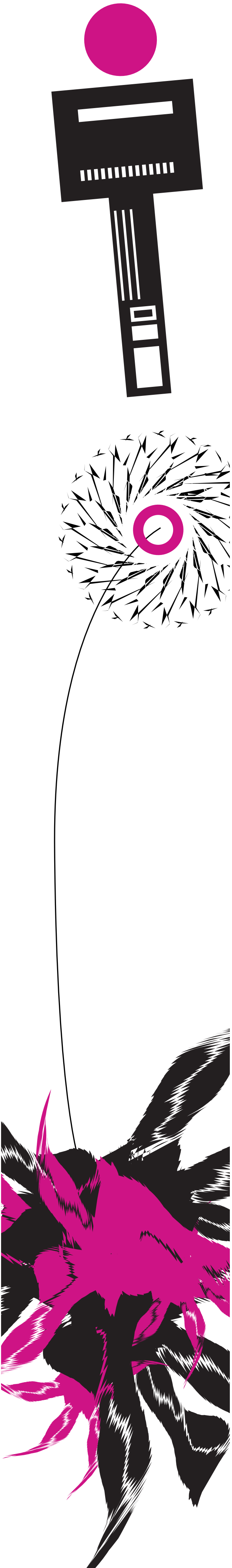

RAM
ROBOTICS
AND
MECHATRONICS

INSIGHTS OF TELE-HANDSHAKE

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Disclaimer

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Summary

The research paper delves into a comprehensive exploration of tele-handshakes, aiming to uncover valuable insights into their dynamics. By conducting an extensive literature review, the study identifies key factors influencing traditional face-to-face handshakes and assesses their applicability within the context of tele-handshakes. To facilitate this investigation, specific hardware setups are adopted, involving the Virtuose 6D robotic arm, H-glove, FRANKA EMIKA-Panda robotic arm, and qb robotic soft hand.

The paper meticulously elaborates on the controllers utilized for these hardware setups, notably highlighting the selection of the Bilateral Impedance Control with Passivity (BICP) for implementation. Moving forward, the study assesses the feasibility of tele-handshakes, concentrating on pivotal aspects such as visual cues, haptic feedback, and the role of ethnicity in these interactions. Through a comprehensive user study, the impact of these factors on the tele-handshake experience is dissected, yielding vital insights.

Analysis of the study data reveals intriguing outcomes. Notably, variations in force feedback did not yield significant differences in users' sense of ownership, agency, self-location, or cognitive workload. While the combination of force feedback from the Virtuose system and the H-glove did not show notable differences in user perception, qualitative findings underscore the importance of refined hardware design for a more authentic embodiment sensation. Furthermore, manipulation of camera perspectives yielded noteworthy results, impacting cognitive workload but not the sense of ownership, agency and self-location.

The study's analysis of regional differences is particularly insightful, demonstrating that participants from diverse regions experience similar levels of ownership and agency in tele-handshake interactions. However, discrepancies emerge in terms of feeling present (self-location) in the remote environment, with Western participants reporting a stronger sense of situational presence compared to their Eastern counterparts. Intriguingly, cognitive workload exhibited consistent patterns across regions.

The paper's qualitative analysis phase delves into participants' experiences through interviews, unearthing two prominent themes: hardware limitations and synchronization challenges. Participants express discomfort and difficulty with hardware components, affecting their sense of authenticity and embodiment. Synchronization delays disrupt the natural flow of interaction, compelling participants to adapt. These findings underscore the necessity for ergonomic hardware design and improved synchronization to enhance emotional engagement and user experience.

In conclusion, the research paper presents a comprehensive exploration of tele-handshake dynamics, unraveling valuable insights into hardware, synchronization, and user perceptions. The implications of these findings for enhancing the design and experience of tele-handshake interactions are substantial, offering a foundation for refining both technical and experiential aspects of this emerging mode of remote communication.

Contents

1 Introduction

Effective communication is a fundamental aspect of human interaction, enabling us to convey information accurately and quickly. While verbal communication is essential, nonverbal communication, such as facial expressions, head movements, body posture, touch, and eye contact, plays a significant role in establishing connections between individuals. Among these nonverbal cues, touch has been widely recognized by researchers for its positive influence on human relationships [1]. In fact, it has been argued that genuine trust cannot exist without touch [2]. Various forms of touch exist, including handshakes, hand-holding, forearm touches, shoulder embraces, waist embraces, and facial touches [3].

A comprehensive examination of touch reveals the significance of handshakes in human interaction. Serving as the primary greeting ritual in Western civilization, handshakes are widely accepted as a form of nonverbal communication. They convey trust, formality, and respect while displaying the least dominance among various forms of touch [4]. Extensive research has further identified nuances conveyed by handshakes, such as immediacy, affection, similarity, equality, depth, and composure [3]. Across cultures, handshakes have emerged as the predominant gesture for exchanging greetings, symbolizing friendship, affection, good wishes, or simply as a polite formality [5]. This ubiquitous social contact symbolizes welcome, farewell, and congratulations in diverse social circumstances, making it a fundamental aspect of human interaction.

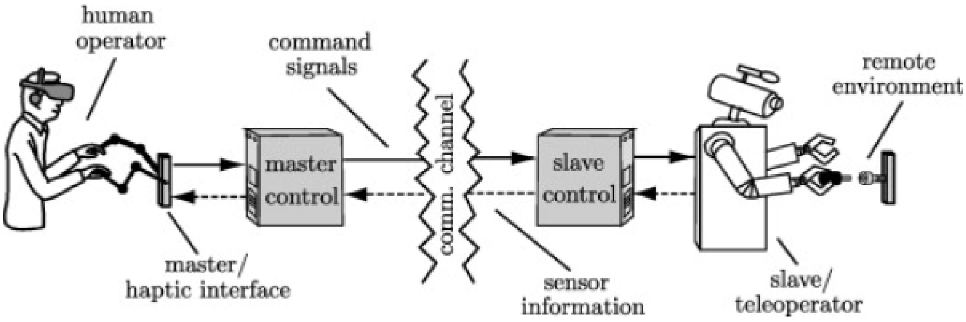

Figure 1.1: Typical teleoperation system architecture, showcasing the interaction between a human operator, a master robot, and a slave robot, highlighting the potential of haptic devices for enhancing social human-robot interaction [6]

1.1 Telepresence Technology

In today's increasingly digital and remote communication landscape, a challenge is to recreate the power of touch. Telepresence technology that enables individuals to experience a sense of physical presence in remote locations [7]. The COVID-19 pandemic has further emphasized the importance of social interaction, propelling teleoperated robots towards the exploration of remote experiences of social behaviors. Combining telepresence with the tactile sensation of a handshake introduces a novel dimension to remote communication. This integration highlights the potential of telepresence technology not only to reproduce visual and auditory cues but also to extend the scope of physical interaction. Such integration has the capacity to enhance the authenticity and effectiveness of remote collaborations, negotiations, and various interpersonal engagements. Through the incorporation of haptic feedback devices into telepresence systems, individuals can remotely experience the act of shaking hands, thereby bridging the physical gap and infusing a personal and human touch into their remote interactions. This promising avenue of research holds significant implications for the future of remote communication and may revolutionize the way individuals connect across distances.

Extensive research has been conducted in recent years to explore various methods for creating and reinforcing the perception of telepresence such as [8], [9]. Notably, Twente University's RAM and HMI laboratories are actively participating in the ANA Avatar XPRIZE challenge, striving to design a robotic avatar system ca-

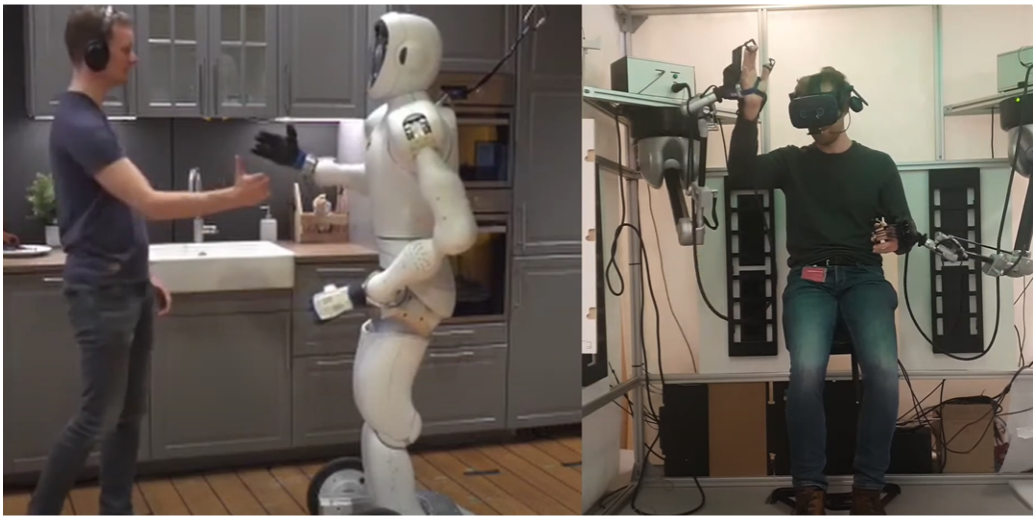

Figure 1.2: Operator side: Teleoperated from a remote location
Image source: YouTube - i-Botics XPRIZE - Semifinalist Selection Submission - Full

pable of transferring humans to remote areas. The accompanying figures showcase the Eve robot engaging with humans, operated from a remote location using technologies like Virtuose and Hglove (figure 1.2).

To create an immersive telepresence experience, it is essential for the operator to have a sense of presence and the ability to interact with the environment where the avatar robot is located. Similarly, it is important for the people present in that environment to be able to perceive and interact with the operator. This two-way interaction allows for a more comprehensive and realistic telepresence, where both the operator and the individuals in the environment can engage with each other as if they were physically present. Figure 1.3 depicts the operator's perception through a Human Mounted Display, providing a visual representation of their viewpoint.

Figure 1.3: Perspective through Head Mounted Display (HMD): The operator's view as seen through the Head Mounted Display (HMD) while remotely controlling the EVE humanoid robot, immersing themselves in the telepresence experience.
Image source: YouTube - i-Botics XPRIZE - Semifinalist Selection Submission - Full

1.2 Problem Statement

The increasing interest and acceptance of social robots in recent years have sparked research on the telerobotics aspects of handshakes. Scholars have conducted studies on handshakes from sociological perspectives [10], [11], as well as investigating the psychological effects of handshakes [12], [13]. Technical aspects of handshakes have also been explored [14], [15], with notable advancements in haptics applications [16], [17].

Despite these existing studies, there is a significant gap in the literature regarding a holistic understanding of tele-handshake.

Hence, there is a need for the following:

- A detailed literature review to bridge the existing research gap on tele-handshake. This review should provide a comprehensive overview of the current state of knowledge, identifying key findings, methodologies, and gaps in the existing literature.
- An exploration of the critical aspects of handshakes that play a pivotal role in achieving a human-like handshake experience in tele-handshake scenarios. Understanding these crucial factors will contribute to enhancing the authenticity and effectiveness of tele-handshakes, furthering the development and application of telepresence technologies.

1.3 Project Goals

The goal of this project is to investigate and gain comprehensive insights into the phenomenon of tele-handshake, focusing on the telerobotics aspects and human-like experience. By conducting a detailed literature review, we aim to provide a holistic understanding of tele-handshake. Furthermore, the project aims to identify the critical factors that contribute to achieving an authentic and human-like handshake experience in telepresence scenarios. Through this research, we intend to advance the development and application of telepresence technologies, fostering more effective social human-robot interaction and enhancing the overall telepresence experience. The findings of this project will provide valuable knowledge and guidance for researchers, engineers, and practitioners working in the field of telepresence and human-robot interaction.

1.4 Research questions

Based on the problem statement and project goals of this thesis the main research question of this thesis is as follows

1.4.1 Research Question - 1

-What aspects of a handshake are most relevant to reproduce a human-like handshake experience in the context of teleoperation?

1.4.2 Research Question - 2

- What technical considerations and challenges need to be addressed to replicate a realistic handshake through teleoperation?

1.4.3 Research Question - 3

- What are the cultural and contextual factors that influence the perception and interpretation of Tele-handshake interactions?

1.5 Report organisation

The research paper follows a clear and organized structure for easy understanding. It begins with the Introduction Section 1 that provides context and goals. The Literature Review section 2 builds on previous research and identifies gaps. Moving forward, Sections 3 delve into the sense of embodiment and compare various control systems of the hardware setup. The User Study is covered in its own section 4. Results of the study are presented in Section 5, followed by a discussion in Section 6. The paper concludes with Section 7 and offers recommendations in Section 8 based on the findings.

2 Literature review

Handshakes play a vital role in human interactions, shaping impressions, conveying emotions, and facilitating collaboration. As teleoperation and social robotics continue to advance, integrating handshakes into the repertoire of social robots has gained importance. The study of handshakes has evolved from physiological and behavioral research to encompass technical and robotic analyses, focusing on designing and implementing handshake interactions in robotic systems. Researchers have demonstrated the impact of handshakes on initial impressions and employment judgments during recruitment processes [13], [18]. Handshakes also contribute to communication by conveying a range of emotions [19] and influencing negotiation outcomes and collaboration [20].

In the context of tele-handshake, a well-executed handshake enhances the perception of robots and fosters collaboration and cohabitation between humans and robots [21]. Drawing upon insights from robotics, psychology, and human-robot interaction, this research aims to design and evaluate tele-handshake systems that capture the nuances and significance of handshakes in human social interactions. Leveraging the advancements in teleoperation and social robotics, the study's contribution lies in the development of realistic, engaging, and socially acceptable robotic systems that effectively incorporate the concept of telepresence. Telepresence is about the sense of being in another environment [22]. It aims to provide the user with a feeling of being physically present in another location.

The following section provide a comprehensive review of the theoretical foundations, empirical studies, and technological advancements that inform the background on tele-handshake. Through multidisciplinary exploration, this research strives to advance the understanding and implementation of handshakes in teleoperation, thereby paving the way for more authentic and immersive human-robot interactions that embody the concept of telepresence. A visual representation of the comprehensive exploration into the evolution and classification of handshakes can be found in Appendix A.

2.1 Aspects of Handshake

Handshakes are a fundamental form of nonverbal communication that can vary in several ways, such as firmness, duration, grip, and presentation. Etiquette books have extensively discussed the different aspects of handshakes, including factors like strength, moisture, temperature, eye contact, and skin texture [23]. Early scientific literature by Vernon [24] briefly touches upon individual differences in handshake characteristics and variations in how the hand is offered.

According to [2], research was conducted on the influence of shaking hands during negotiations using telepresence that incorporates haptic feedback. The results showed that handshaking improved cooperation. However, haptic feedback for the telepresent negotiator had no significant impact and did not affect perceived trustworthiness. The highest level of cooperation was observed when feedback was present.

To assess the impact of a Tele-handshake system on human experience, it is crucial to evaluate the qualitative aspects of handshakes in social settings before adapting them to tele-interaction environment. Nonverbal contact, which includes touch and handshakes, plays a significant role in human communication, accounting for approximately 65% of overall communication [12]. Thus, the development of a tele-handshake device has substantial implications for enhancing the human experience.

In this study, we aim to comprehensively examine handshake features and their relevance in the context of Tele-interactions. We draw inspiration from a range of disciplines, including social studies, technical literature, behavioral studies, and robotics research. By considering the various aspects of handshakes studies in human-human interactions, we can explore their potential application in tele-interaction environment.

By taking a multidisciplinary approach, we aim to bridge the gap between social studies and robotics research, contributing to the design and implementation of a authentic robotic handshake system. Through our investigation, we strive to enhance our understanding of handshake characteristics and their role in human-robot interactions, ultimately improving the overall user experience.

Table 2.1 presents an overview of handshake characteristics extracted from relevant research papers that investigate various aspects of handshake. Each research paper focuses on examining one or more specific as-

Handshake Characteristics	Paper dealing with it
Grip and Grasp	[12] , [5] and [25]
Duration	[26] and [27]
Frequency	[26], [28] and [25]
Temperature	[12] and [25], [17]
Texture of hand (dry or wet)	[12] and [17]
Anatomical Consistency	[25] and [29]
Gender and Ethnicity	[11] [25]
Synchronization	[26] , [30] , [9] [31]

Table 2.1: Studies Investigating Various Handshake Characteristics.The table presents a compilation of studies that have examined specific handshake characteristics. These studies have explored factors such as grip, grasp, duration, frequency, temperature, texture of hand, anatomical consistency, gender, ethnicity, and synchronization.

pects of handshakes, shedding light on their significance and impact in social interactions. Understanding and studying these handshake aspects can provide valuable insights into human behavior, social dynamics, and the development of tele-handshake systems. This comprehensive exploration of handshake characteristics aims to unravel the intricacies of this fundamental human interaction and facilitate the design of more authentic and human like tele-handshake experiences.

2.1.1 Grip and Grasp

In the context of this study, grip and grasp aspect play a roles in understanding the dynamics of a handshake. Grip refers to the force or strength applied during a handshake. On the other hand, grasp encompasses the way the hand is held, taking into account the movements of the wrist and forearm.

Research by Cabibihan et al. [5] identifies specific areas where high contact forces are experienced during a handshake, including the palm, back of the palm, thumb, and various finger phalanges. These areas play a crucial role in achieving a firm grip during handshaking. Psychologically, a firm handshake is associated with higher levels of extroversion and emotional expressiveness, while a loose handshake may be related to neurotic characteristics [12, 25]. Studies have also shown that the strength of a handshake is related to various personality traits. Freeman et al. [12] found a positive correlation between handshake strength and the traits of aggression, dominance, and exhibition (extroversion). Similarly, Aastrom et al. [25] found that a strong handshake is positively correlated with aggression and dominance, while negatively correlated with sociability and neuroticism. Notably, participants were able to discern differences in dominance based on haptic behaviors, such as grasping force and joint stiffness, with low and high values eliciting distinct responses [32] and [33].

In the study [34] examined the impact of varying the viscosity and stiffness of the human elbow joint in handshakes using a variable viscoelastic handshake manipulator. They found that handshakes with low viscosity were perceived as more natural, offering a smoother interaction, while handshakes with high stiffness were perceived as firm, creating a stronger sensation. These results highlighted the significance of the human elbow in shaping handshaking experiences, providing insights for designing more realistic and engaging handshake systems, such as robotic or haptic devices.

2.1.2 Duration

In the context of a handshake, "duration" refers to the length of time it takes for the entire handshake interaction to occur. It includes the time from the initial hand contact to the final release of hands. In [27], it was demonstrated that a typical handshake lasts less than 3 seconds, while a prolonged handshake indicated a disparity in conduct, including less pleasure, affection, and friendliness. Furthermore, [26] examined the four handshake stages and their respective durations, shedding light on the temporal aspects of this social interaction.

2.1.3 Frequency(Vigor)

Frequency refers to the rate or speed at which the hand movements occur during the handshake interaction. It represents the number of handshake movements or cycles that occur within a given time frame, typically measured in hertz (Hz). A higher frequency indicates a faster and more rapid movement of the hands, while a lower frequency signifies a slower and more leisurely movement.

Regarding frequency, studies [25] [26] indicate that the frequency of the rhythmic movement during a handshake does not seem to have direct psychological or clinical implications. However, a data glove designed to measure the frequency of hand movement showed that a frequency of approximately 4Hz can provide a more human-like handshake experience. This information can be valuable when designing systems that involve handshakes between humans and robots, as it helps ensure synchronization and a natural interaction between the two.

