn't use brick textures or materials to build robots. The VR Method as an HRI design tool enables ascertaining such preferences that exist among people about robot material, shape and path.

4 Discussion

The previous sections described the two innovative methods: the Actor Method and the VR Method, and how they were applied to two different HRI user studies. This section will discuss the idea of *suspension of disbelief* [31] in social robotics and how we found it to relate to both the innovative methods developed in this document.

The believability of robots is important for evoking social responses from participants. This believability can also lead to more natural human-robot interactions and is often associated with improved task performance [32]. Some key features for making believable robots having a backstory and dynamic storyline, using nonverbal expressions of emotions, and incorporating social cues and sociocultural context into the robot's behaviors. All these features can help develop a *suspension of disbelief*. This concept, often considered to be an essential component of theatre, refers to an intentional avoidance of critical thinking or logic in examining or immersing oneself in something that is surreal or imagined. Most humans have grown up playing pretend, be it pretending to practice an occupation to learn (playing Doctor to learn about the human body) or be it pretending to be a character in a fictional storybook while learning about human emotional constructs like bravery, camaraderie and adventure. With a film, for instance, the viewer has to ignore the reality that they are viewing a staged performance and temporarily accept it as their reality in order to be entertained. Similarly, user studies are all about what the human participant is experiencing. The vivid imaginations we possess as humans can be leveraged to simulate research conditions and robot interactions in HRI user studies.

We stereotypically consider machines and robots to be unimaginative and built for a purpose. As we observe living entities, we also feel the need to create the illusion of life in inanimate objects [31]. The illusion of living machines implies the users' willingness to perceive robots as living. To facilitate human-robot interaction and augment social interaction, robot designers often explicitly try to suspend a human participant's disbelief in a machine's inanimacy [31]. This can commonly be seen in the anthropomorphic design of robots like the NAO, with human-like faces and limbs. Such robots are also noticed to be more believable [32]. The two methods: Actor Method and VR Method similarly develop different kinds of proxies to enable the *suspension of disbelief*. The Actor Method creates such a proxy of the human participant themselves, by asking them to play the scripted role of an imaginary persona and the VR Method creates a virtual robot as a proxy of a physical robot while enabling the participant's immersion through virtual reality. Considering that user studies are all about what a user might be experiencing, researchers can use these two innovative proxies, while leveraging people's imagination, to simulate human-robot interactions.

4.1 The Actor Method

This section talks about the contributions of the Actor Method and the specific things that the researchers noticed while using the Actor Method in its instantiation experiment. Specifically, we talk about how the Actor Method helped suspend disbelief by immersing the user study participants in the experience.

4.1.1 Suspending Disbelief

In previous HRI research, the concept of suspending disbelief has been used to make the robot seem as anthropomorphic as possible [31]. The Actor Method instead focused on the *Interaction* aspect of a user study by enabling the human participant's experience in a study through an imagined persona. Such immersion is also noticeable in method acting, allowing actors to execute their roles well by "living the character" that they are playing. In this method the *Story* was used to enable the participant's immersion into the scenario of the experiment. The Actor Method puts the participant into a certain role, which develops as they learn more about the character through the script that they read from. Hence, despite being removed from the situation (to provide psychological and informational safety) the participant can still be invested in the story of the experiment by imagining themselves as the cultivated persona. As previously discussed, this leverages humans' vivid imaginations allowing user studies to explore many research variables and conditions especially in new research topic areas that require simulated violations. The Actor Method might be particularly helpful when designing new social functionality into machines, and in research areas where user sensitivities aren't known. Next, we discuss the instantiation of the Actor Method revolving around social privacy and data use in human-robot interaction.

Fig. 12: Participants experienced and expressed emotions in the in-person study. Snapshots (a) and (b) demonstrate reactions to a negative robot comment, while (c) and (d) are to a positive robot comment.

In the study, we found that exposing the participants via the Actor Method allows them to reflect on the study conditions and helps them introspect and determine their emotions since they have taken on the character detailed in the script. Taking on the role of the character whose privacy was being violated as per the script helped participants feel vicariously through the characters (Fig. 12). For example, one participant said, “I felt weird having one person telling me that I am fit for the job and the robot telling me that I suck, not cool”. In another instance, another participant commented, “Totally inappropriate, the way the robot expressed really made me feel inferior and not good at all”. These comments show the Actor Method’s efficacy in helping participants feel for a character they might be playing, hence allowing the character to act as a suitable substitute in high-stakes situations. The Actor Method also added the advantage of the researcher being able to ask the participant follow-up questions about their emotions and reactions, giving the researchers access to the comments mentioned above.