The direction of hand movement during a handshake is also explored in research [28]. They found that the initial hand movement direction, whether upward or downward, can influence the overall handshake experience. They developed a shake-motion leading model based on the analysis of handshake motions between humans. Notably, participants in their study who moved their hands upward were more prevalent, and the mean height of the downward hand movement group was higher than that of the upward group. This suggests that the direction of hand movement can have a subtle but noticeable impact on the perception and dynamics of a handshake interaction.

2.1.4 Temperature

In the context of handshakes, it refers to the thermal condition of the hands during the interaction. The temperature of hands plays a role in the perception and interpretation of handshakes. According to [12], colder handshakes are often associated with social introversion in both men and women. Women with warmer hands and a stronger handshake tend to exhibit higher levels of rational dominance. Additionally, [25] found that lower temperature and humidity of the palmar skin were associated with social introversion, depression, and susceptibility to symptom amplification among psychiatric inpatients.

In the context of robotics, the temperature factor has also been addressed. In [17], researchers focused on adjusting the temperature of a robot hand using resistance wires integrated into its mechanical architecture. This temperature control mechanism aims to minimize mechanical stress and provide a more comfortable and realistic handshake experience. This approach was implemented to address the limitation of conventional robot hands, which lack the ability to convey temperature information. The absence of warmth in robot hands can create a perception of coldness, emphasizing their mechanical nature and stark contrast to human hands.

Temperature in relation to handshake can influence the user's perception and experience of the handshake. When a robotic hand is used in teleoperation, the temperature of the hand can be adjusted to mimic the warmth or coolness of a human hand. This temperature adjustment can enhance the sense of realism for the recipient, making the tele-handshake interaction more immersive and engaging.

2.1.5 Texture

Texture can be expressed in a different ways. In [12] researcher observed that hand dryness was linked to psychological masculinity in women while moist hands in men were found to be depressed. Men's perceived handshake dryness correlated positively with sociability. In [17] researchers describes a texture procedure, that involved covering the fingers and palms in a cloth that resembled artificial skin. This gave participants a realistic handshake experience with the robotics hand.

2.1.6 Anatomical Consistency

Anatomical consistency in the context of a handshake refers to the alignment and matching of hand structures and proportions between individuals. It encompasses factors such as hand size, finger length, and grip patterns. In the paper [25], it was observed that anatomical consistency plays a role in the effectiveness and comfort of a handshake. Similarly, in [29], the variation in force applied by a haptic interface was attributed to the anatomical differences among users, including hand size and grasping techniques. These findings highlight the significance of considering anatomical consistency when designing and evaluating handshake interactions, as it can impact the quality and effectiveness of the handshake experience.

2.1.7 Synchronization

Synchronization of handshakes plays an important role in experiencing realistic handshakes. In [30], the researcher describes the mechanism of Human-Robot Interaction(handshake) which is initiated by synchrony detection. Paper [31] present a control algorithm capable of anticipating human intention to achieve handshake synchrony. The study in [9] suggests that when individuals synchronize with agents (such as robots on recipient side) that exhibit better overall perception, the interaction becomes more fluid and harmonious. This implies that in tele-handshake interactions, if the robotic hand movements are well-coordinated and responsive to the human operator's actions, the overall handshake experience is likely to feel more natural and satisfying to both parties involved. On the other hand, [26] explores the phenomena of synchrony in humanoid robot behavior in a social environment. By using specially designed data gloves to measure rhythmic movements, they propose materials and methods to measure handshake synchrony. This emphasizes the significance of synchronizing the hand movements of the human operator and the robotic hand during a tele-handshake. When there is a sense of synchrony between the two, the handshake interaction can feel more authentic and engender a stronger sense of connection between the remote individuals.

2.1.8 Gender and Ethnicity

Gender and ethnicity can influence the dynamics of a handshake even before the physical interaction takes place. In terms of gender, dominant women tend to position themselves directly in front of the other person during a handshake, while highly sociable and aggressive women may engage in a shorter mutual gaze before initiating the handshake. Anthropological studies suggest that taller men often exhibit more strength and vigor in their handshakes compared to women [25].

Furthermore, it's important to consider that physical interactions vary across cultures, age groups, and geographic locations. Different gestures and forms of contact, such as kissing, patting, fist-bumping, or high-fiving, may be more prevalent in specific contexts to convey increased affection or create a fun atmosphere. The influence of gender and ethnicity on the impact of handshakes on social evaluations is evident in studies such as [11], The research found that handshakes had a more positive effect on social appraisals among Caucasians compared to East Asian participants. Moreover, the effect was stronger when evaluating social interactions with individuals from the same ethnic group rather than an outgroup. Additionally, the effect was more pronounced in male participants, particularly in male-male social interactions.

It's worth noting that women tend to be more expressive in their nonverbal affective behaviors and are more attuned to the nonverbal cues displayed by others compared to men. Understanding gender-based handshaking experiences often involves considering the broader spectrum of "whole-body" nonverbal signaling rather than solely focusing on subtle differences in facial expressions conveying specific emotions [25].

2.2 Influence of non-haptic factors for human-like experience of handshake

2.2.1 Visual

In the papers [8,9,17], the role of visual cues in tele-operation scenarios is emphasized. These studies highlight the importance of visual feedback in enhancing the user's perception, control, and overall experience during teleoperation. Visual cues play a crucial role in human-humanoid interactions, as highlighted by [9]. They emphasized the importance of realistic visual representations in promoting a sense of presence and engagement. In line with this, a study conducted by [8] found that the quality of telepresence is improved when the visual representation of the conversation partner is presented in a stereoscopic or life-size format.

The demand for perception stems from the fact that people have a high capacity to act physically in their surroundings, interact with them, and adapt to them. This capability is mainly based on their ability to perceive and interpret their environments using their two primary senses, vision and touch. Then, in direct tele-handshake, vision, and force feed-backs are crucial for sense of telepresence [35].

In a study [17], researchers explored adding touch sensations (haptic feedback) to virtual handshakes in video conferencing. They found that this made the experience more engaging and lifelike. Participants reported feeling a stronger sense of presence and connection with the other person. By combining touch with visuals, virtual interactions became more immersive and realistic, offering exciting possibilities for future communication technologies.

2.2.2 Facial cues

The role of facial expressions and haptic feedback in perceiving emotions has been a subject of investigation in the field of human-robot interaction. In studies conducted by researchers such as [32] and [33], participants engaged in handshake interactions with humanoid robots, where both facial expressions and haptic cues were involved. The findings revealed that participants combined these cues additively to evaluate the emotional dimensions of valence, arousal, and dominance.

2.2.3 Smell

Intriguingly, another study by [36] shed light on an additional aspect of the human handshake experience. The research demonstrated that individuals exhibited repetitive investigation of their own hands following handshakes, often accompanied by increased sniffing. This suggests that the sense of smell may also play a role in shaping the overall handshake experience. The integration of olfactory cues adds another layer of sensory input, contributing to the multisensory perception of handshakes.

2.3 Hardware Background

Handshakes are intricate nonverbal communications involving various factors such as grip, grasp, duration, frequency, temperature, texture, anatomical consistency, and even factors like gender and ethnicity. Each element plays a role in shaping the perception and significance of a handshake. When transitioning handshakes to tele-interaction environments, careful consideration of these factors is crucial to ensure a realistic experience. The hardware utilized in this context also holds significant importance. In this section, background information on the hardware used will be provided. It's worth noting that the selection of hardware was influenced by the choices made for the hardware utilized in the ANA Avatar XPRIZE challenge.

2.3.1 H-Glove

The H-Glove serves as a haptic device tailored for adept interaction within robotics. It is worn on the dorsal side of the hand and is connected to the fingertips. The glove is adaptable, allowing it to accommodate hands and fingers of different sizes.The exoskeleton comprises three fingers, each consisting of three links, providing a total of 3 degrees of freedom per finger. This results in a total of 9 degrees of freedom for the H-Glove. All 9 joints in the exoskeleton are measurable, enabling precise tracking and control. The H-Glove is capable of providing force feedback on the three fingers, allowing users to sense the applied forces during interactions. However, only 2 degrees of freedom on each finger are actuated, meaning that these specific degrees of freedom can reproduce the sensation of contact [37]. Table 2.2 gives overview of HGlove features.

Feature	Specifications
Number of Finger Mechanisms	3
Number of Links per Mechanism	3
Degrees of Freedom per Mechanism	3 (active and non-active)
Active Degrees of Freedom per Mechanism	2
Position-Measurable DOF per Mechanism	3
Continuous Force in Translation	5N
Continuous Torque in Rotation	0.13

Table 2.2: Key Features of the HGlove by Haption

2.3.2 qb soft hand

The qb Soft Hand is equipped with five fingers, collectively offering 19 non-actuated degrees of freedom. Among these, each finger (excluding the thumb) boasts four degrees of freedom, while the thumb features three. The intriguing aspect lies in its single actuator control, an elegant and effective approach. To elevate its performance, the qb Soft Hand integrates two sensor types: an electric current sensor and a position sensor. These integrated sensors empower the hand to perceive and quantify both electrical current and finger positions, respectively. The qb SoftHand is capable of replicating around 75 percent of the gripping abilities found in a human hand. Its mechanical intelligence lets it naturally adjust its grip on objects without needing complex sensors or intricate electronic programming. This hand is anthropomorphic, meaning it's designed to mimic human hand characteristics, and it's based on soft-robotics technology [38]. Table 2.3 gives overview of qb softhand features.

Feature	Description
Flexibility	Soft-robotics design providing flexibility, adaptivity, and robustness
DOFs (Degrees of Freedom)	19 anthropomorphic DOFs controlled in one single synergy motion
Phalange Capability	Dislocatable and self-reposition phalanges
Grasping Force	Up to 60 N
Maximum Payload	Up to 2.0 kg
Closure Time	Maximum closure time of 1.1 s
Total Weight	770 g (including aluminium flange and screws)

Table 2.3: Key Features of the QB Softhand

2.3.3 Virtuoso 6D

The Virtuose 6D provides haptic feedback and motion control to the operator. The Virtuose 6D consists of a fixed base and three links, with four joints providing 6 degrees of freedom (6D) motion [39]. It is equipped with four joints, with the first three being revolute joints providing one degree of freedom each, and the fourth joint being a spherical joint with three degrees of freedom. This configuration allows for a total of six degrees of freedom, enabling versatile and flexible motion. One notable feature of the Virtuose 6D is the inclusion of electric current sensors, which are utilized to calculate the force exerted by the operator on the end-effector. These sensors provide valuable feedback and enhance the system's ability to interact and respond to external forces. Overall, the Virtuose 6D offers a compact and capable solution for various robotic applications. Table2.4 gives overview of Virtuose 6D features.

Feature	Description
Number of links	3
Number of joints	4
Rotation workspace	±165° x ±65° x ±135°
Translation workspace	0.67m x 0.29m x 0.51m
Peak force in translation	35 N
Peak torque in rotation	3.1 Nm

Table 2.4: Key Features of the Virtuose 6D

2.3.4 Franka Emika Panda robotic arm

The Franka Emika Panda is a 6D motion-capable serial robotic arm consisting of a fixed base and six links. With its 7 joints, it offers 7 degrees of freedom. Notably, each joint is equipped with force sensors, enhancing its functionality and allowing for precise force measurement and control [40]. Table2.5 gives overview of Franka arm features.

Feature	Description
Payload Capacity	The maximum weight the Frank Arm can lift or carry is 3kg
Reach	The maximum distance the Frank Arm can extend horizontally is 855mm
Degrees of Freedom	The number of independent movements the Frank Arm can perform is 7
Force/torque sensing	link-side torque sensor in all 7 axes

Table 2.5: Key Features of the Franka Arm

2.3.5 Display - HMD

The HTC VIVE Pro Eye is a head-mounted display (HMD) known for its high-resolution visuals, offering an immersive experience. With a wide field of view, it incorporates eye-tracking technology, allowing interaction based on gaze. This innovation enhances intuitive interaction with the remote environment, fostering a natural connection [41]. Table 2.6 gives overview of HTC VIVE Pro Eye Headset features.

Feature	Description
Display Resolution	dual OLED displays with a combined resolution of 2880 x 1600 pixels
Field of View (FOV)	110 degrees
Refresh Rate	90 Hz
Eye Tracking	Integrated eye-tracking technology for gaze-based interaction and enhanced user experience
Tracking System	SteamVR 2.0 base stations for precise and accurate room-scale tracking
Connections	DisplayPort 1.2, USB-C 3.0, Bluetooth 4.2, and proprietary connector for audio and power
Comfort	Compatible with SteamVR and Unity
Software Compatibility	Ergonomic design with adjustable head strap and built-in ventilation

Table 2.6: Key Features of HTC VIVE Pro Eye Headset

2.3.6 Zed Mini Stereo Camera

Zed mini stereo camera is used to captures high-quality images of the remote environment. These images are processed and projected onto virtual planes within the Unity environment, which act as surfaces for rendering the camera images [42].

2.4 Handshake aspects feasibility investigation

To advance the project, a thorough evaluation of handshake characteristics in practical feasibility is crucial. This requires considering hardware capabilities and limitations. By merging insights from handshake aspects research from section 2.4 with robotic capabilities, targeted priorities can be defined.

Grip and Grasp

The investigation into handshake feasibility, particularly regarding grip has been partially explored by [43]. The study indicates that conveying the handshake grip from the operator to the recipient is plausible using available subsystems. However, the reverse—transmitting the recipient's grip to the operator—is hindered by two main reasons. Firstly, the system lacks the capability to determine if the replica system is actively engaging with the environment, as the qb soft hand lacks a sensory system to measure the recipient's grip. Secondly, the H-Glove exoskeleton lacks an actuation system to provide tactile feedback to the operator, corresponding to the recipient's grip. In essence, while the recipient can experience a complete handshake as they can grip the soft hand and have their hand gripped in return, the operator's handshake experience remains incomplete, as they can simulate gripping a hand but can't feel their own hand being gripped.

Beyond mere grip strength, handshakes carry a range of social cues, cultural subtleties, and emotions. Concentrating solely on grip simplifies the intricate mix of emotions, intentions, and personality traits that handshakes convey. Particularly in practical situations like meetings, these broader factors outweigh isolated grip aspects. Thus, fully understanding handshakes involves amalgamating cultural, psychological, emotional, and social dimensions that collectively define this nonverbal communication mode. Due to these limitations from both a hardware and practical perspective, grip and grasp aspects is not prioritized in our considerations.

Duration, Frequency and Synchronization

When considering human-controlled tele-handshakes, certain factors shift in importance. Variables like duration, frequency, and synchronization become more adaptable and flexible. The duration of a handshake can vary based on individuals' comfort levels, cultural norms, and interaction context. Unlike preprogrammed actions, human-controlled tele-handshakes offer a personalized exchange with adjustable movements, enhancing the organic nature of the interaction. Therefore, in tele-handshake involving human control, the duration of handshake maybe irrelevant. However in interactions, the duration of the handshake can be affected by factors such as latency or delay in the communication channel. These delays can disrupt the real-time synchronization between the participants and may impact the perception and effectiveness of the handshake.

Frequency of hand movements gains prominence in human-controlled scenarios for fostering synchronization and mutual understanding. Human operators guide robotic hands, into a natural flow of interactions. The pace and rhythm can be tailored by operators to synchronize with the recipient's actions, resulting in a harmonious experience. However in tele-handshake scenarios, where individuals are remotely connected through robotic systems, achieving synchronization becomes crucial. While operator and recipient guide tele-handshake frequency, maintaining coordination is essential for a seamless tele-handshake. Operator and recipient must establish mutual understanding, adjusting hand movements to ensure a cohesive and synchronized motion. This synchronization enhances the interaction's authenticity, making participants feel engaged with each other rather than simply controlling remote devices. But, maintaining synchronization and coordination requires a certain level of transparency in the tele-handshake system. Transparency, i.e. the feeling of directly being present and interacting in the remote environment. It refers to providing human operator and recipient with immediate and accurate feedback of other environment. This empowers operator and recipient to adjust actions in real-time, ensuring that the duration, frequency, and synchronization align with the natural dynamics of the interaction. When transparency increases, it often leads to increase of control, task performance and a reduction of cognitive load [44], [45]. A telerobotic system that is transparent enables a natural and intuitive interaction [46]. This real-time feedback loop contributes to an authentic, seamless, and immersive tele-handshake experience where the participants feel genuinely connected and engaged.

Temperature, Texture and Anatomical consistency

On the other hand, temperature, texture and anatomical consistency being a highly individualized characteristic, poses a unique challenge. In an ideal tele-handshake scenario, the aim is to achieve a replication of not only the handshake's grip and motion but also the intricate tactile details, including temperture and texture. This entails transmitting the tactile sensations of the operator's hand to the recipient and reciprocally from the recipient's hand to the operator. However, in our current project, the qb soft hand deviates from this scenario. The qb soft hand, despite its advanced capabilities, lacks the necessary sensory components to accurately measure tactile sensations such as temperature and texture. This limitation prevents the qb soft hand from fully replicating the nuanced tactile experiences that humans can perceive through their sense of touch. As a result, the hand's interactions are predominantly focused on kinesthetic aspects and forces, rather than providing a comprehensive representation of the complete range of tactile sensations like temperature gradients and surface textures. It's worth noting that the H-Glove exoskeleton follows a different trajectory. Since the operator does not physically clasp a tangible hand, the concern over hand texture becomes inconsequential. Instead, the operator relies on haptic feedback, which is activated upon contact between the human participant and the soft hand. This innovative approach circumvents any concerns regarding the realism of the hand's surface.

While the transmission of the recipient's hand temperature and texture might not be facilitated by the robotic handshake system, it notably outperforms the study conducted by [17]. Nakanishi's research primarily concentrated on hand temperature. Nakanishi addressed the coldness issue in a mechanical robot hand, which could affect the sense of tele-presence. Yet, the qb soft hand is designed with soft materials and a human-like texture. So, worries about coldness are unnecessary as the soft hand naturally regulates temperature. While it might not provide exact temperature feedback between operator and recipient, its human-like mimicry renders temperature a secondary concern. Similarly The anatomical consistency of the qb soft hand has been meticulously crafted with a focus on anatomical consistency. With its chosen size, the soft hand offers a comfortable fit for recipient's with a range of hand dimensions. This ensures that the tele-handshake experience feels natural and accessible to individuals of diverse backgrounds, contributing to a more inclusive and enjoyable interaction for all.

Gender

While gender-specific cues in handshake behavior offer interesting insights, they might not be the central focus in the design of a tele-handshake system for several reasons. Firstly, handshakes occur across a spectrum of contexts, and attempting to replicate behaviors like dominant women's positioning might not be universally relevant. Secondly, variations in gender norms around handshakes across cultures could complicate the system's design and limit its cross-cultural applicability.

Ethnicity

Ethnicity in tele-handshake system is pivotal due to the profound impact these factors have on the authenticity and relatability of the interaction. While other aspects of the handshake experience, such as force, duration, and texture, contribute to realism, ethnicity introduce a layer of cultural sensitivity that resonates deeply with participants. Here's why these considerations stand out:

Cultural Relevance: Handshakes are not universally uniform; they are culturally bound and can vary significantly across different regions and ethnicities. Ignoring these variations risks creating an inauthentic or even alienating experience for users whose cultural norms differ from the default.

Enhanced User Engagement: Ethnicity play a substantial role in how individuals perceive and respond to social interactions. Adapting handshaking behaviors to align with users' expectations based on their cultural background can foster a stronger sense of engagement.

Cultural Respect: Acknowledging ethnicity in the design demonstrates a commitment to cultural respect and awareness. Users are more likely to connect with a system that respects their individual identity and backgrounds. This inclusivity can lead to higher user satisfaction and a positive perception of the technology.

Visual

Combining both visual and haptic feedback can notably enrich the human experience of handshakes, creating a more immersive and authentic interaction. Haptic feedback, despite being a crucial element in a interactive systems, is not inherently a facet of the handshake itself. Handshakes primarily involve the physical interaction between hands and the associated social and cultural implications. Haptic feedback in this context replicates the sensations of a real handshake, enhancing the sense of presence and connection. Visual cues hold significant importance in interactions between humans and humanoid entities, as underscored by [9]. Realistic visual depictions are pivotal in fostering a feeling of being present and engaged in the interaction. Correspondingly, [8] highlighted that telepresence quality improves when conversation partners are represented visually in a life-like, stereoscopic format.

A study by [17] delved into incorporating touch sensations (haptic feedback) into virtual handshakes during video conferencing. This integration enhanced the engagement and lifelikeness of the experience. Participants reported an increased sense of presence and connection with their counterparts.

In summary, the integration of visual and haptic feedback within tele handshake systems emerges as a critical consideration. Research underscores the potency of this amalgamation in replicating the depth and authenticity of interpersonal interactions.

Facial cues and Smell

Regarding the other sensory aspects, like facial cues and smell, while they do play roles in human interactions, they present practical challenges in a teleoperation context. Capturing and transmitting facial expressions precisely can be complex and may not always add significant value to the handshake experience. Similarly, incorporating smell into tele-handshakes presents logistical difficulties and might not be as feasible. Given these considerations, focusing on enhancing visual and haptic feedback appears to be a more feasible and impactful direction.

2.5 Conclusion

Based on the extensive analysis conducted on the diverse facets of tele-handshakes, it becomes clear that attaining an authentic and immersive human-like handshake within a tele-interaction environment necessitates an approach that harmonizes the technical capabilities of robotic systems with the subtleties of human communication. Drawing from the revelations and understandings gleaned from this inquiry, the subsequent aspects come forth as pivotal areas warranting further exploration:

- Transparency emerges as a fundamental necessity in the realm of tele handshake systems. To engender trust and authenticity in remote interactions, clear communication and open disclosure are imperative.
- Visual and Haptic Feedback Integration: The convergence of visual and haptic feedback presents a compelling avenue for establishing a tele-handshake encounter that closely mirrors human interactions.

  The foundational concept underlying the integration of visual and haptic feedback is to construct a facade wherein operators seamlessly embody the avatar's body and hands, effectively erasing the demarcation between concrete, tangible actions and those intermediated by technology. This endeavor heightens the transparency of the teleoperation system, as highlighted by [47], with the intention of minimizing operators' conscious recognition of the mediation process. This notion draws inspiration from the concept of Sense of Embodiment (SoE), Sense of Embodiment (SoE) can be defined as the sensation of regarding an external body (or a component of it) as an extension of one's own [48].
- Ethnicity Sensitivity: The cultural relevance and inclusive nature of a tele-handshake system can be greatly enhanced by integrating ethnicity sensitivity. Acknowledging and accommodating cultural variations in handshaking norms can contribute to a more engaging and relatable experience for users from diverse backgrounds.

Despite the individual discussions on visual cues along with haptic feedback and cultural influences, there is a gap in the literature regarding the combined exploration of these factors in the context of tele-handshake. Therefore, there is an opportunity for a novel methodological approach where the influence of visual feedback , haptic feedback and cultural background can be compared and analyzed in tele-handshake scenarios. By conducting a study that combines visual cues and participants' cultural backgrounds, we can explore how these factors interact and influence the perception and experience of tele-handshakes. This combination is referred as Visuo-Cultural Nexus. The term "Visuo-Cultural Nexus" refers to the intersection and interplay between visual perspectives and cultural factors in the context of tele-handshake interactions. It represents the dynamic relationship between the visual aspect of the telepresence system, such as camera perspectives and the cultural backgrounds of the participants involved in whole study.

3 Analysis

3.1 Sense of Embodiment

Over the past decade, research has surged in exploring the phenomenon of embodiment and its experiential aspects [49], [50] , [51] . This exploration has significantly focused on understanding how a strong sense of embodiment can positively impact tasks related to telepresence and teleoperation ([52], [44]. The primary goal is to establish a profound connection between operators and their remote avatars, enabling them to feel deeply attuned, as if they were directly controlling their own physical bodies. This heightened connection ultimately aims to enhance their performance in teleoperation tasks.

Embodiment, as understood through Kilteni's perspective [48], pertains to the intriguing phenomenon where an individual perceives an external body or its components as an integral part of their own identity. This is a rather nuanced phenomenon and lacks a universally standardized definition or assessment framework. However, Kilteni's work provides a foundational understanding, which we build upon. While Gonzalez-Franco and Peck [53] propose an alternative perspective by deconstructing Sense of Embodiment (SoE) into six distinct components, it's crucial to highlight that Kilteni's conceptualization holds versatility beyond virtual reality contexts it extends its adaptability to the domain of telerobotics, as underscored by [54]. Therefore, our paper centers on Kilteni's framework for the remainder of the discussion.

Kilteni's viewpoint dissects the concept of Sense of Embodiment (SoE) into three essential constituents:

1. Sense of Ownership (SoO): This aspect involves a deep-rooted sense of ownership, where an individual attributes an external object or body part to their own self, blurring the distinction between self and non-self.

2. Sense of Agency (SoA): The concept of agency pertains to the empowering feeling of exerting control over the external entity, effectively allowing the individual to interact with and manipulate the distant environment through this external conduit.

3. Sense of Self-Location (SoS): The sense of where one is located in the remote environment constitutes the notion of self-location. This not only encompasses a spatial awareness of one's position but also involves the perceptual experience of being immersed within that environment.

Measuring the Sense of Embodiment (SoE) entails evaluating an individual's perception of an external entity or body part as fused and integrated with their own body. This intricate concept is typically assessed through a blend of subjective self-report questionnaires, physiological responses, behavioral indicators, and even qualitative interviews [55], [54]. Self-report measures necessitate participants articulating their sense of ownership, agency, and the extent of their identification with the external body or component. Physiological responses, including indicators like skin conductance and heart rate variability, can offer clues about shifts in emotional engagement and body ownership. Furthermore, behavioral cues such as proprioceptive drift, a phenomenon where participants estimate the location of their body parts, contribute to the understanding of the sense of embodiment. Integrating qualitative interviews into this multidimensional approach adds a deeper layer of insight by capturing participants' nuanced experiences and perceptions, enhancing the comprehensiveness of SoE measurement.

In the scope of this paper, our emphasis will be on measuring the Sense of Embodiment (SoE) primarily through the utilization of self-report questionnaires and qualitative interviews. These two approaches provide a comprehensive avenue for capturing both the subjective experiences and the nuanced insights of participants regarding their perception of body integration with external entities. By concentrating on self-report questionnaires, we aim to gather structured data on participants' feelings of ownership, agency, and identification with the external components. Complementing this quantitative aspect, the incorporation of qualitative interviews allows us to delve into participants' rich narratives, shedding light on the intricate emotional and cognitive dimensions of their sense of embodiment. This dual approach promises to yield a multifaceted understanding of the SoE phenomenon.

Just as various methodologies exist for measuring SoE, a multitude of approaches are available for its manipulation. Comprehensive summaries of these techniques can be explored in [54], [48]. Building upon the insights outlined in section 2.4, where the significance of visuals and haptics in tele-handshake was underscored, our focus will be on manipulating these two pivotal factors.

3.2 Hypotheses

Building upon the insights presented in the preceding sections, particularly from section 2.1, 2.4 and 3.1 that discuss the aspects of handshakes, crucial aspects influencing tele-handshake, the sense of embodiment and the insights gained from relevant studies, we can now develop hypotheses to guide our investigation of tele-handshake systems.

- *H1 - The manipulation of Sense of Embodiment (SoE) through visual perspective will have a significant effect on the perceived level of embodiment.*
- *H2 - The sense of embodiment is highest when haptic feedback of both virtuose and H-Glove is present.*
- *H3- Individuals from cultures emphasizing physical touch and interpersonal closeness are expected to feel a stronger sense of embodiment during Tele-handshake interactions compared to individuals from cultures that place less emphasis on physical touch and interpersonal closeness.*

These hypotheses serve as essential building blocks for our research. While H1 doesn't directly answer research question 2, it does inform decisions about visual representation of the handshake and emphasizes the importance of creating a realistic visual experience. This aspect, in turn, aids in addressing research question 2.

H2 directly addresses research question 2 by highlighting the significance of haptic feedback for a strong sense of embodiment. Addressing this hypothesis involves thorough research and implementation of technologies that provide realistic haptic sensations. This is crucial for effectively replicating a lifelike handshake experience.

H3's focus on cultural differences and their impact on the sense of embodiment during teleoperated handshake interactions guides the investigation into how individuals from various cultural backgrounds perceive and interpret these interactions. Furthermore, it indirectly underscores the need to develop culturally sensitive teleoperated interactions. This consideration can influence design choices to ensure that remote handshake experiences are meaningful and respectful across diverse cultural contexts. Thus, these hypotheses contribute to addressing both research question 3 and research question 2.

H1, H2, and H3 collectively provide comprehensive insights into the first research question.

3.3 Controllers for Tele-Handshake Hardware System

This section delves into the intricate control mechanisms governing two distinct tele-handshake hardware systems: the H-Glove and qb-Soft hand, as well as the Virtuoso and Franka robotic arm. Comprehensive elaboration of each hardware device is presented in Section 2.3. It's important to understand that the control and haptic feedback systems for the H-Glove and qb-Soft hand are separate from those of the Virtuoso and Franka systems. This separation means that any issues or delays in one set of systems do not affect the other set. Let's now take a closer look at the role and mechanism of each controller.

3.3.1 Controller of H-Glove and qb-Soft hand

Haptic feedback integration has been effectively demonstrated in the H-Glove and qb Softhand through research conducted by [56]. This work builds upon the foundational papers of [57] and [58], which provide crucial insights into the haptic feedback domain. The fundamental idea behind the haptic feedback in these systems is based on the concept of synergies [59], which simplifies the grasping process to a single Degree of Freedom (DoF). In the context of this work, "synergy" refers to the coordinated and combined action of different elements or components working together to achieve a desired outcome. Specifically, it refers to the synergy-based approach employed in the control of the qb SoftHand, a soft and adaptive robotic hand, using the Haption H-Glove, a haptic exoskeleton.

The synergy-based approach involves mapping the movements and actions of the operator's hand, as sensed by the Haption H-Glove, to control the qb SoftHand. This mapping allows the operator to manipulate the robotic hand in a way that mimics the natural movements and capabilities of a human hand. By leveraging the concept of synergy, the control method aims to create a seamless and intuitive interaction between the operator and the robotic hand.

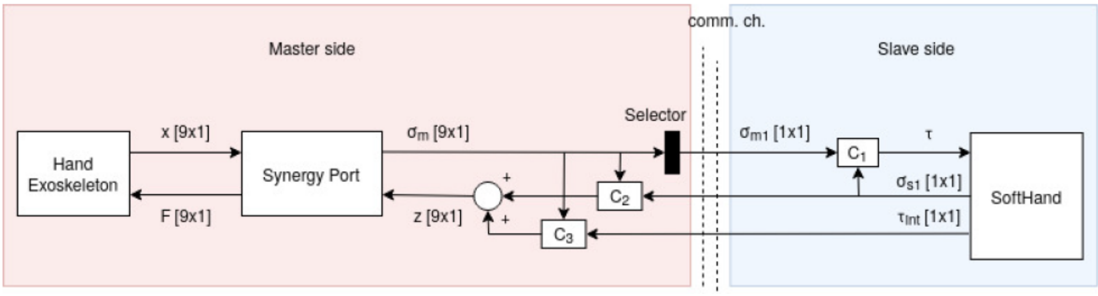

Figure 3.1: Synergy-Based Tele-manipulation with Haptic Guidance and Impedance Control [56].

In the study by Nadgere [56], the existing techniques were enhanced by introducing a pose tracking controller. This controller effectively guides the operator's finger tips along the first synergy, aiming to minimize the discrepancy between the remote and local hand positions. By aligning these positions more accurately, the overall grasping performance is improved.

One challenge encountered during the implementation of haptic feedback using the HGlove was the fluctuating nature of the feedback, particularly for low gripping velocities nearing zero. To address this issue, Nadgere extended the controller by incorporating a dead band controller.

The incorporation of a dead band controller helped mitigate the impact of inconsistent haptic feedback by introducing a threshold or dead zone within which no force feedback is applied. This dead zone is typically centered around the zero gripping velocity point. When the gripping velocity approaches zero or falls within the dead zone, the dead band controller effectively filters out any fluctuating or unreliable force feedback signals. By ignoring the fluctuating feedback in this range, the dead band controller prevents erratic or undesired force feedback from being perceived by the user.

3.3.2 Controller for Franka EMIKA-Panda robotic and Virtuoso

In the context of Section 2.4, it becomes evident that the handshake system must prioritize transparency. Complete transparency, which evokes the sensation of direct presence in the remote environment, is expected to lead to improved control, task performance, and reduced cognitive strain. This connection between heightened transparency and better results is in line with research by [45] and [44]. Achieving ideal transparency involves a precise alignment of position and force signals between the primary and replica devices, or a direct match between environmental and operator-perceived impedance [60]. From an application standpoint, the transparency criterion is paramount for tele-handshake systems. This criterion guarantees a genuinely effective and human-like handshake interaction between the operator and the recipient.

Three existing controllers were assessed for implementation in the system to conduct a user study. After thorough examination and comparison, the most suitable controller was selected. The existing controllers under consideration were:

- Classical bilateral impedance control(BIC) also known as Position-force architecture: one impedance controller which couples the primary and replica device.
- Classical bilateral impedance control with passivity(BICP): Adding a passivity layer to the BIC method [61].
- Bi-directional impedance reflection technique(BIR):a impedance reflection technique is designed based on the work of Hannaford [6]

3.3.3 Classical bilateral impedance control (BIC)

Classical bilateral impedance control (BIC) is a control strategy commonly used in bilateral teleoperation systems, BIC provides the necessary impedance connections for the primary and replica devices to create the energetic connection.

In BIC, the primary and replica devices are connected via a single impedance controller. Based on positions measured by the replica devices, the impedance controller modifies the forces applied to the primary and replica devices. This coupling allows for force feedback and ensures that the replica device exhibits the desired impedance behavior, as dictated by the impedance controller. Figure 3.2 shows a block diagram of classic bilateral teleoperation.

Bilateral teleoperation systems typically involve communication delays between the primary and replica devices. While time delays are not directly addressed in BIC, it is well-known that they can significantly affect the performance and stability of teleoperation systems. Time delays can introduce instability, reduce transparency (the sense of direct interaction), and affect the system's ability to transmit force and position information accurately [62]. Mitigating delays requires careful consideration and compensation technique.

Proper tuning of control parameters is essential for achieving satisfactory performance with classical BIC. Selecting appropriate gains and parameters can be challenging, and suboptimal choices can lead to oscillations, instability, or poor performance. To address the effects of friction and inertia present in the replica robot, the position-measured force architecture can be employed, which introduces a force sensor at the tip of the replica robot to provide force feedback to the user. This architecture allows the user to only perceive the external forces acting between the replica and the environment, resulting in a clearer sense of the environment.

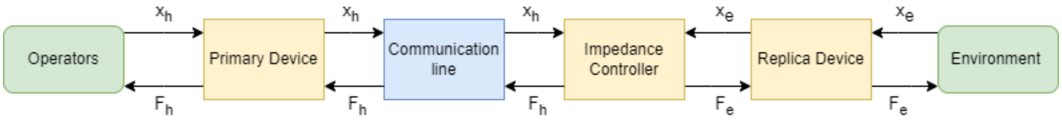

Figure 3.2: Classical Bilateral Impedance Control (BIC)

To derive the control equation for BIC, we can consider a basic proportional controller that adjusts the replica's position based on the force sensed at its tip. The force control equation in the Position-computed Force architecture is given by

$$F_h = F_e = K \cdot (x_e - x_h) \tag{3.1}$$

This equation represents:

- F_h is the desired force to be exerted by the of the operator.
- F_e is the desired force to be exerted by the remote robot.
- K is the spring stiffness
- x_e is the position of the remote robot, and
- x_h is the current position of the operator interface.

The force control equation in the BIC represents a basic proportional controller that adjusts the replica's position based on the force sensed at its tip. It relates the desired force (F_h) to be exerted by the operator's hand and the desired force (F_e) to be exerted by the remote robot, taking into account the spring stiffness (K) and the difference in positions between the remote robot's desired position (x_e) and the operator's current position (x_h).

When the spring stiffness (K) approaches infinity, the equation indicates that the forces exerted by the operator and the remote robot would become equal when their positions are the same, that is, when $x_h = x_e$. The presence of a time delay leads to heightened energy consumption as we interact with the spring through a communication channel with delays. When the spring stiffness is higher, it creates larger force disparities, subsequently causing more significant differences in power generation and increased energy consumption. This establishes a direct relationship between energy generation and spring stiffness. Nevertheless, this connection underscores a substantial constraint of the system: the un-attainability of an infinitely stiff spring.

As a result, there will always be a discrepancy between the operator's position and the remote robot's position, even if the spring stiffness is very high. This discrepancy reduces the transparency of the system, as the operator's perception of the remote environment may not precisely match the actual position or forces experienced by the remote robot.

3.3.4 Classical bilateral impedance control with passivity layer (BICP)

In the domain of bilateral teleoperation, the development of control strategies that balance both passivity and transparency has been a significant challenge. However, the emergence of the Bilateral Impedance Control with Passivity (BICP) controller offers a promising solution. The main objective of BICP is to maintain stable and transparent communication between the primary and the replica devices, even when the communication channel is subject to time delays and disturbances.

A system is said to be passive if the energy that can be extracted from it is bounded by the injected and initial stored energy. Any proper combination of passive systems will again be passive [63]. Passivity is an important concept in BICP, which refers to the property of a system that is able to store and dissipate energy. In BICP, passivity is used to ensure that the control system is stable, even when the operator applies excessive force or when there are disturbances in the communication channel. By leveraging passivity theory, the interaction between passive systems can be guaranteed to remain stable. The environment and human(operator) can be assumed to be passive, ensuring the passivity of the tele-manipulation system itself guarantee's passivity and thus stability in the interactions between the user/environment and the tele-manipulation system [64].

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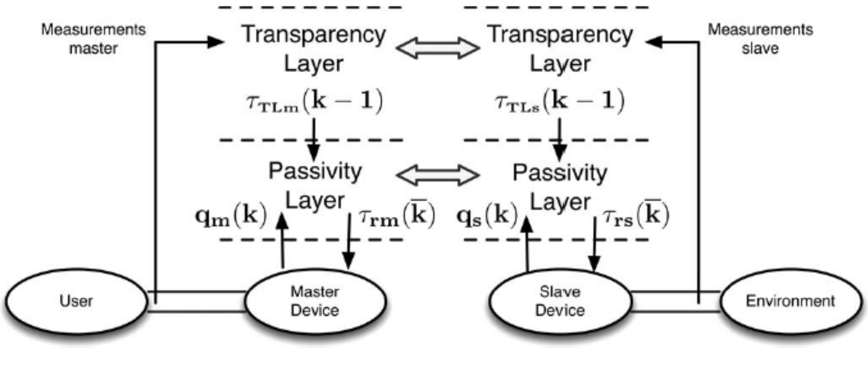


Figure 3.3: The bilateral tele-manipulation algorithm consists of a two-layer approach, where double connections signify an energetic interaction [61]

The control framework in [61] consists of a hierarchical structure comprising two layers. Each layer serves a specific purpose, either achieving transparency or ensuring passivity. The upper layer, known as the transparency layer, enables the implementation of a control structure that maximizes transparency in the tele-manipulation chain. It takes into consideration all available information about the system, environment, and user's task. The commands generated in this layer are then passed to the lower layer, referred to as the passivity layer. The passivity layer incorporates an algorithm to maintain overall system passivity. This algorithm revolves around defining two interconnected energy storage tanks, which power the motions of both the slave and the master. The passivity layer operates in a manner that treats energy in the broadest possible sense, without relying on assumptions about time delays in the communication channel.