4.2 The VR Method

This section talks about the contributions of the VR Method and the specific things that the researchers noticed while using the VR Method in its instantiation experiment. Specifically, we talk about 3 key things: (1) how the VR Method helped suspend disbelief by immersing the user study participants in the experience; (2) how this immersion inspired the participants to reflect and build mental models about the different robots; and (3) some of the limitations in our VR implementation that could be improved in future studies that use the VR Method.

4.2.1 Suspending Disbelief

Instead of targeting the *Interaction* aspect of an HRI user study like the Actor Method, the VR Method focused on the *Robot* aspect of a user study by enabling the human participant's experience in a virtual environment. In this method *Visuals* were used to enable the participant's immersion into the scenario of the experiment. The immersive effects of VR are well documented and experienced, by gamers and VR enthusiasts alike. As an example, due to its immersiveness, virtual reality has been used to treat acrophobia (the fear of heights) [33] and engender empathy for immigrants through film [34]. The *Visuals* of the VR Method influenced the immersion of the participant in the experiment. There was, however, another key factor, interactivity, that was enhanced by the VR Method. Immersion and interactivity are considered as the two main components of VR that impact the experience in virtual reality [35]. The VR Method can be used to increase the interactivity in a user study, an important factor in HRI user studies, by tracking the virtual manifested robot with a physical robot.

Next, we discuss an instantiation of the VR Method along with some specific contributions of the method. The following sections will explore how using the VR Method resulted in participant's building mental models of the virtual robot and its behavior, hence speaking to the immersiveness of the method. Previous research studies have shown that a similar setup, the Snake Charmer (an extension of robotic graphics that uses virtual reality to physically enable virtual objects) has shown promise and allowed users to easily abstract and pretend that virtual objects are real, i.e. can be seen and touched [36]. Similarly, the VR Method offers a suspension of disbelief to the user study participants, letting them believe that the various robots are physically present by them.

4.2.2 Participant Mental Models in VR

The immersivity of this method had some interesting results among multiple participants in the experiment. Though not recorded as quantitative data, the VR system setup (described in the Data Collection enabled by VR section), allowed us to record the participant's speech throughout the interaction. The timed video feed from the VR headset helped us correlate the participant's reactions and what they were seeing in VR. One interesting characteristic of this method was the participants' tendency to form associations and mental models about everything that they were seeing in VR.

In terms of mental models, many participants affectionately talked about pets, dogs, and children. One participant even greeted the robot directly with, "*hello random dog, what are you doing?*". The participant reemphasized the robot's doglike nature by saying, "*when it runs onto my foot it's like a puppy*". Another common mental model that participants seemed to indulge in was furniture, often saying things like "[the robot] *looks like a nice piece of furniture*". Another participant reflected, "*it's kind of like a block of wood I would like to sit on it, it's coming to serve me*" and another referring to the carpet robot mentioned, "*it wants to give me a manicure*". Others referred to the same carpet robot as a stool, an ottoman, a chair, a cushion, and a pillow. Other miscellaneous categories included mechanical devices and building materials. These various interpretations and analogies demonstrate the immersiveness of VR. Such a virtual environment could be used to create multiple different scenarios for easier to implement user studies and experiments.

4.2.3 Material Legibility

As a check for the VR method, we assessed whether the materials were legible. As described in the Manipulations in VR section as well as Fig. 10, we had chosen 3 different materials for each category in color, soft, hard and special. However, our choices and interpretations of the material may not have matched the participants' interpretations. To this end, we coded participant's qualitative descriptions of the robots' appearance. The results are summarized in Table 3. While colors had a perfect recognition rate, there were 3 materials that participants interpreted as having totally different properties (less than 33% recognition rate), and 6 that were mostly interpreted consistently (greater than 64% recognition). For example, one of the inconsistent materials, brushed metal was predominantly interpreted as a flat gray, a color that happened to match quite well with the VR room in which the virtual scene took place, as commented on by some participants, one asking, "*does the robot intentionally match the walls?*".

The participant's responses were labelled based on how similarly they described the material throughout the interaction, how neutral or unrelated their responses were and the level of hardness or softness that they ascribed to the material. For example, soft/hard materials were coded based on the respective soft/hardness of participant descriptions, and color and special materials were coded visually, i.e., we coded ember as visually consistent with lava. Neutral codings included color (for non-colors) and abstract objects. Nine of the twelve materials, however, were predominantly rated as consistent with the intended category. This speaks to the consistency of this method. Despite some variations and fluctuations, after proper alpha user testing, such a system could be used for prototyping real world robots. The literal descriptives given to every material but brushed metal were consistent with the descriptions of the materials on the Unity Asset Store. Wool was fairly close to carpet, steel was substantially similar to traction tread, and the rest provoking the same descriptors in participant descriptions as originally intended.