In a telemanipulation system, where a slave device is controlled by a master device. Every movement of the slave device incurs an energetic cost, which must be present at the slave side when the movement is executed. The passivity condition requires that the same amount of energy has been injected by the user at the master side and transported to the slave side. Energy exchange between the master and slave systems is necessary, but due to time delays, simultaneous monitoring of energy exchange is not possible. To address this, lossless energy tanks are introduced at both sides, serving as an energy budget for controlled movements. The level of these tanks determines the system's movement restrictions, and if the tank is empty, no controlled movement is possible. The passivity layer adjusts the commands of the bilateral controller to maintain passivity, but this may decrease transparency. Figure 3.4 indicates the two steps of the energy flow computation where $\dot{q}(t)$ represent the velocity vector of the actuators at time t and $q(k)$ the sampled position vector of the actuators at sample instant k.Consider the sample period to be $\bar{k}$, where k is used to indicate instantaneous values at the sampling instant k and $\overline{k}$ indicates variables related to an interval between sampling instants (k-1) and k. The torques exerted by the actuators on the robot during sample period $\overline{k}$ is given by $\tau_r\ \overline{(k)}$ which is held constant during the sample interval

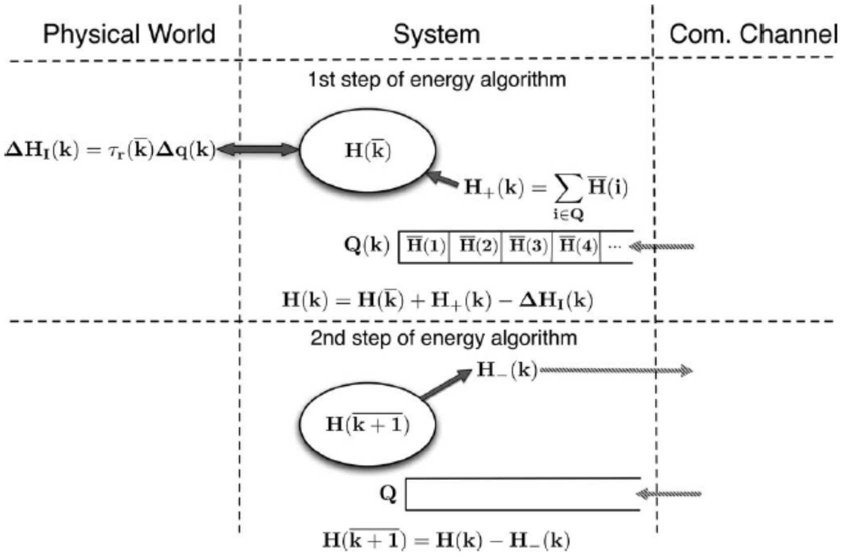


Figure 3.4: The processing of energy flows involves two steps. Firstly, the energy received from the communication channel is added to the energy tank level, while the energy exchanged with the physical world is subtracted from the energy level. Secondly, an energy packet is transmitted to the other system. The double arrow signifies that the energy exchange with the physical world can be either positive or negative [61]

3.3.5 Bi-directional impedance reflection

The concept of "bi-directional impedance reflection" (BIR) is a control technique in telemanipulation systems. It involves mirroring the impedance of the remote environment back to the operator. The BIR control system, aims to achieve improved transparency in the presence of time delay. This control method, proposed by R.J. (Robin) Lieftink in a research paper [6], presents a simplified model of the master and slave devices and utilizes impedance reflection to mitigate the impact of time delay.

In traditional position-force architecture, an impedance controller is employed to evaluate the forces exerted on the master and slave devices, establishing a physical connection between them. However, introducing latencies in the system leads to uneven dynamic characteristics on both sides, reducing transparency and stability. To address this, the BIR control method adopts a position-position architecture and reflects the impedance of the operator to the remote robot and back to the operator in a bidirectional manner. In BIR, the master device directly interacts with a model of the environment and the remote robot with a model of the operator. Instead of transmitting forces, communication involves the exchange of impedance/model parameters and positions. These parameters are estimated using sensory information from both sides. The advantage of this approach is that time delay does not directly affect the system, as the master and slave devices are decoupled, and force feedback is calculated locally. This design enhances transparency and maintains system stability.

The impedance estimator of the environment estimates the impedance based on the measured force and corrects any deviation between the reflected impedance and the measured impedance. Additionally, a trajectory predictor is introduced as an enhancement to the BIR system to account for the temporal delay in the motion of the master and slave, enabling faster estimation of the surroundings. Figure 3.6 illustrates a schematic representation of the controller design. As depicted, both the master and slave have a local model where the impedance is adjusted based on the estimation made on the other side, and both the master and slave trajectories are predicted. Based on the master position X_m, the anticipated slave position $X_{p,s,d}$ and the estimated the stiffness of the environment - a force F_m is generated on the master side. Similarly, based on the expected master position $X_{m,s,d}$, the slave position X_s and the estimated operator impedance the generated forces F_s on the slave side are determined.

$$F_m = \hat{K}_m(X_m - X_{p,s,d}) \tag{3.2}$$

$$F_s = \hat{K}_s(\eta)(X_s - X_{p,m,d}) \tag{3.3}$$

A force threshold F_{thres} is used to determine if an object is touched. If the measured external force F_{ext} is below the threshold, a low impedance K_{low} is used to prevent the operator from feeling the dynamics of the manipulator during free movement. It is important to note the method assumes the rigid environment. When the force exceeds the threshold, a high stuffness is used to represent the rigid environment. The advantage of using a low impedance during free space movement is that the operator doesn't feel the dynamics of the manipulator.

The method estimates the operator's impedance is based on the co-contraction level of specific muscle pairs in the arm. Co-contraction refers to the simultaneous activation of muscle pairs. By adjusting the co-contraction level of these muscle pairs, the impedance level of the operator, such as the stiffness or resistance, can be modified. This adjustment is done without changing the limb configuration or the exerted force.

The normalized contraction levels of the $\hat{\alpha}_{flexor}$ and $\hat{\alpha}_{extensor}$ muscles are limited to positive values. The co-contraction level, which represents the commonality between these muscle groups, can be determined using the following equation:

$$\eta = \min(1, \hat{\alpha}_{flexor}, \hat{\alpha}_{extensor}) \tag{3.4}$$

To ensure that the impedance level does not exceed the maximum level, the value of $\hat{\eta}$ is restricted to be less than or equal to 1. It is possible for a higher value to occur if the maximum level is inaccurately determined during the calibration process.Finally, the normalized co-contraction level$\hat{\eta}$ is passed through a low-pass filter with a cutoff frequency of 5Hz. This filtering helps reduce the influence of high-frequency behavior.

The variation law for the impedance controller at the slave side can be expressed as

$$\hat{K}_s(\hat{\eta}) = K_{\min} + (\hat{\eta}) \cdot (K_{\max} - K_{\min}) \tag{3.5}$$

In this equation,$\hat{\eta}$ represents the filtered normalized co-contraction level, K_{min} denotes the minimum impedance level, and K_{max} represents the maximum impedance level. This variation law determines the slave-side impedance controller based on the filtered co-contraction level, allowing for adjustment within the specified minimum and maximum impedance range.

A simple linear trajectory predictor is employed using the velocity (v) and the delay t_{delay}. The predicted position X_p is calculated by subtracting the product of the velocity and delay from the current position $X_{current}$. This calculation is performed for both the master and slave devices in both directions.

$$X_p \leftarrow X_{\text{current}} + (v \cdot t_{\text{delay}}) \tag{3.6}$$

In summary, the trajectory predictor helps account for the time delay in communication by estimating the positions of the operator. A linear relationship between velocity, delay, and position is utilized for prediction purposes.

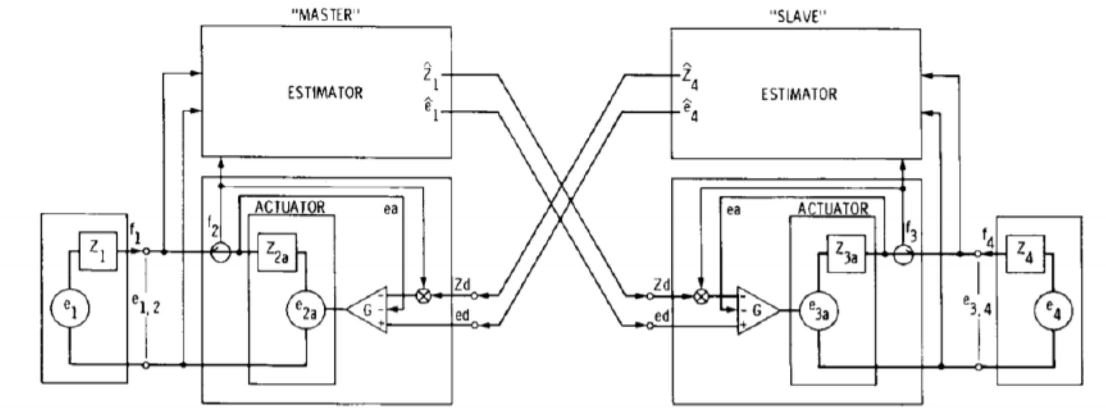


Figure 3.5: Bilateral impedance control proposed by Hannaford [65]

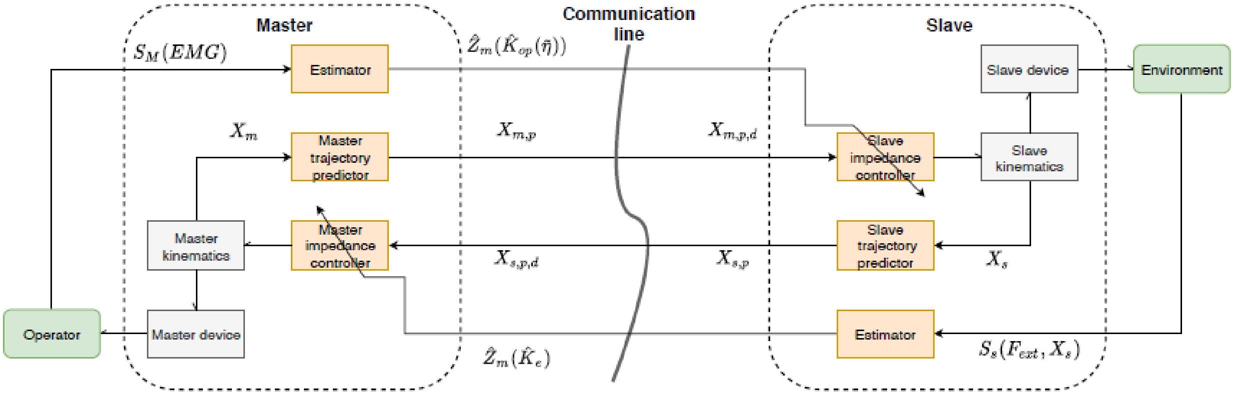


Figure 3.6: Overview of the bi-directional impedance controller. It involves estimating and exchanging impedance and trajectory information between the master and slave sides [6]

3.3.6 Comparison between BIC,BIR and BICP

In our study, we primarily on comparing the effectiveness and user experience of Classical Bilateral Impedance Control with Passivity (BICP), Bi-directional Impedance Reflection (BIR), and Classical Bilateral Impedance Control (BIC).

Classical Bilateral Impedance Control (BIC) establishes a direct connection between the operator and the remote robot through impedance matching, providing force feedback and interaction. However, it can face challenges with stability and transparency when dealing with time delays. Bi-directional Impedance Reflection (BIR) takes a different approach by decoupling the master and slave devices, reflecting impedance back and forth. This design enhances transparency and stability by localizing force feedback calculations and mitigating the impact of time delays. Classical Bilateral Impedance Control with Passivity (BICP) seeks to balance transparency and stability. It employs a dual-layer structure with a transparency layer and a passivity layer. This method leverages passivity theory to ensure stable interactions even in the presence of time delays, though it may require increased computational complexity due to its dual-layer approach. The choice among these strategies depends on the specific needs of the teleoperation system, including transparency requirements, time delay considerations, and implementation complexity. Table 3.1 gives the comparison between BIC, BIR and BICP.

When considering the absence of time delay, Bilateral Impedance Control with Passivity (BICP) emerges as the preferred choice among the evaluated control approaches. Our study highlighted that BICP provides enhanced stability and satisfactory user experiences compared to Classical Bilateral Impedance Control (BIC) and Bi-directional Impedance Reflection (BIR). The incorporation of passivity bounds in BICP ensures energy dissipation, stability, and controlled energy flow between the master and slave systems. This leads to a more transparent and intuitive force feedback for the operator, fostering a better sense of control and interaction with the remote environment. BICP's positive and satisfactory user experiences indicate its effectiveness in providing a reliable and enjoyable teleoperation experience, even without the influence of time delay.

While BIR may show promise in scenarios with high time delay, its performance may be compromised in situations without time delay. The system is new and yet to be tested. It's ability to reflect the environment's dynamics and provide transparency can help operators overcome the challenges associated with time delay, resulting in a more intuitive and immersive teleoperation experience. Therefore, in scenarios where high time delay is a significant concern, Bi-directional Impedance Reflection (BIR) could be a suitable choice. It offers the potential for improved stability and user experience by directly reflecting the forces and motions experienced by the robot to the operator, even in the presence of significant time delay.

Since we are not considering time delay in our study, Bilateral Impedance Control with Passivity (BICP) emerges as the preferred choice over Bi-directional Impedance Reflection (BIR). By selecting BICP, operators can benefit from improved stability, performance, and task execution while maintaining a high level of user satisfaction. It offers the advantages of stability guarantees and transparency, enabling operators to perceive and manipulate objects remotely with confidence and precision.

Considering the advantages of the BICP controller over BIC and BIR, several key points stand out:

1. Passivity and Stability: One of the primary advantages of BICP is its focus on passivity and stability. BICP is designed to maintain stable communication between the primary and replica devices even in the presence of communication delays and disturbances. This emphasis on passivity ensures that the control system remains stable and energy bounded, preventing instability issues that can arise in traditional BIC due to time delays. BICP's foundation in passivity theory provides a strong guarantee of stability.

2. Transparency and Responsiveness: BICP also strives to achieve high transparency, allowing the operator to feel a direct connection to the remote environment. By incorporating a two-layer approach with transparency and passivity layers, BICP can optimize both transparency and stability simultaneously. This is in contrast to BIR, which decouples the master and slave devices but primarily focuses on transparency, potentially sacrificing stability.

Table 3.1: Comparison of BIC, BIR, and BICP

Aspect	BIC	BIR	BICP
Control Strategy	Position-Force architecture	Modified Position-Position architecture: Predicted positions are sent along with impedance estimates.	Two-layer approach: Transparency and Passivity
Interaction Principle	Forces exchanged between devices	Impedance and model parameters exchanged	Impedance and position exchanged
Main Objective	Force feedback and impedance match	Transparency, stability, and delay handling	Stability, transparency, and passivity
Delay Handling	Not directly addressed	Decoupled devices and local force feedback	Passivity theory and energy exchange
Stability	Depends on tuning and delay	Utilizes impedance reflection	Ensured through passivity theory
Transparency	Affected by delays and tuning	Enhanced through impedance reflection	Balances transparency and passivity
Energy Consideration	Not explicitly considered	Accounts for energy exchange	Maintains energy balance for stability
Architecture	Single impedance controller	Mirrored impedance for transparency	Dual-layer approach for stability and passivity
Impact of Time Delay	Can lead to instability and issues	Mitigated through impedance reflection	Mitigated through passivity-based approach

3. Mitigating Delay Effects: While both BIC and BIR need to deal with the challenges posed by communication delays, BICP tackles this issue head-on. The passivity layer in BICP helps to mitigate the negative effects of delays, maintaining system stability by managing the energy flows between the devices. BIR might achieve transparency, but it does not explicitly address stability concerns arising from delays.

4. Broad Applicability: BICP's passivity-based approach is generally applicable to various teleoperation scenarios. It takes into account the passivity of the environment, operator, and tele-manipulation system itself, ensuring stability across different contexts. BIR, on the other hand, is new design and yet to be tested.

   In summary, the BICP controller stands out as a strong contender due to its focus on passivity, stability, transparency, and energy management. While BIC and BIR have their merits, BICP's comprehensive approach addresses many of the challenges posed by communication delays, disturbances, and energy exchange, making it a promising choice for teleoperation systems where stability, transparency, and robustness are critical factors.

4 User Study

The goal of the user study is to demonstrate the system's ability to create a human-like tele-handshake experience. By considering the inputs mentioned earlier, we design an experiment that provides valuable insights into how users perceive the tele-handshake interaction.

4.1 Experimental Set Up

Tele-handshake is a technology that recreates the experience of shaking hands in a remote environment. It lets people in different places virtually shake hands through robotic devices and advanced communication tools. In this study, The system incorporates an range of robotic hardware components on both the operator and recipient sides. On the operator side, one person(in this study its a participant) plays the role of the operator. They control the robotic devices and make the handshake motion. The operator's actions are then sent to the recipient side. On the recipient side, another person(in this study untrained actor) acts as the recipient. They feel the handshake motion through recipient equipment and react to it.

The operator's side, serving as the primary side (see figure 4.2), encompasses the utilization of the Virtuose 6D robotic arm [39] and the H-Glove [37] exoskeleton. On the recipient side, which corresponds to the mirrored setup (see figure 4.1), it involves the integration of the FRANKA EMIKA-Panda robotic arm [40] and the qb robotic soft hand [38] (depicted in figure 4.1). To capture a high-quality view of the remote environment, a Zed mini stereo camera [42] is employed, transmitting its output to the HTC VIVE Pro Eye [41]—a head-mounted display (HMD) worn by the operator (visible in figure 4.2) on the primary side. Comprehensive details regarding each hardware component and its specifications is presented in Section 2.3. Note that this user study is majorly focused on operator side of the handshake and only qualitative data has been collected from the recipient side.

Figure 4.1: The recplica side of the telerobotic setup consists of a Franka Emika Panda Robotic Arm and QB Softhand

In order to comprehensively gauge the visual impact of the tele-handshake interaction, the camera has been strategically configured in two distinct modes:

1. *First perspective view: Depicted in Figure 4.3, offered participants to see the recipient side(including face, body and the recipient robotic hand) from their own perspective.*
2. *Third perspective view:As illustrated in Figure 4.4, enabled participants to observe themselves from an external viewpoint, with only the recipient robotic hand visible.*

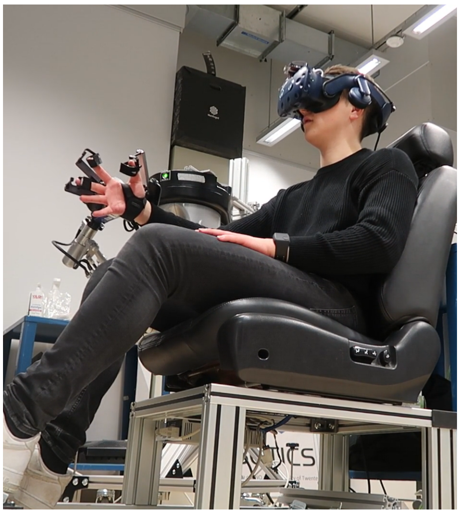


Figure 4.2: The primary side of the telerobotic setup consists of a Virtuose 6D and H-Glove, enabling precise control and haptic feedback for an immersive user experience.

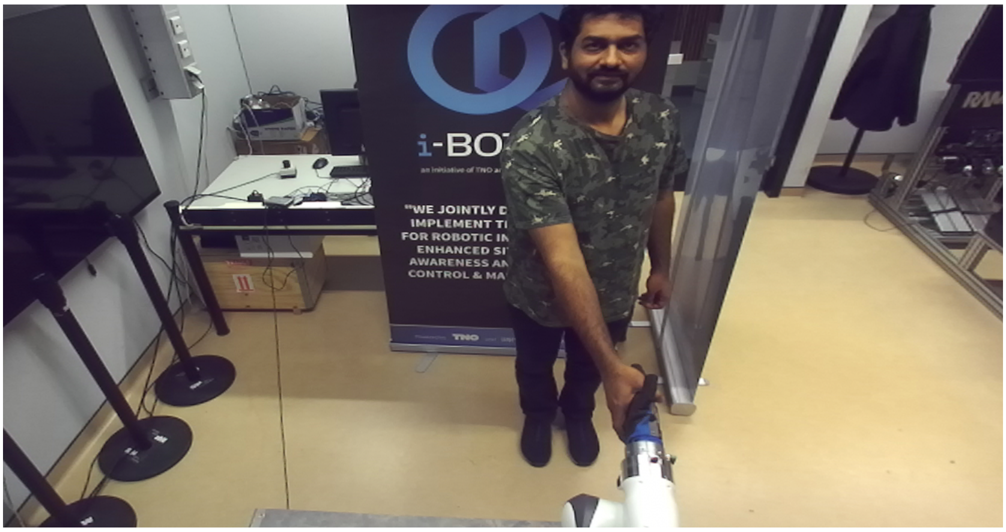


Figure 4.3: Immersive First-Person Visual Experience

Figure 4.4: Third-Person Visual Experience

The Virtuose 6D employs haptic feedback through a passive bi-directional impedance controller, which reflects the estimated impedance of the remote environment. The Virtuose 6D is also equipped with gravity compensation to impart a weightless feel to its end-effector, thereby mitigating fatigue stemming from its own weight. It's important to note that the configuration of the Franka arm, based on specific tasks, can potentially lead to joint limits being exceeded. This can trigger an error mode that locks all joint movements, disrupting the user experience. To circumvent this, the controller of the Virtuose and Franka arm integrates rotational springs into each joint, pushing the arm away from its joint limits based on the proximity to the respective joint, as detailed in [60].

4.2 Experimental Design

The experimental design employed in this study is a mixed design. We manipulated one independent variable between groups: visual perspective (first person and third person). Within the group, we manipulated haptic feedback.

To manipulate the Sense of Embodiment (SoE) in the study, haptic feedback was chosen as the primary sensory cue, aiming to enhance participants' perception of physical contact and embodiment during the tele-handshake interaction. We observed the effects of these manipulations and factors on the following dependent variables: sense of ownership, sense of agency, self-location, and cognitive workload.

Within the experimental group, we introduced six distinct conditions as illustrated in Table 4.1. As a handshake involves mutual interaction, both the participant and the untrained actor on the recipient side play interactive roles. While the untrained actor does engage with the recipient's robotic hand during the handshake, the extent and nature of their reaction varied based on the condition, influencing the vigor or intensity of their response. This two-way communication aspect was considered to ensure a comprehensive exploration of the handshake interaction, adding another layer of complexity to the study.

The experimental conditions and their corresponding force feedback manipulations are outlined in Table 4.1. he type of force feedback employed is kinesthetic. Haptic feedback encompasses various sensory cues such as touch and vibration, simulating physical interactions. Kinesthetic force feedback is geared towards conveying forces and movements.

The table 4.1 outlines the distinct experimental conditions that were employed to investigate the impact of force feedback on participants' experiences within a teleoperated handshake context. Each row of the table represents a specific condition participants encountered during the study. The "H-Glove Feedback" column indicates whether haptic feedback was provided through the H-Glove device, with "No Feedback" denoting its absence and "On Feedback" indicating its presence. Similarly, the "Virtuose Feedback" column signifies whether force feedback was provided through the Virtuose robotic device. The "Recipient Reaction" column reflects whether the untrained actor on the recipient side responds. "No reaction" means the untrained actor did not respond intensely to the handshake, while "Reaction" means the untrained actor responded strongly to participants' handshake gestures.

	H-Glove Feedback	Virtuose Feedback	Recipient reaction
Condition - 1	No Feedback	No Feedback	No reaction
Condition - 2	No Feedback	No Feedback	Reaction
Condition - 3	No Feedback	On Feedback	No Reaction
Condition - 4	On Feedback	No Feedback	No Reaction
Condition - 5	On Feedback	On Feedback	No Reaction
Condition - 6	On Feedback	On Feedback	Reaction

Table 4.1: Different conditions involving haptic feedback and the researcher's reaction

To stream the remote environment to the operator, the system employs an HTC VIVE Pro Eye headset [41] and a Zed Mini stereo camera [42]. The Zed Mini stereo camera captures high-quality images of the remote setting. These images are subsequently processed and projected onto two virtual planes within the Unity environment. These planes act as surfaces onto which the camera images are projected.

These rendered images are then seamlessly displayed on the lenses of the HTC VIVE Pro Eye, a high-resolution head-mounted display (HMD). With a wide field of view, this HMD ensures that the operator's peripheral vision remains engaged. This setup allows the operator to interact with the remote environment intuitively, fostering a more natural and immersive experience.

The camera setup incorporated two distinct perspectives: the First-person view and the Third-person view. By utilizing these two different camera angles during the tele-Handshake study, valuable insights into the role of visuals in enhancing the sense of embodiment were gained. Half of the participants (the first 50%) were assigned to the first-person perspective view, while the other half (the remaining 50%) experienced the third-person perspective view. This arrangement enabled researchers to compare the effects of these perspectives on participants' experiences.

In addition to the analysis of camera perspectives, the study also gathered information about participants' regional backgrounds to explore potential influences on the tele-handshake experience. Although the participant sample size was relatively small, participants were categorized into 'East' and 'West' regions for exploration.

1. *East:* People with cultural backgrounds where a handshake was not the first form of greeting. For example, in India, Japan, and Spain, people greet each other with 'Namaskara' (folding of hands), bowing, kissing on cheeks, or hugs, respectively.
2. *West:* People with cultural background where Handshake is there first form of greeting like Netherlands, Germany.

A balanced representation was ensured, with 50% of participants from the 'West' region and the remaining 50% from the 'East' region.

Through the manipulation of these factors across six distinct conditions, researchers aimed to uncover how changes in haptic feedback and visual perspective shape participants' perceptions of teleoperated handshakes. Furthermore, the study delved into the impact of ethnicity by recruiting participants from diverse regions (see participant demographics in 4.4). This approach enabled researchers to investigate potential cultural influences on participants' reactions to the teleoperated handshake experience.

4.3 Measures

In a mixed design user study, within subjects we explored the effect of the manipulation of two dependent variables (force feedback of the Virtuoso and force feedback of H-Glove at two levels (on and off) in all the possible combination (by obtaining six conditions as represented in 4.1) on four independent variables (the sense of ownership, agency, self-location, and cognitive workload). Between subjects, we manipulated the vision perspective (first and third person perspective) and we observed the effect on the four dependent variables already mentioned. Finally, considering the region of origin we observed the effect of the demographics on the four dependent variables.

To assess the sense of embodiment, explicit measures have been developed that capture the subjective experience of embodiment. These measures involve surveys and interviews where individuals rate their level of embodiment or describe their experience. The explicit measures aim to tap into different aspects of embodiment, such as body ownership, agency, and presence. By utilizing these measures, valuable insights can be gained into how individuals perceive and experience their sense of embodiment.

4.3.1 Survey

The sense of embodiment is described by three sub-components, as outlined in [46]. These sub-components are as follows:

- Sense of Ownership: The sense of ownership refers to the feeling of considering an external object or device as one's own. For example, when teleoperating a robotic arm, a sense of ownership arises when the user feels a personal connection or ownership over that robotic arm. It involves the subjective experience of attributing the object or device to oneself, as if it is an extension of their own body [66].

- Sense of Agency: The sense of agency encompasses the feeling of being able to actively interact with the environment using the controlled device. It involves the user's confidence and trust that their intended actions will be accurately translated and reflected by the device. This sense of agency is crucial for establishing a seamless and responsive interaction, where users feel empowered and in control of the teleoperated device's movements and actions [67].
- Sense of Self-Location: The sense of self-location relates to the perceived spatial extent in which users feel they are situated. It involves users' awareness and understanding of the surrounding space while teleoperating, including aspects such as distance, position, and the properties of objects in the remote environment, such as their stiffness. Ideally, users should feel confident in navigating and maneuvering within this space, enabling them to move around comfortably and effectively interact with the teleoperated environment. This sense of self-location is crucial for creating a sense of presence and spatial immersion in remote operations. [68].

Cognitive workload: Cognitive workload refers to the mental effort and resources required to perform a specific task or cognitive activity. It encompasses the cognitive processes, such as attention, memory, decision-making, and problem-solving, that are engaged during task performance. Assessing cognitive workload provides insights into the level of mental demand or burden experienced by individuals while engaging in a particular activity. In the context of teleoperation or human-robot interaction, measuring cognitive workload can help evaluate the mental demands placed on users as they control or interact with robotic systems or remote environments. This assessment can provide valuable information about the efficiency, usability, and user experience of such systems [46] .

To evaluate both the Sense of Embodiment (SoE) and Cognitive Workload, the study utilized a survey adapted from previous works [69], [70]. Participants were asked to rate eleven items using a Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). Questions 1 and 2 measured the sense of ownership, questions 3 and 4 assessed the sense of agency, and questions 5 and 6 captured the sense of self-location. Additionally, questions 7-11 were designed specifically to measure Cognitive Workload.

For a comprehensive view of the complete survey, including all the questions, please refer to the study's appendix C.2. This survey allowed researchers to gain insights into participants' experiences of both the Sense of Embodiment and the level of Cognitive Workload during the task.

4.3.2 Interviews

The interview followed a semi-structured approach with a five-phase structure [71]. It covered general user experience, including questions about levels of Sense of Embodiment (SoE) similar to those in the survey. The semi-structured format allowed participants to provide detailed explanations of their perceived SoE levels. The interview questions for each phase can be found in Appendix C.3.

4.4 Participants

We recruited 30 participants (20 male, 10 female) for our experiment, aiming for diversity in terms of age and geographical region. Participants ranged in age from 18 to 34 years, with equal representation (51% and 49%) from the 18-24 and 25-34 age groups, respectively. Half of the participants were from the 'West' region, while the other half were from the 'East' region.

To minimize potential variations caused by impaired vision, we included participants with normal to normative vision. We also excluded participants with upper body injuries or issues to ensure equal task performance opportunities and minimize distractions. To maintain consistency and comparability, all participants were required to be right-handed since the equipment used in the experiment was designed specifically for right-handed individuals. The Virtuose 6D and H-Glove configuration used in the experiment was designed specifically for right-handed individuals. This criterion ensured the reliability and validity of the results obtained from the study. We specifically sought participants without prior experience with telerobotic setups or experiments related to the sense of embodiment (SoE). This ensured a fresh perspective and unbiased reactions from participants.

To acknowledge their time and effort, participants were provided with 10-euro vouchers as compensation, ensuring a positive and inclusive participant experience. These improved recruitment criteria and compensation aimed to enhance the experiment's quality and reliability.

4.5 Procedure and Tasks

In the user experiment, the participants were introduced to the project and given an overview of the tasks they would be performing. They were encouraged to ask any questions they had, with the assurance that their doubts and questions would be addressed at the end of the session. This approach aimed to provide participants with just enough information to perform the tasks while maintaining a natural interaction. To create a more realistic scenario, there was an untrained actor present on the recipient side of the handshake. However, participants did not meet the untrained actor at the beginning of the session, replicating the experience of meeting a new person in real life. To ensure efficiency and respect for participants' time, the entire session, including the semi-structured interview, will be conducted within a total duration of no longer than 70 minutes. This time constraint ensures that participants' engagement and focus are maintained, while still allowing for a comprehensive exploration of their experiences and perspectives.

The study began by obtaining informed consent from the participants, which involved signing a consent form. The participants were then asked to provide demographic information, including age, gender and region of origin. Additionally, they were asked if they engaged in any sports activities, specifying the sport and whether they participated at an amateur or professional level. Participants were also asked if they had any previous issues related to the upper body nerves or muscles, ensuring their awareness of the study's purpose and their involvement.

After the initial information collection, participants were provided with an explanation of the operator and recipient sides of the handshake. The first group of 15 participants experienced a first-person perspective of the camera, while the remaining 15 participants experienced a third-person perspective. This sequential approach allowed for a comprehensive examination of the tele-handshake experience from different perspectives, enabling insights into the effects of camera perspective on the participants' perception and engagement during the handshake scenario.

4.5.1 Operator side

Once the participants have filled out the necessary consent forms, they will undergo a calibration process for the H-Glove, which involves creating a synergy database specifically for the right hand of each participant. To calibrate the system, participants were required to perform a series of actions. Firstly, they needed to fully open and then close their hand to reach its maximum open and closed positions. Following this, participants were instructed to gradually close their hand from a fully open pose. Additionally, participants were asked to hold a ball in their right hand, which served as a guide for their grasping movement along the first synergy. This calibration ensures optimal performance and accuracy of the H-Glove during the experiment. Once a participant's hand has been successfully calibrated, they can proceed to the next step.

Once the participant's hand had been successfully calibrated, the Virtuose 6D and the Franka arm were clutched in. The Franka arm would only begin to replicate the movements of the Virtuose 6D once the participant was properly synchronized or "clutched in." "Clutching" refers to aligning world frames of master and slave devices . Accurate participant clutching is crucial to prevent workspace limitations. If clutched too high or too low, it can result in a limited remote workspace. This synchronization enabled the generation of haptic feedback through the Virtuose 6D. Following the completion of the calibration procedure and the participant being clutched in, the actual experimental tasks were initiated. Once the calibration process is complete and the participant's hand movements are locked in, they will be assisted in putting on the Head-Mounted Display (HMD) to further enhance the remote environment.

To simulate the effect of handshaking, a specific scenario is created for the participants. They are asked to imagine a situation where they will be meeting a professional colleague for the first time. With this scenario in mind, they are then instructed to shake hands with the untrained actor who acts as the recipient.

During the handshake, the participants are required to move the Virtuose 6D in such a way that it mimics the motion of shaking hands with the untrained actor, who has already extended their hand. The H-Glove provides haptic feedback, allowing the participants to feel a sense of touch and physical interaction during the handshake. After each handshake is completed, participants are instructed to gently return hand to their resting position. Following this, a questionnaire is administered to gain further insights into their experience during that particular condition.

The entire process is repeated six times, with a combination of different feedback conditions as outlined in Table 4.1.The conditions are not randomised as selection of participants are randomised. Each condition represents a unique combination of haptic feedback, of the H-Glove and Virtuose, as well as variations in the untrained actor's reaction to the handshake. During each repetition, participants are encouraged to engage actively and respond to the cues provided, taking into account the specific feedback condition presented.

Once the experiment is completed, participants will undergo an interview and survey session to gather valuable insights and feedback. Following the interview, a short break will be provided to allow participants to relax and mentally prepare for the recipient side of the experiment.

4.5.2 Recipient side

During the recipient side of the experiment, participants were informed beforehand that an operator is present on the other side of the room, responsible for controlling the movements of the robot arm. Participants will be informed that they will experience a robotic handshake created by the operator's hand movements, even though they cannot directly see the operators.

Participants will be required to react to the hand that is offered to them for a handshake, based on the cues provided by the movements of the robotic hand. No additional information about the operator will be provided to the participants during the experiment, ensuring a neutral and unbiased experience. One of the researchers will be present on the operator side to assist with the coordination of the experiment.

The task of reciprocating the handshake gesture will be performed once, but participants will have the option to repeat it one more time if they feel the need to become more familiar with the robotic handshake experience. This additional repetition aims to capture a more comprehensive understanding of participants' reactions and impressions.

After the recipient side of the experiment is concluded, a interview was conducted to gather feedback and insights from the participants. This survey will allow participants to provide their subjective opinions, preferences, and any additional comments regarding their experience with the robotic handshake.

5 Results

For the user study, a repeated measures 2x2 ANOVA was conducted to analyze the data. The p-value threshold was set at 0.05 to determine statistical significance. Please note that the results section primarily encompasses the analyses conducted from the operator's perspective in the study. Qualitative data collected from the recipient side of the experiment is presented in detail in Section 5.4.

The result section provides insights into the effects of force feedback, camera perspective, and regional differences on participants' experiences in the tele-handshake study. The analysis indicated that the change in force-feedback did not significantly influence variables such as sense of ownership, agency, and cognitive workload. However, the p-value of the sense of self-location was close to significance, indicating a potential influence that warrants further exploration. For what concerns the variation of camera perspective, it had no significant impact on variables such as sense of ownership, agency and self-location. However, the score attributed to cognitive workload between first-person and third-person perspective significantly differed, we observed a reduced cognitive workload in the first-person view. Finally, the analysis of regional differences highlighted only a significant influence of regional origin on participants' perception of self-location, but not of the other independent variables. Participants from the West region reported a stronger sense of self-location compared to participants from the East region, emphasizing the importance of considering cultural and contextual factors when designing tele-handshake systems for diverse regions. Following, we report the descriptive statistics of the previously summarized results.

5.1 Analysis of Force-Feedback Effects (With-in Study)

The study aimed to measure the effect of the manipulation of six conditions on the sense of ownership, agency, self-location, and cognitive workload. The manipulating of force feedback settings of both the H-Glove and Virtuoso devices. Operators experienced two levels of feedback (with feedback/without feedback) on their hand (H-Glove) and arm (Virtuoso), with some conditions providing feedback and others without feedback shown in table 4.1. The statistical analysis revealed not a significant difference among conditions. The specific manipulation corresponding to each condition is elaborated upon in Section 4.2.

Sense of Ownership:

The results indicated that there was no significant difference in the sense of ownership experienced by the participants across the six conditions (F(5, 29) = 0.855, p = 0.512, n.s.) (p > 0.05). This suggests that the variations in force feedback provided by the H-Glove and Virtuoso did not have a substantial impact on the participants' sense of ownership.