Material Type	Original Label	Consistent Descriptions	Neutral/Other Descriptions	Inconsistent Descriptions
Color	White	100%	0%	0%
	Blue	100%	0%	0%
	Red	100%	0%	0%
Soft	Carpet	75% wool	25% pink	0%
	Woven	33% velvet	33% tan	33% cement
	Fur	27% fur	27% brown	47% sandstone
Hard	Metal	17% cement	78% gray	6% pillow
	Tread	77% steel	15% sparkle	8% fabric
	Wood	64% wood	29% Saturn	7% puppy
Special	Lava	93% lava	7% flower	0%
	Grass	73% grass	20% green	7% hard
	Brick	75% brick	17% transport	8% cozy

Table 3: Material Legibility Percentages and Examples

The misinterpreted soft materials are probably a good representation of the current state of VR technology. For example, even people that recognized fur, complained that it was "*low res*", or that they "*couldn't see the detail correctly*". Other words used for the fur material included "*a block of desert*", "*sandstone*" or "*dirt*". This indicated that many participants could see a textured color, but had trouble placing it due to the virtual setting, and hence sought out color associations. Improving the state of VR technology to be able to better depict fibrous materials and small details with the proper lighting might be needed for an accurate portrayal of real-world textures and materials.

5 Future Work

The two innovative methods broaden the scope of user studies in HRI. The Actor Method allows user studies investigating complex socially sensitive questions that may not be permissible in traditional user studies while the VR Method enables exploring multiple research conditions in immersive virtual environments to enable faster robot prototyping. Based on the results and participant immersiveness in the two instantiations of these two innovative methods, we believe future work can be conducted to enable more use cases and varied data collection by using these two methods. The following subsection discusses how the Actor Method could be applied to various research areas and topics in HRI. The next subsection, inspired by the narrative storytelling seen in the experiment using the VR Method, details possible future work around storytelling using robots in virtual reality.

5.1 Advancing the Actor Method

In future work, we would like to explore how other types of robot comments and situated factors influence perceptions of a robot barista. The Actor method could possibly be further enhanced by conducting a naturalistic study in a real cafe, a setting with more ecological validity. This study demonstrated that context is extremely important to robot data use. How the meeting between the customers is going affects the perception of a service robot's social appropriateness. Following this finding, we would like to use the Actor Method with a more active role for the participant, where they could choose between options to lead the conversation. This would help us investigate how humans might expect robots to react to different pieces of information, rather than the robot being the one violating the participant's privacy.

Along the lines of accessing data not available to typical user studies, we would like to apply the Actor Method to other sensitive questions in robotics, such as a robot's morality and the effects of it performing an unethical action. A question about robotics and AI that is often pondered in popular media is how a robot might react when faced with a moral decision requiring humanity, soul, or whatever each person may consider "human" about themselves. A study using the Actor Method could be designed to understand our own expectations from robots in such critical life changing encounters. The two methods discussed in this thesis could be combined to increase the immersiveness (designing a tamer situation in VR) for such an experience while also protecting the participant by using the Actor Method. Further areas of study for such high-stakes data could include a robot's potential role in moderating interactions between people in arguments or debates. Emotions running high can often cause debates to lose their meaning and significance. The Actor Method could be used to evaluate how a robot might mediate such discourse between two participants and how this might be received by the two participants that are acting out an argument. This is just one example of a plethora of robot personality and interaction traits that we believe could be explored by using the Actor Method. Hence, this method could be particularly helpful when designing new social functionality into robots or even just machines, and in areas where user sensitivities are not yet known.

5.2 Utilizing VR to delve deeper into HRI

From a novel design methodology perspective, this experiment leveraging the VR as an HRI design tool was successful in differentiating robot materials along HRI-relevant design criteria. One insight provided by this experiment was that white colored robots were ranked as the least aggressive and liked the best. The makers of many common companion robots (often designed with white robot bodies) will be happy to see this result. On the other hand, the high levels of success of the wood texture across all survey categories could also offer a call to action for the HRI field. People have an attraction to this sustainable, organically produced material, finding it friendly, safe, and feeling like it liked them. This offers a helpful design possibility for future minimal robots and would be an avenue that we would love to delve into further.