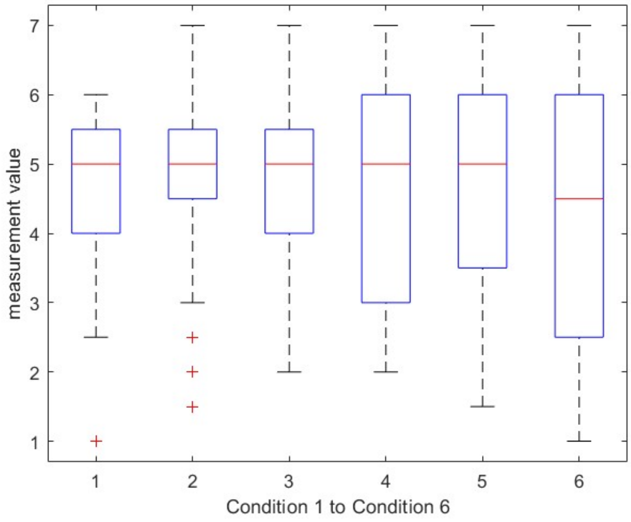


Figure 5.1: Sense of Ownership Across Six Conditions

Sense of Agency: Similarly, the analysis revealed no significant differences in the participants' perceived agency across the six conditions (F(5, 29) = 0.294, p = 0.9159, n.s.) (p > 0.05). The variations in force feedback did not appear to influence the participants' perception of control or agency over the virtual environment or the virtual objects.

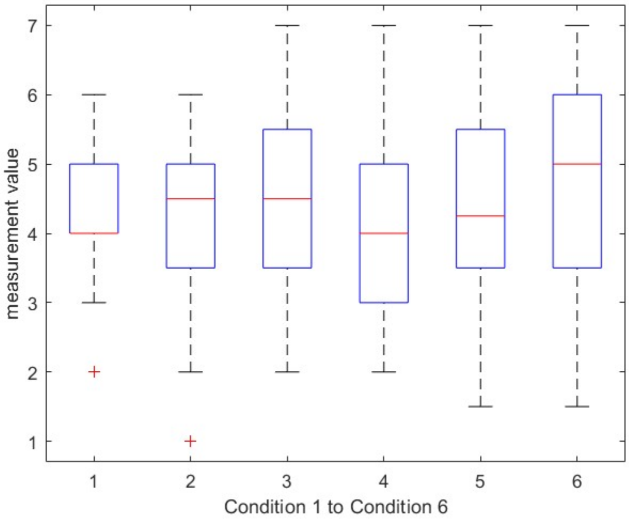


Figure 5.2: Sense of Agency Across Six Conditions

Sense of Self-Location:

The statistical analysis showed that there were no significant differences in the participants' self-location across the six conditions (F(5, 29) = 2.099, p = 0.0688, n.s.), indicating that the p-value obtained was close to, but still larger than, 0.05. This suggests that the variations in force feedback provided by the H-Glove and Virtuoso devices did not lead to notable changes in the participants' perceived location within the virtual environment.

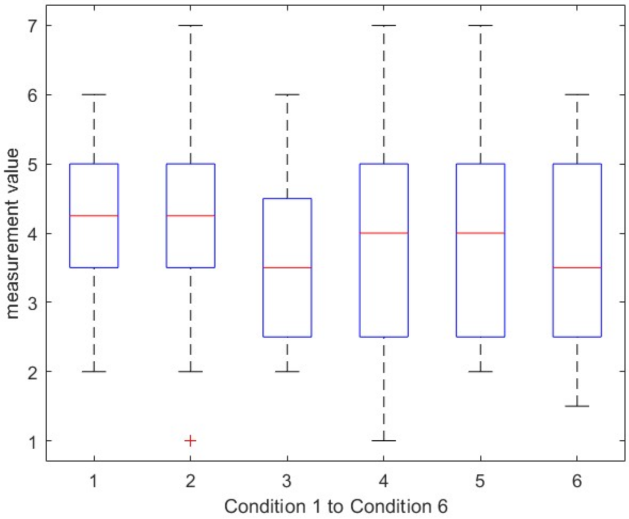


Figure 5.3: Sense of Self-Location Across Six Conditions

Cognitive Workload: The results also indicated that there were no significant differences in the participants' reported workload across the six conditions (F(5, 29) = 1.244, p = 0.2918, n.s.)(p > 0.05). The variations in force feedback did not result in significant variations in the perceived mental or physical demands of the task.

Overall, the findings suggest that the changes in force feedback provided by the H-Glove and Virtuoso device did not have a substantial impact on the sense of ownership, agency, self-location, or workload experienced

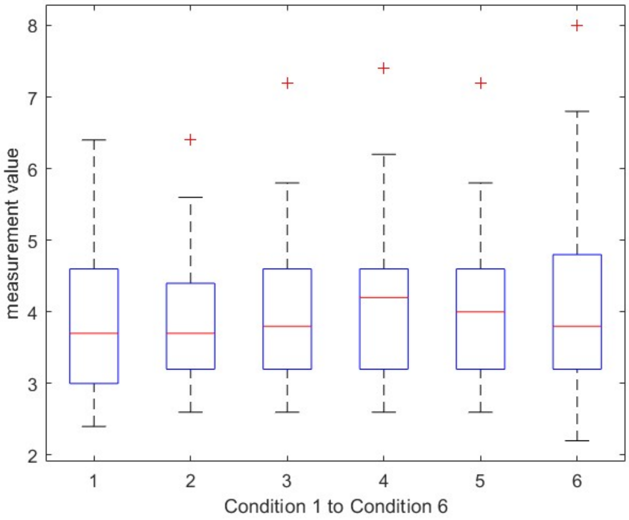


Figure 5.4: Cognitive Workload Across Six Conditions

by the participants. These results may indicate that the participants' perception and experience were not significantly influenced by the variations in force feedback within the context of the study.

5.2 Analysis of Camera Perspective and Regional Differences(Between Group)

5.2.1 Analysis of Camera Perspective Effects

Between subjects, we aimed at investigating the impact of different camera perspectives (first and third person) on the sense of embodiment components (sense of ownership, agency, self-location) and cognitive workload. We observed if the visual viewpoint variation influences participants' perceptions and engagement during tele-handshake interactions. Since, as reported above, we did not observe an effect of the force feedback, we report a between subjects comparison without considering force feedback as a relevant factor.

Sense of Ownership:

The analysis of the tele-handshake user experiment did not reveal a significant effect on the sense of ownership between the two camera perspectives (F(1, 28) = 1.4523, p = 0.35685, n.s.). Participants' sense of ownership did not significantly differ when experiencing the first-person perspective view (M = 4.4833) compared to the third-person perspective view (M = 4.6833). This suggests that the choice of camera perspective did not have a significant impact on the sense of ownership in the tele-handshake interaction.

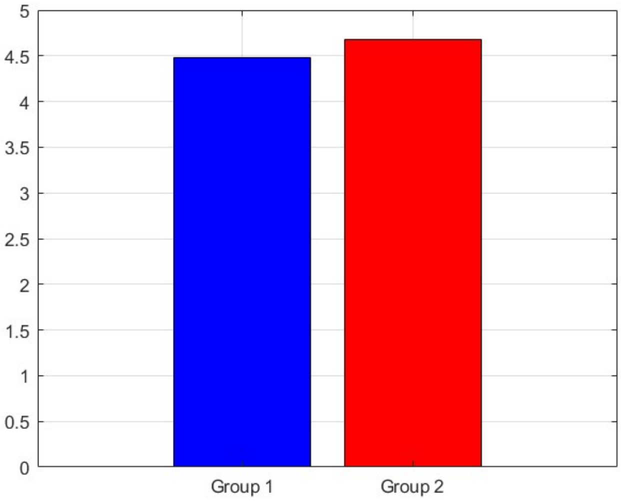


Figure 5.5: Sense of Ownership in Tele-Handshake: First-Person vs. Third-Person Perspective

Sense of Agency:

Similarly, there was no significant difference in the sense of agency between the two camera perspectives (F(1, 28) = 1.3358, p = 0.84538, n.s.). Participants reported similar levels of agency in the first-person perspective view (M = 4.3611) compared to the third-person perspective view (M = 4.4000). This indicates that the camera perspective did not significantly influence participants' perception of control and agency in the tele-handshake.

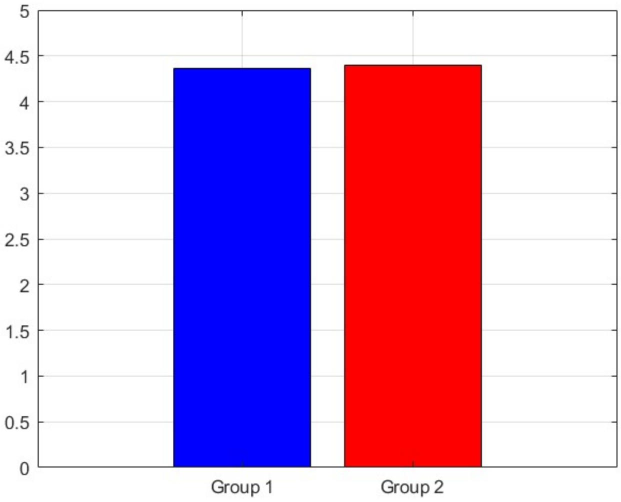


Figure 5.6: Sense of Agency in Tele-Handshake: First-Person vs. Third-Person Perspective

Sense of Self-Location:

The analysis of self-location data also did not show a significant effect between the first-person and third-person perspectives (F(1, 28) = 1.3310, p = 0.41789, n.s.). Participants' self-location ratings did not significantly differ between the first-person perspective view (M = 4.0167) and the third-person perspective view (M = 3.8556). Thus, the camera perspective did not have a significant impact on participants' sense of being present in the tele-handshake environment.

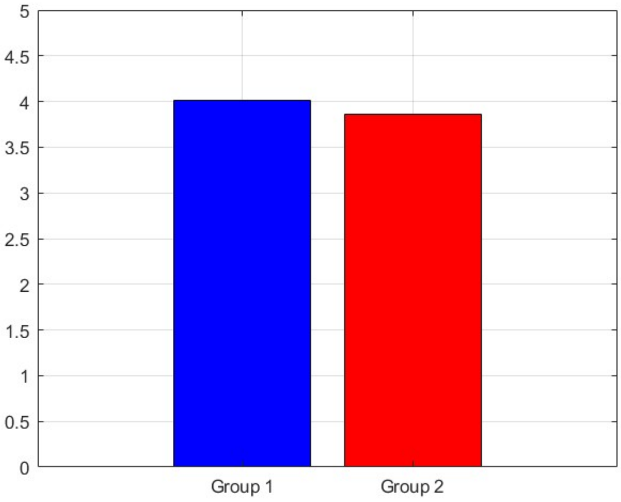


Figure 5.7: Sense of Self-Location in Tele-Handshake: First-Person vs. Third-Person Perspective

Cognitive Workload:

The analysis revealed a significant difference in cognitive workload between the two camera perspectives (F(1, 28) = 1.0726, p = 0.043929, n.s.). Participants' Cognitive Workload differ between the first-person perspective view (M = 3.8511) and the third-person perspective view (M = 4.1756). Although the p-value indicates a marginal level of significance, it suggests that there is a reasonable basis to believe that the difference in cognitive workload scores between the first-person and third-person perspectives is not due to chance alone.

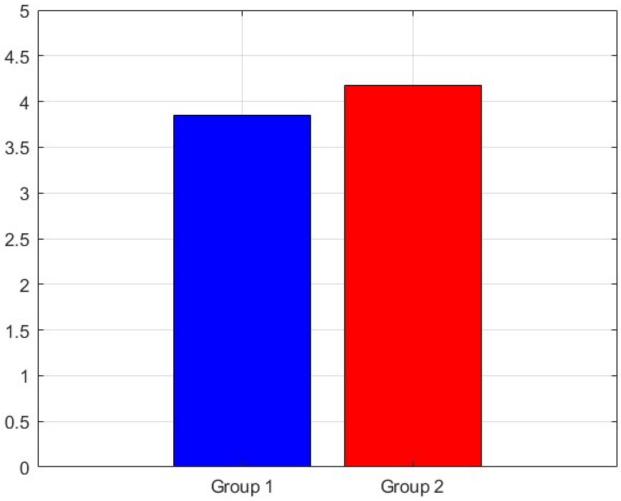


Figure 5.8: Cognitive Workload in Tele-Handshake: First-Person vs. Third-Person Perspective

5.2.2 Analysis of Regional Differences: East vs. West

We present the findings from the analysis of regional differences between participants from the East and West regions in the tele-handshake study. This analysis aimed to examine the impact of regional origin on variables such as sense of ownership, agency, self-location, and cognitive workload. Understanding how regional differences may influence participants' perceptions and experiences can be relevant in evaluating the generalizability and cultural influence of the study's findings.

Sense of Ownership:

The analysis of regional differences between participants from the East and West regions revealed no significant effect on the sense of ownership (F(1, 28) = 1.4519, p = 0.3307, n.s.). Participants from the East region (M = 4.6889) and the West region (M = 4.4778) reported similar levels of sense of ownership in the tele-handshake interaction. These findings indicate that regional origin did not have a significant impact on the sense of ownership experienced by participants.

Sense of Agency:

Similarly, there were no significant differences in the sense of agency between participants from the East and West regions (F(1, 28) = 1.3328, p = 0.35737, n.s.). Participants from the East region (M = 4.4722) and the West region (M = 4.2889) reported comparable levels of agency during the tele-handshake interaction. These results suggest that regional origin did not significantly influence participants' perception of control and agency in the tele-handshake.

Sense of Self-Location:

Regarding the sense of self-location, a significant difference was observed between participants from the East and West regions (F(1, 28) = 1.2928, p = 0.0009131). Participants from the East region (M = 3.611) reported lower levels of self-location compared to participants from the West region (M = 4.2611). These findings indicate that the regional origin significantly influenced participants' perception of being present in the tele-handshake environment.

Participants from the West region reported a stronger sense of self-location, suggesting a greater feeling of being physically situated within the tele-handshake environment. Conversely, participants from the East region reported a weaker sense of self-location, indicating a diminished perception of being present in the tele-handshake scenario.

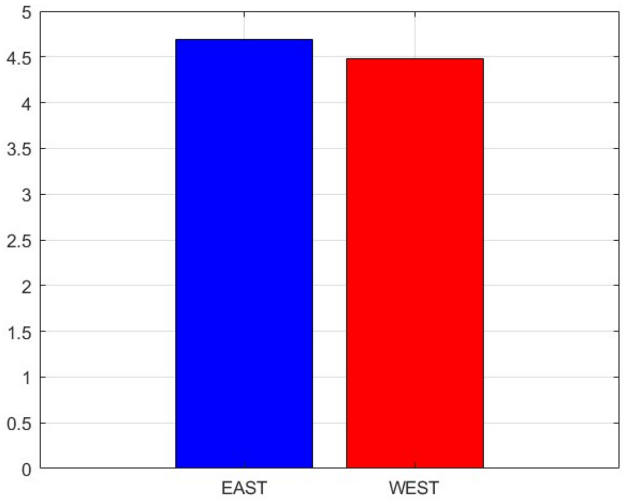


Figure 5.9: Sense of Ownership in Tele-Handshake: East vs. West

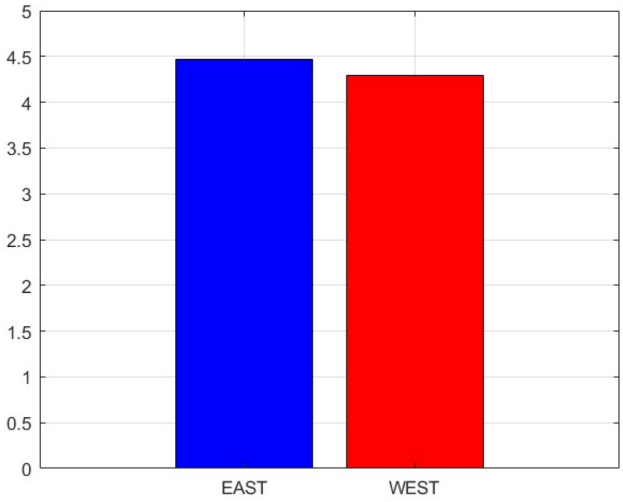


Figure 5.10: Sense of Agency in Tele-Handshake: East vs. West

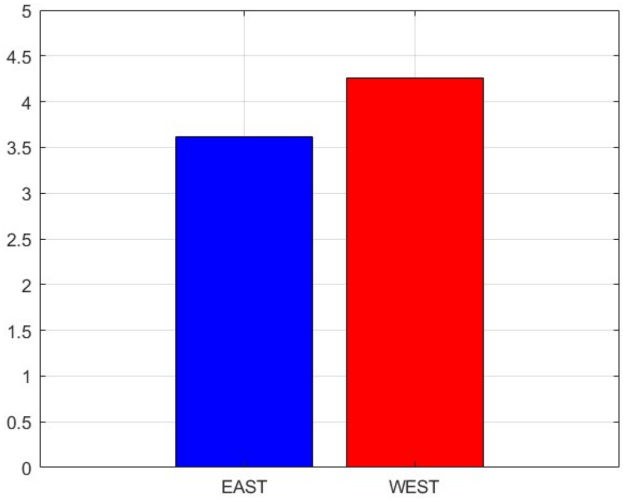


Figure 5.11: Sense of Self-Location in Tele-Handshake: East vs. West

Cognitive Workload:

Furthermore, no significant differences in cognitive workload were observed between participants from the East and West regions (F(1, 28) = 1.0832, p = 0.45838, n.s.). Participants from the East region (M = 3.9533) and the West region (M = 4.0733) reported comparable levels of cognitive workload during the tele-handshake interaction. These results suggest that the regional origin did not significantly influence the mental effort and demands experienced by participants.

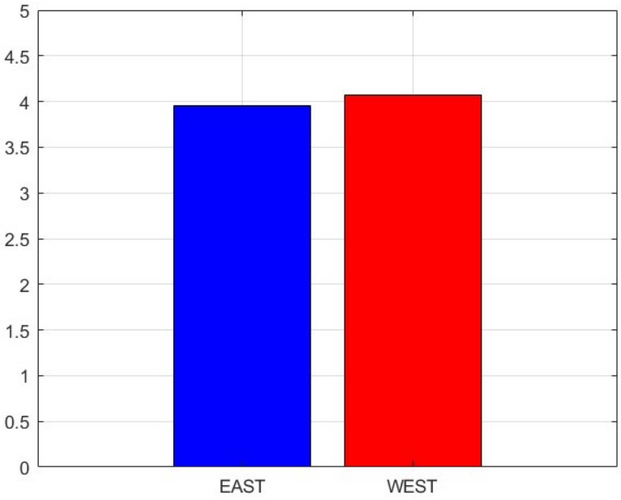


Figure 5.12: Cognitive Workload in Tele-Handshake: East vs. West

These results provide valuable insights for the development of tele-handshake systems, guiding the optimization of camera perspectives,consideration of force-feedback implementation,and acknowledging regional variations to enhance user experiences. By understanding the factors that influence users' sense of ownership, agency, self-location, and cognitive workload, we can strive to develop more effective and human-like tele-handshake interactions.

5.3 Interviews

The interview phase aimed to gain in-depth insights into participants' experiences and perceptions related to the sense of embodiment during the tele-handshake user study. Through open-ended questions and prompts, participants shared their subjective experiences, providing valuable qualitative data. Detailed interview transcripts capturing the participants' responses can be found in Appendix C.4, allowing for a more comprehensive understanding of their perspectives and enriching the qualitative findings of the study. In this revised version, the paragraph introduces the purpose of the interview phase and highlights the qualitative nature of the data collected.

5.3.1 Data Collection

The interviews were conducted individually with each participant after they completed the tele-handshake user study. The interviews were audio recorded with participants' consent to ensure accurate capture of their responses. The audio recordings were subsequently transcribed for analysis.The transcribed data has then been analyzed via IPA [72].