Filmmakers have already been leveraging the emotional impact of VR to create empathy in the viewer by placing them in a first-person perspective [37].While this specific experiment illustrated the utility of VR in prototyping robots, the potential for investigating mutual empathy, developing relationships, and complex interactive communications remains unexplored. As we saw with the participant jumping over the robot, or thinking the pink cushion wants to come do her nails, people are open to engaging in simulated or real games while using this interactive user study method.

The emergent interaction behaviors and storytelling argue for strong entertainment potentials of physical robots in character-based VR storytelling. People are visual creatures, thus leveraging the ability of virtual environments to change out backdrops, forms, motions (using animations) and apparent materials is an efficient way to expand the reach and impact of entertainment robots, while grounding people's VR experience in haptic interaction is already known to increase sense of place and a scene's immersiveness [38]. To this effect we have started working on a mixed reality system, focusing on the storytelling capability of this method. The general idea for this future work lies in an amalgamation of a virtual environment with enthralling visuals, virtual characters and NPCs enacting animations, talking and interacting with participants, ambient and environmental audio and both a virtual robot and its parallel physical manifestation in the real world.

As shown by the experiment, participants are open to games and a higher level of human-robot interaction than just collisions while in VR. As an extension to the VR Method we would like to add haptics like mist and wind to our current approach of using and analyzing the physical sensation of touch/collision while in a virtual environment. Previous implementations of such a system have explored utilizing a fan, a hot air blower, a mist creator and a heat light to recreate multiple tactile sensations in VR [39]. We would like to explore human-robot interaction and robot-based story telling by adding these immersive features to the VR method.

6 Conclusion

This honors thesis explores and recounts the innovative experimental methods used in two human-robot interaction user studies in CHARISMA Lab at Oregon State University. Both of these big research projects were team efforts where I worked with six other undergraduate and graduate researchers in the lab. This thesis highlights and evaluates the design methods used in these projects to provide access to high-stakes social data not typically collectible through traditional user studies. Leveraging humans’ innate vivid imaginations, both innovative methods enabled participants in suspending their disbelief and being immersed in the HRI user study. The Actor Method used an imagined persona as a proxy innovating on the *Interaction* aspect of an HRI user study by using *Stories* about a roleplayed person on a script to immerse the participant in a user study and hence providing psychological and informational safety. The VR Method innovated on the *Robot* aspect of an HRI user study by using interactive and immersive *Visuals* (augmented with designed physical touch) to enable investigating multiple research conditions and participant narratives through a virtually manifested robot. These results show that the two innovative methods can add to the field of HRI by allowing user studies to explore complicated social research areas as well as manipulate multiple research variables with minimal robot prototyping and build time.

Using the theater-inspired Actor Method for this specific experiment allowed participants to experience a variety of scenes without putting their personal privacy at risk. In fact, in-person participants reported feeling real emotions during the scenes as illuminated in the Discussion section, demonstrating the credibility of the Actor Method. Most online study results were replicated in the in-person study, and the dual format allowed us to explore many variables (online), and also ask questions of people (in-person Actor Method). In the VR Method, while many participants dutifully repeated each trial without variation of their own behaviors, others explored the interaction as the experiment went on: moving out of the way, asking to sit on the robot, letting the robot go through their legs, and one even jumping over it. This shows the potential for further physical interaction and play in this mixed reality format. Another interesting development while using the VR Method was participants' tendency to form mental models of the different robots, often treating the robots as pets, dogs and children.

Over the course of my 3 years working as an undergraduate researcher with CHARISMA Lab, I have learnt a lot of human-robot interaction, especially with regards to user studies and designing experiments. I have been fortunate to be involved in multiple projects giving me a diverse background in the HRI field ranging from being the driver of a wizard of oz service robot to developing robot animations and backdrops in virtual reality. From a study perspective, I have been exposed to different types of user studies with many different types like in the wild recruitment of solo participants, recruitment of whole audiences as participants in studies, designing controlled experiments with planned paths and dialogues, improvising as a health coaching robot and running quantitative data analysis and statistical tests. These experiences have been a fundamental part of my learning experience as an undergraduate student at Oregon State University.

This thesis illustrates the rich potential of both these innovative experimental methods to gain access to typically inaccessible high-stakes data in user studies. The thesis develops the theater-inspired Actor Method, demonstrating its effectiveness in simulating a high-stakes social situation without endangering the participant while also underlining the methods effectiveness in eliciting human emotions and reactions. It also presents our accessible approach to localizing and tracking a simple robot in a VR system while detailing our calibration techniques VR design to enable varying the virtual robot's rendering. It also describes our approach to robot communication design, adapting insights from real world experimentation into the VR-communication setting.

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