5.3.2 Interview Protocol

The interview protocol was carefully designed to explore participants' experiences during the tele-handshake user study and their perceptions of embodiment [71]. The questions were structured to encourage participants to reflect on various aspects of their tele-handshake interaction. The following are notable statements made by participants:

5.3.3 Initial Impressions

Participants' initial thoughts and expectations regarding the tele-handshake system are discussed. This section provides insights into their curiosity, expectations, and initial challenges they faced when encountering the tele-handshake technology for the first time.

"When I first heard about the handshake system, I was intrigued but also skeptical. I wondered if it could truly replicate it actual handshake. However, I was excited about the potential for connecting with others despite physical distance."

"I had high expectations before using the handshake system. I thought it would provide a realistic and immersive experience. I was eager to explore its capabilities."

"I found it difficult to connect with the remote partner through the handshake. The lack of physical touch and not able to actually close my hand made it hard to establish a sense of presence."

The participants' initial impressions of the tele-handshake system varied, reflecting a range of curiosity, excitement, skepticism, and challenges. While some participants were intrigued by the potential for connecting with others despite physical distance and had high expectations for a realistic and immersive experience of touch, others found it difficult to establish a sense of presence due to the lack of physical touch and limitations in replicating a handshake.

5.3.4 Tele-handshake Experience

This section provides observations and reflections of participants during the actual tele-handshake interactions, highlighting their perceptions of realism, challenges encountered, and the overall sense of connection they felt during the experience.

"During the handshake, I could feel the pressure and vibrations, which added a sense of realism to the interaction. It was fascinating to experience touch remotely, even though it was different from physical touch."

"I found it challenging to synchronize my movements with my remote partner. There were slight delays in the system, and it affected our coordination. However, despite the challenges, I still felt a sense of connection."

"While the technology and hardware were impressive, I felt that the system didn't fully engage me. I could sense the remote touch, but it didn't have the same depth as real physical contact. It felt more like interacting with a digital representation rather than truly feeling the other person's hand."

"Despite the technical limitations, the handshake experience allowed me to connect with someone in a distant location. It opened up opportunities for remote collaboration and bridging physical distances. Although it wasn't perfect, it sparked my imagination for the future of remote interactions."

The Tele-handshake Experience subsection showcases participants' diverse firsthand encounters with the tele-handshake system. While some participants found the system intriguing and felt a sense of realism through the sensation of pressure and vibrations, others encountered challenges in synchronizing movements and experienced slight delays in the system. Despite these challenges, participants still reported a sense of connection during the tele-handshake interactions.

5.3.5 Sense of Embodiment

The Sense of Embodiment refers to participants' subjective experiences of ownership, agency, and location within the tele-handshake user study. This section explores their perceptions and feelings related to these aspects.

Sense of Ownership

The Sense of Ownership refers to participants' perceptions and experiences related to their sensation that part of or the whole body belongs to oneself remote hand during the tele-handshake user study. The following participant statements provide insights into their sense of ownership:

"Having control over the remote hand provided me with a strong feeling of responsibility and the ability to direct its actions and movements."

"I experienced a limited sense of ownership over the remote handshake. To initiate a handshake, I had to exert excessive force and squeeze my fingers tightly, which created a disconnect between the remote hand and my own."

Participants' experiences with the sense of ownership during the tele-handshake varied. While some felt a strong connection and control over the remote hand, others reported a limited sense of ownership, experiencing challenges in establishing a personal connection.

Sense of Agency

These statements reflect the participants' varying experiences and highlight the importance of examining the sense of agency within the tele-handshake context.

"I had a combination of feeling in terms of control. At times, I felt in complete command on movements. But, there were also moments where I was restrictions I felt while trying to move the hand across."

"I had control over the hand. The handshake required a deliberate effort, as if I was doing each movement with a sense of purpose.

"The shape of hand and closing to fingers to give handshake was not comfortable."

"My experience of control fluctuated throughout the experiment. There were moments when I had complete command and could move the hand effortlessly but some times I was not able to control it at all. Despite all this, I still felt a significant level of influence over the actions of the virtual hand."

The participants' perception of control and active involvement varied, while some moments involved effortless control and a strong feeling of influence over the virtual hand, there were also challenges and limitations that impacted their sense of agency. However, on the whole, participants expressed a positive perception of agency. They highlighted their ability to express themselves and actively participate in the tele-handshake interaction.

Sense of Location

The sense of location refers to participants' perception of their presence and spatial position within the tele-handshake environment. This subsection explores participants' experiences and perspectives regarding their sense of location. The two groups of participants (first-person or third-person perspective) provided valuable insights into their perception of presence. The following participant statements highlight their experiences with the sense of location:

- Participant of First person perspective:

  "I was aware of my position, but at times, I experienced a slight disconnection. It was as if I existed in a separate reality where interaction with others was possible, yet I still had a sense of being separated."

- Participant of Third person perspective:

  "As I was seeing complete hand, I felt I was in complete control of hand but being present in remote environment not so much. It gave me the impression of watching a scene unfold, rather than having a physical presence in that remote side."

  "my experience varied, while I was able to observe the interaction between the hands, I did not feel natural."

  "I experienced a combination of feelings, While I could see the hand interaction, it gave me the impression of being an external observer rather than actively participating in the scene."

In conclusion, participants' sense of location within the tele-handshake system varied depending on their perspective. Those with a first-person perspective expressed awareness of their position within the remote space but also experienced a subtle sense of physical separation. Participants viewing the interaction from a third-person perspective described a more restricted sense of presence, feeling like external observers rather than active participants in the remote environment. These findings highlight the importance of further improving the tele-handshake system to enhance the feeling of presence and spatial immersion for a more immersive and engaging user experience.

5.3.6 Implications and Feedback

The implications and feedback section explores the potential applications of the tele-handshake system and incorporates participant feedback regarding its limitations and areas for improvement. Participants highlighted the potential benefits of the system for various applications, while also providing valuable insights into the limitations they encountered during the study. The following participant statements shed light on the implications and feedback

"The system has great potential for many applications. It can enhance collaboration and bridge the gap between individuals in long-distance relationships. It opens up new possibilities for sure."

"The lack of realistic touch sensations left me disconnected from the experience, making the handshake feel less like a natural interaction."

"While the handshake system provided a different feeling, I felt that there were certain part of touch that were missing. Improvements in touch could make the experience even more realistic."

"I felt the hardware was very weird. The locks around my fingers made it very difficult to feel handshake."

"Why that the brackets were positioned only on three fingers, leaving the other two fingers seemingly inactive. This gave the impression that these two fingers were somewhat neglected in terms of functionality. Moreover, the weight of the hand(H-Glove) felt notably heavy. It was distracting during the experiment."

The participant feedback highlights both the potential and limitations of the tele-handshake system. Participants recognized its potential for enhancing remote collaboration and facilitating intimate interactions across distances. However, the lack of realistic touch sensations and haptic feedback emerged as a notable limitation, hindering the overall sense of embodiment.

Interplay between Physical and Virtual Touch

The interplay between physical and virtual touch refers to the dynamic relationship between the sensation of touch experienced during the tele-handshake and the absence of physical contact. This subsection explores participants' experiences and perspectives regarding this interplay.

"I could sense the pressure and vibrations in the experiment, which made it feel more real. It was intriguing how the system simulated touch without physical contact."

"Even though it was a feel of resistance, it still created a sense of connection. I felt a surprising level of control over my remote hand."

"There was a sensation but noting close to real handshake"

The interplay between physical and remote touch within the tele-handshake system provided participants with intriguing tactile sensations. Despite the absence of physical contact, participants reported perceiving pressure, vibrations, and resistance, leading to a sense of connection and control. These findings highlight the system's ability to simulate touch and pave the way for immersive and realistic remote interactions.

Challenges of Synchronization and Co-Presence

The challenges of synchronization and co-presence refer to the difficulties encountered in coordinating movements and maintaining a sense of togetherness during the tele-handshake. This subsection explores participants' experiences and perspectives regarding these challenges.

"Coordinating movements with my remote partner was challenging because of hand movements delay. It felt sense of being in sync"

"We encountered instances where our movements didn't align perfectly, but we adjusted and synchronized, to some extent it felt organic connection."

In conclusion, participants in the tele-handshake study encountered challenges related to synchronization and co-presence. Delays in the system affected their ability to coordinate movements and achieve perfect alignment, impacting the sense of being in sync. However, participants demonstrated adaptability and were able to adjust their movements to maintain a level of synchronization and connection. Despite occasional discrepancies, participants experienced an organic sense of togetherness during the tele-handshake interaction. These findings highlight the importance of minimizing delays and optimizing system responsiveness to enhance synchronization and foster a seamless and connected tele-handshake experience.

Emotional Connection and Shared Presence

The participants' statements highlight the range of emotions and connections they felt during the interaction, considering factors such as visual cues, intentions, and the absence of eye contact.

"Despite the physical separation, I felt emotionally connected to my remote partner. I could see his face and gave sense of what was intention. We also shared a laugh "

" I did not see remote partner face and did not know it was female or male until you mentioned it was a differed situation never experienced such handshake. It felt every mechanical " –(Participant with Third person perspective)

"I did not experience a emotional connection during the tele-handshake. It felt more like a technical interaction rather than a personal connection."

"The handshake lacked the emotional depth I expected. I didn't feel emotionally engaged or connected to the person."

Participants' experiences varied regarding emotional connection and shared presence during the tele-handshake. Some felt emotionally connected, with the ability to see their partner's face and sense intentions. Others described a more technical or mechanical interaction, lacking emotional depth.

5.4 Qualitative analysis of recipient side

The qualitative analysis conducted on the recipient side of the experiment revealed valuable insights into participants' experiences and perceptions during teleoperated handshake interactions. Participants taking on the role of recipients provided a range of emotional responses and observations regarding the setup.

Upon transitioning to the recipient side of the experiment, participants conveyed a sense of disappointment with the arrangement. This sentiment stemmed from the encountered limitations, notably the inability to view the operator and the restricted visibility of the recipient's body, limited to the hand alone. This discrepancy markedly deviated from their customary understanding of a handshake. Nevertheless, participants displayed a strong fondness for the QB Soft Hand, recognizing its merits to the extent that some even inquired about the feasibility of exchanging the qb-Hand with the H-Glove. The challenges arising from visual and contextual constraints highlighted the significance of maintaining a comprehensive and authentic representation of the handshake experience.

6 Discussions

In the following section we explore and explain the outcomes of the study on tele-handshake interactions, by revisiting the initial research questions and proposed hypotheses. The study's investigation into the impact of visual cues, haptic feedback, and cultural factors on tele-handshake experiences allows for a comprehensive assessment of their significance and the resulting implications.

6.1 Hypotheses

6.1.1 Hypotheses - 1

-The manipulation of Sense of Embodiment (SoE) through visual perspective will have a significant effect on the perceived level of embodiment.

The first hypothesis proposed that the Sense of Embodiment (SoE) remains constant when manipulating visual perspectives (first person vs. third person). This hypothesis is not accepted. There is no significant differences in the Sense of Ownership (SoO), Sense of Agency (SoA), and Sense of Self-Location (SoS) between the two group.

However, the survey revealed that the camera perspective have an impact on cognitive workload. In particular, the study revealed that the first-person perspective had a slightly lower mean score of cognitive workload compared to the third-person perspective. Although the difference in mean scores may seem subtle, the significance of even minor variations in cognitive workload, showcasing their potential to notably influence participants' mental exertion and their perceived challenges during tele-handshake interactions.

The narrower deviation observed in the survey results of cognitive workload could be attributed to the fact that the first-person perspective seems to require less cognitive effort for navigating through the handshake process compared to the third-person perspective. This insight is supported by feedback gathered during interviews. Notably, participants expressed difficulties in maneuvering the robotic arm when viewing it from a third-person perspective. They encountered challenges in accurately assessing the arm's position along all axes, particularly its height from the ground (z-axis).

The absence of significant differences in Sense of Ownership (SoO), Sense of Agency (SoA), and Sense of Self-Location (SoS) between conditions could be attributed to a range of factors. Insights from the participant interviews shed light on potential reasons behind this lack of distinction.

Participants who experienced the first-person perspective mentioned that there was a noticeable discrepancy between the height at which they visualized the robotic hand and its actual real-life position at which they usually shakehand.This disparity might have been influenced not only by the camera's placement but also by the participants' individual heights. On the other hand, among participants who interacted with the third-person perspective, a different observation emerged. They appeared to handle the robotic arm with greater ease, likely due to having a clearer and more complete view of the hand's movements. However, a noteworthy drawback in this perspective was that these participants expressed a sense of unnaturalness stemming from their inability to see the person they were virtually shaking hands with. This aspect could have influenced their Sense of Self (SoS) and, to some extent, their Sense of Ownership (SoO) and Sense of Agency (SoA).

In summary, while no significant differences in Sense of Ownership (SoO), Sense of Agency (SoA), and Sense of Self-Location (SoS) were detected between the two visual perspectives, participant feedback revealed several contributing factors. Discrepancies in the visualization of the hand's height in the first-person perspective, potentially due to camera placement and participants' individual height, along with the reduced naturalness in the third-person perspective due to the absence of visual contact with the remote handshake partner, are key aspects that may have influenced the observed outcomes.

6.1.2 Hypotheses - 2

The sense of embodiment is highest when haptic feedback of both virtuose and h-glove is present.

The second hypotheses posits that the level of embodiment, will be at its highest when both the feedback from the virtuose system and the haptic glove are present. In simpler terms, the combination of feedback from the virtuose and feedback from the h-glove is expected to create a synergistic effect, leading to a stronger feeling of being embodied with the remote environment. Nevertheless, this hypothesis doesn't hold true.

The survey indicates that the variations in force feedback did not have a significant impact on the participants' perceived SoO, SoA, and SoS. But it is intersting to notice the p-value of SoS is 0.06 falls just outside the conventional threshold of statistical significance ($p < 0.05$), it is important to interpret these findings cautiously. The proximity of the p-value to 0.05 implies that there may be a trend or a potential effect that warrants further investigation. It is possible that a larger sample size or alternative analysis methods could reveal a significant difference. However, based on the available data and analysis, the current results suggest that the variations in force feedback did not have a significant impact on the participants' perceived self-location. It is important to acknowledge that other factors, such as individual differences or specific task characteristics, could have influenced the outcome.

The absence of discernible differences in Sense of Ownership (SoO), Sense of Agency (SoA), and Sense of Self-Location (SoS) despite the presence of haptic feedback can be attributed to several factors, with two primary explanations emerging from the participant interviews.

Anatomical Structure of H-Glove: Participants reported a notable issue stemming from the anatomical design of the haptic glove. Although they perceived the force feedback, the sensation was insufficient to convincingly replicate a handshaking experience. Participants mentioned that to simulate a handshake, they had to nearly clasp their fingers together, leading to an unnatural gesture. This discrepancy between the participants' natural hand movements and the required actions with the haptic glove hindered the establishment of a genuine sense of embodiment. The configuration of the exoskeleton, featuring only three fingers, created an unintended impression that the remaining two fingers were non-functional. This contributed to participants perceiving the act of shaking hands with only three fingers, which deviated from the natural and expected handshaking gesture involving all five fingers. This unnatural experience disrupted the participants' sense of embodiment and authenticity during the interaction.

Impact of Technical Limitations on SoA: Another plausible explanation revolves around the impact of technical constraints, which could have influenced the perception of Sense of Agency (SoA), consequently affecting Sense of Ownership (SoO). Insights from interviews highlighted the crucial role of SoA in shaping SoO. Instances in which the robotic system behaved unexpectedly or when participants faced difficulties in controlling the robot as intended disrupted the sense of being in control and engaged. For instance, participants recounted challenges in fully extending the robot's hand when necessary, leading to a disconnection from the illusion of embodiment.

6.1.3 Hypotheses - 3

Individuals from cultures emphasizing physical touch and interpersonal closeness are expected to feel a stronger sense of embodiment during Tele-handshake interactions compared to individuals from cultures that place less emphasis on physical touch and interpersonal closeness.

This hypothesis suggests that people from cultures that highly value physical touch and close interpersonal relationships will likely experience a more profound sense of embodiment during Tele-handshake interactions. In contrast, individuals from cultures where physical touch and interpersonal closeness hold less significance are anticipated to have a comparatively weaker sense of embodiment in similar interactions. This hypothesis can be partially accepted.

The survey outcomes reveal that ethical background among participants did not significantly influence their perceptions of Sense of Ownership (SoO) and Sense of Agency (SoA). However, a substantial distinction emerged in the context of Sense of Self-Location (SoS). Notably, the p-value associated with SoS is 0.0009131, falling beyond the conventional threshold for statistical significance ($p < 0.05$). This statistical indication confirms that sense of self-location was indeed significantly impacted. This indicated that participants from the West region reported a stronger sense of self-location, suggesting a greater feeling of being physically situated within the tele-handshake environment. Conversely, participants from the East region reported a weaker sense of self-location, indicating a diminished perception of being present in the tele-handshake scenario for the details please 5.2.2.

The difference in sense of location between the Western and Eastern participant groups could be due to several factors, including cultural and psychological influences. One possible reason is that handshaking is a common social practice in many Western cultures, symbolizing greetings and agreements. The frequent practice of handshaking in Western cultures might make participants from these backgrounds more comfortable with the concept. As a result, they could feel a stronger sense of location during the tele-handshake interaction. In contrast, Eastern cultures might not emphasize handshaking as much, leading to less familiarity and comfort with the gesture. This could result in a lesser sense of location for participants from Eastern backgrounds. The cultural variation in handshaking practices could explain the observed difference in sense of location between the two groups.

While potential reasons for the difference in the sense of location between the Western and Eastern participant groups can be theorized, the exact cause remains uncertain. To gain a deeper understanding of this phenomenon, further investigation is required. Conducting in-depth studies that consider cultural nuances, individual perceptions, and additional variables could illuminate the underlying factors contributing to this observed disparity. Such an investigation might involve more extensive participant interviews, cultural sensitivity analyses, or even neurological research to delve into the cognitive processes at play. Only through a comprehensive exploration can the intricate reasons behind this difference in the sense of location be uncovered and a more conclusive explanation provided.

6.2 Research questions

6.2.1 Research Question - 1

-What aspects of a handshake are most relevant to reproduce a human-like handshake experience in the context of teleoperation?

Addressing first research question, Through the literature review aspects that influences the handshake was studied along with what aspects of handshake influence the tele-handshake within the context of teleoperation. Through this it was evident that aspects like Grip, Gasp, duration, frequency, synchronization, temperature, texture , anatomical consistency, gender, ethnicity ,visual cues, facial cues and smell do play role in handshake. However, which of these aspects are most relevant for reproduce a human-like handshake experience in teleoperation.

The study on handshake feasibility, as discussed in 2.4, delved into various aspects, but directed the study with a focus on the integration of haptic feedback alongside visual cues and the influence of ethnicity. The conducted user study centered around exploring the integration of haptic feedback, visual cues, and ethnic backgrounds. Notably, the outcomes of the study indicated that while factors like visual perspective and ethnicity had some influence, the presence of haptic feedback alone did not yield statistically significant differences.

After conducting thorough interviews with all 30 participants, it became abundantly clear that achieving a truly lifelike handshake experience within tele-operated scenarios hinges on three critical factors.

First and foremost, the observer's perspective emerged as a pivotal influence on the perception of the handshake. However, it's important to note that the visual representation employed in our experiment might not have been the most suitable. This inference was drawn from the participants' consistent expression of dissatisfaction with the provided views, regardless of whether it was presented from a first-person or third-person perspective.

The second crucial factor, as highlighted by participants, revolves around the imperative of improving the anatomical structure of the operator's exoskeleton design. The discomfort and unnatural feel stemming from the current design were emphasized as hindrances to creating an authentic handshake experience.

Lastly, the seamless synchronization of movements between the tele-operated exoskeleton hand, the Franka arm, and the qb softhand emerged as the third vital factor. It's worth noting that the response time of the Franka arm and qb softhand was considerably slow. This delay, attributed to factors such as latency and response time, significantly impacted the synchronization between the different components of the system.

6.2.2 Research Question - 2

- What technical considerations and challenges need to be addressed to replicate a human-like handshake through teleoperation?

Replicating a realistic handshake through teleoperation involves several intricate technical considerations and challenges. These are the critical technical challenges that have been identified and must be addressed to achieve a human-like handshake through teleoperation.

- H-Glove Design and Comfort: During the interview process, participants consistently expressed their dissatisfaction with the HGlove brackets, citing discomfort as a predominant issue. These brackets frequently came loose, undermining the overall user experience. Notably, the concentrated weight on the back of the hand led to a lack of flexibility, causing further inconvenience. Evidently, the primary and foremost challenge revolves around significantly enhancing the design and functionality of the HGlove.
- Wrist Movement Incorporation: During the assessment phase, numerous participants consistently highlighted a notable obstacle they encountered while attempting to manipulate the robot arm's wrist. Given the pivotal role of wrist movement in executing a convincing handshake, this challenge significantly impacted the authenticity of the interaction. Given the pivotal role of wrist movement in executing a convincing handshake, this challenge significantly impacted the authenticity of the interaction.Because of this, there was a noticeable mismatch between how participants moved their hands and how the remote robotic arm responded.
- Haptic Feedback: Participants shared that they didn't feel a strong force feedback when using the HGlove. They were able to overcome the force feedback, which affected the realism. To perform a handshake, they had to almost close their fingers completely, resulting in an unnatural gesture. Additionally, they noticed that the haptic feedback from the hand would sometimes become unstable, causing an awkward and unnatural handshake experience. Therefore, a significant challenge lies in improving the force feedback of the H-Glove to make it more realistic and stable.

6.2.3 Research Question - 3

- What are the cultural and contextual factors that influence the perception and interpretation of Tele-handshake interactions?

Although notable cultural and ethnic distinctions weren't readily discernible, participants' expectations from tele-handshake interactions did exhibit considerable divergence. Participants from West Group frequently emphasized aspects like feedback quality, the anatomical accuracy of the H-glove, and visual perception. Conversely, participants from East Group, in addition to the mentioned factors, also highlighted the significance of untrained actor reactions that contributed to a sense of comfort. Furthermore, they found that establishing eye contact significantly enhanced their overall experience. While the results might not be overtly significant, they do suggest that cultural and ethnic backgrounds do indeed play a role in shaping participants' perceptions of tele-handshake interactions. This underscores the notion that cultural factors have an influence on how individuals interpret and react to the concept of tele- handshakes.

6.2.4 Overall discussion user study

The user study aimed to investigate the effects of force feedback, camera perspective, and regional differences on participants' experiences in the tele-handshake interaction. The results of the study shed light on various aspects of user perception, sense of embodiment, and overall engagement with the tele-handshake system. This section provides a comprehensive discussion of the findings, their implications.

Force Feedback Effects

The analysis of force feedback effects revealed that variations (feedback on and off) in force feedback provided by the H-Glove and Virtuoso devices did not significantly influence participants' sense of ownership, agency, self-location, or cognitive workload. Despite the technical advancements in simulating touch sensations, the absence of significant changes suggests that the current force feedback implementation might not be finely tuned to replicate the nuanced sensations of a real handshake. Continued advancements in refining force feedback mechanisms and the seamless integration of haptic technologies hold the promise of elevating the authenticity of touch sensations to unprecedented levels.

Camera Perspective Effects

The investigation of camera perspective effects indicated that the choice of camera perspective (first-person vs. third-person) did not significantly impact participants' sense of ownership, agency or self-location. However, a significant difference was observed in participants' cognitive workload between the two perspectives. This finding suggests that while participants perceived similar levels of control and ownership in both perspectives, the first-person view was associated with reduced cognitive workload. This could be attributed to the familiarity and naturalness of first-person visual feedback, which aligns with users' expectations and cognitive processes.

This divergence in cognitive demands could be attributed to the innate familiarity and naturalness associated with the first-person visual feedback. This alignment with users' expectations and cognitive processes potentially facilitates a smoother cognitive engagement.

Regional Differences

The analysis of regional differences highlighted that participants' regional origin had a significant influence on their perception of self-location. Participants from the West region reported a stronger sense of self-location compared to those from the East region. This outcome underscores the importance of considering cultural and contextual factors when designing remote interaction systems. Regional variations in perception could be attributed to differences in cultural norms, experiences, and expectations, suggesting that customization of interaction design based on regional preferences might be beneficial for enhancing user engagement and immersion.

Qualitative Insights

The insights gleaned from the qualitative interviews shed light on the intricate nuances of participants' experiences within the tele-handshake system. These interviews offered a deeper understanding of their perspectives, emotions, and challenges, enriching the quantitative findings with valuable qualitative depth. The detail interview is presented in Appendix C.4

The tele-handshake experience presented participants with a spectrum of perceptions. While some participants highlighted the system's ability to convey tactile sensations through pressure and vibrations, thus enhancing the sense of realism, others confronted challenges in synchronizing their movements with their remote partners. Delays in system responsiveness occasionally disrupted coordination, leading to moments of disconnect. Despite these challenges, participants consistently reported a sense of connection during the tele-handshake interactions, reflecting the adaptability and resilience inherent in their engagement.

The exploration of participants' sense of ownership, agency, and spatial presence revealed a nuanced interplay. Participants reported varying degrees of ownership over the remote hand, with some feeling a strong connection and others encountering limitations that impacted their perceived ownership. Similarly, participants expressed fluctuations in their sense of agency, noting moments of complete control alongside instances of challenge. The sense of spatial presence was influenced by the camera perspective, with those in the first-person view reporting awareness of their location and occasional disconnection, while those in the third-person view described a more detached observer role. These findings highlight the intricate nature of embodiment in virtual interactions, influenced by both technological factors and individual perspectives.

Participants' emotional connections and shared presence during the tele-handshake interaction underscored the complexity of remote touch. Some participants reported emotional engagement, attributing their connection to visual cues, shared laughter, and a sense of intention. Others, particularly those in the third-person perspective, felt a lack of emotional depth, describing the experience as more technical and less personal. This variability in emotional engagement highlights the importance of considering individual preferences and the role of visual and contextual cues in fostering emotional connections.

In summary, the qualitative insights gleaned from the interviews provide a multifaceted understanding of participants' experiences within the tele-handshake system. These insights deepen our comprehension of the interplay between technology, embodiment, emotions, and challenges.

7 Conclusion

The study was conducted to gain a comprehensive understanding of tele-handshakes. A thorough literature review was undertaken to identify the key aspects that influence handshakes in traditional face-to-face interactions, and subsequently, to ascertain their applicability in the context of tele-handshakes.

To facilitate the study, specific hardware setups were chosen. On the operator's side, the Virtuose 6D robotic arm and H-glove were utilized, while on the recipient's side, the FRANKA EMIKA-Panda robotic arm and qb robotic soft hand were employed. Detailed explanations of the controller of the qb robotic soft hand and H-glove was provided, and three distinct controllers for the Virtuose 6D and FRANKA EMIKA-Panda robotic arms were introduced: Position-Force Architecture Controller, Classical Bilateral Impedance Control with Passivity (BICP), and Bi-directional Impedance Reflection Technique (BIR). Among these, the BICP controller was selected for implementation.

After investigating the feasibility of tele-handshakes, the study focused on visual cues, haptic feedback, and the influence of ethnicity in tele-handshake situations. Through a comprehensive user study, the affects of these factors on tele-handshakes were examined, revealing important insights into their impact on user experience. The visual(camera perspective) and haptic feedback of Virtuoso and H-Glove were manipulated.

The analysis of the user study data revealed intriguing insights into the participants' experiences across the six distinct force feedback conditions(more details in section 4.2). Notably, the findings demonstrated no significant differences in participants' sense of ownership, agency, self-location, or cognitive workload based on the variations in force feedback. Although the combination of force feedback from the virtuoso system and the H-glove did not yield significant differences in participants' perceptions, qualitative insights underscored the critical role of hardware design in achieving a realistic sense of embodiment. Technical limitations and discrepancies between natural hand movements and H-glove actions showcased the need for a more refined and intuitive design. Quantitative analysis also indicated that manipulation of camera perspective did not affect the sense of ownership, agency, and self-location. While the choice between first-person and third-person viewpoints did not affect SoE, it notably impacted cognitive workload. The first-person perspective yielded reduced cognitive demands, suggesting a more natural cognitive engagement.

The study's analysis of regional differences reveals that participants from different regions experience similar levels of ownership and agency in tele-handshake interactions. However, when it comes to feeling present(sense of self-location) in a remote environment, there are differences. Participants from the West felt more situated in the environment compared to those from the East. Interestingly, cognitive workload showed no significant variation across regions. These findings highlight the importance of cultural diversity in tele-handshake design, ensuring that user experiences accommodate both shared and distinct cultural perspectives.

The qualitative analysis provided valuable insights into how participants experienced the tele-handshake study. Three main issues emerged: problems with the hardware, difficulties with synchronization between the operator's robotic setup and the remote robotics setup, and issues with haptic feedback. Participants felt uncomfortable and had trouble using the hardware (specifically the H-glove), which affected how connected they felt. Delays in synchronization disrupted the flow of the interaction, causing them to adjust their movements. Additionally, problems with haptic feedback affected their experience.

These findings highlight the need for better hardware design, improved synchronization, and addressing haptic feedback issues to enhance the tele-handshake experience.

8 Recommendations

Building upon the comprehensive understanding gained from the study on tele-handshakes, several recommendations and avenues for future research emerge.

Hardware Design and Comfort: The HGlove's discomfort and issues with brackets loosening stem from the design's physical limitations. To address this, a holistic redesign is needed, focusing on both bracket architecture and weight distribution. Brackets should be re-engineered to provide a more secure fit that minimizes shifting during interaction. The weight of H-Glove is majorly focused on back of the plam, redistributing the weight across the hand can alleviate concentrated pressure points, enhancing comfort and allowing for more natural movements during a tele-handshake.

The realism of the handshake experience heavily depends on haptic feedback quality. Participants' ability to overcome force feedback indicates the need for stronger and more realistic tactile sensations. One approach involves enhancing the control system to adjust the force feedback dynamically based on the interaction's context. For instance, applying higher resistance during hand closure to simulate the sensation of grasping. This requires intricate force control algorithms and the integration of real-time interaction data to generate accurate force profiles. Addressing unstable haptic feedback necessitates signal filtering techniques to minimize noise, ensuring a consistent and stable tactile experience. A collaboration between haptic engineers, control specialists, and human factors experts can yield refined force feedback solutions.

The handshake is a bilateral experience. However, due to our setup with only a Franka arm and QB Soft Hand on one side, we were limited to qualitative analysis on the recipient's side of the handshake. Unfortunately, this provided only limited insights. To gain a comprehensive understanding of the true impacts and nuances of the handshake, it's essential to incorporate hardware for the complete recipient's side and conduct an extensive user study involving distinct participants on both sides. This approach could potentially offer a more holistic and insightful comprehension of the handshake phenomenon.

The user study primarily relied on surveys and interviews to gather insights into participants' perceptions and experiences. While these methods yielded valuable qualitative data, it's worth considering the potential for incorporating additional measurement techniques to offer a more comprehensive understanding of the interaction. For instance, integrating physiological measurements, such as heart rate variability, skin conductance, or facial expression analysis, could provide objective indicators of participants' emotional responses and engagement levels during the teleoperated handshake. Furthermore, incorporating eye-tracking technology could offer insights into participants' visual attention patterns and focal points during the interaction, shedding light on elements that contribute to their perception and engagement. These alternative measurement methods could enrich the research findings by providing both qualitative and quantitative data, offering a more nuanced perspective on participants' reactions and experiences within the teleoperated handshake context.

A Appendix: Aspects of Handshake

Tracing the Evolution and Classifying Handshake Research: A Holistic Investigation

Social and Sensors

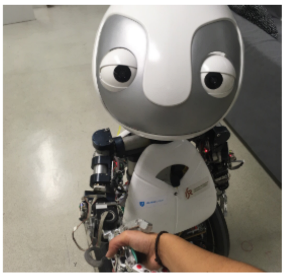
Robotic handshake and Tele-handshake

2023

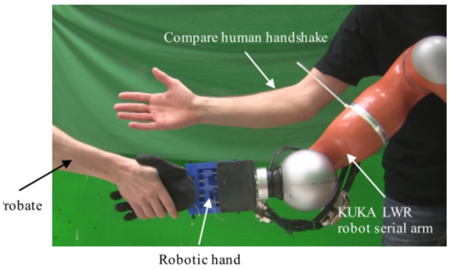
2021 - ANA Avatar

2020 - Handshake Turing Test for anthropomorphic Robots

2018-social robot handshake

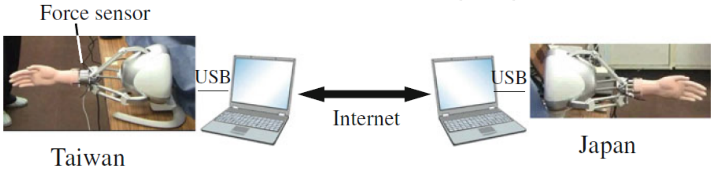


2017 - Haptic robotic hand

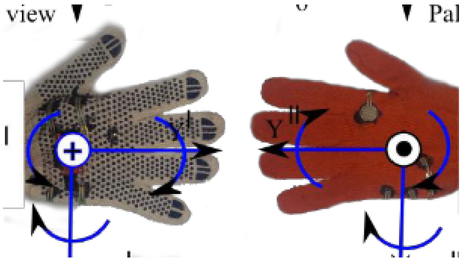


2017-Ethicity and Gender in the Effect of Handshake on Social Appraisals

2015 -Handshake gadget



2014 sensor Network



2014 - Human bilateral tele-handshake system

2014 - touch enhanced video mediated system

2010

Social and psychological

Robotic handshake and Tele-handshake

2010

2008 - role of handshake in interview

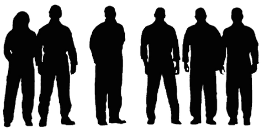
2003-Handshake first impression and personality trait's

1995

before 1995

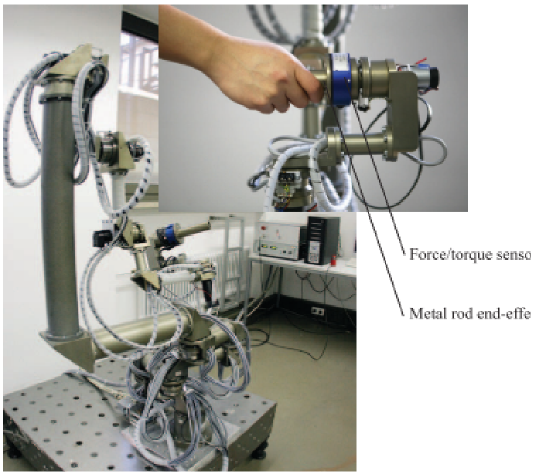
1992 Handshake as non-verbal communication in business

1978 human communication

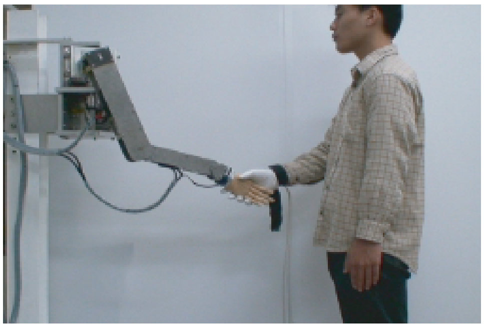


1972 non-verbal communications

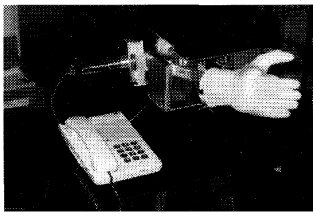
2009 - handshake with haptics



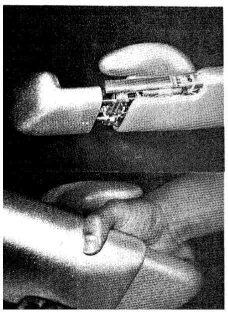
2008- shake motion model



1997 -Tel-handshake through telephone system



1995- first Tele-handshake device



B Appendix: Ethical Documents

The Ethics Committee for Computer and Information Science at the University of Twente has granted approval for this research, with the reference number RP 2021-151. The informed consent form is included.

Informed Consent Form

PP nr.	Control

Project title: Insights of Tele-Handshake
Researchers: Mrudula Kodihalli Shashikumar, Sara Falcone, Douwe Dresscher
Contact: **m.kodihallishashikumar@student.utwente.nl**, **s.falcone@utwente.nl**

What you will do:

1) You are asked to fill the health check questionnaire.
2) we would like to inform you about the research you have applied to participate in. In the proposed research, entitled "Insights of Tele-handshake". The aim of the research is to understand the tele-operated handshake requirements and what are the technical solutions that can be done to achieve the realistic handshake experience. The research could provide important clues in understanding futuristic scope and technical solution ideas/suggestion to achieve realistic of tele-handshake in the field of robotics.
3) **Background:**
   Tele-operations have received a lot of attention in robotics research because they allow humans to do complex, and sometimes dangerous, tasks from a distance. However, the human needs do not stop at performing tasks in industrial environments. The social needs of human are also of substantial importance. As a result, robotics research has expanded to include not just the study of tele-operational systems that execute industrial tasks, but also the study of tele-presence robotics, which is a robotics research topic that combines tele-operational robotics with interaction robotics. During a Human- robot - Interaction, physical contact plays a major role in the numerous applications of social robots. As a interactive non-verbal behaviour it is a crucial to enhances the naturalness of the interaction. The handshake is a more significant activity than other physical exchanges that do not need significant touch, such as high-fives and Asian cultural welcomes. As a result, HRI (Human Robot Interaction) puts a focus on handshakes To evaluate the effects of a robotic handshake system on the human experience, qualitative research on components of the handshake in a social environment must first be conducted before being projected into the robotics setting.

4) You have been invited to participate in a remote interaction. During the experiment, your task will involve shaking hands with an untrained actor present in the remote environment. This interaction will be facilitated using a specialized robotic setup provided by the researchers. You will perform the handshakes with the untrained actor setup a total of six times. Following each handshake, you will be asked to provide feedback by answering a set of survey questions. The study's details will be explained to you in person before the experiment begins. The anticipated duration of your participation is approximately 50 minutes.

What we will do:

1) We will provide you the instructions and information needed to accomplish the tasks.
2) We will answer to all your questions.
3) We will take care that the experimental session will be carried out in safety and with respect to the COVID-19 measures.

What we will collect:
We collect your questionnaires and interview responses for analysis of data.
Why we do it:
We want to test tele-handshake with the hardware and analyse what can be done to improve the user experience

Please tick the appropriate boxes

Informed Consent Form

Taking part in the study

Yes No

I have read and understood the study information in the Informed consent form, and details of the experiment has been explained to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction. ☐ ☐

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason. ☐ ☐

I understand that taking part in the study involves: ☐ ☐

1. Executing a teleoperation task that requires me to wear a HMD and a set of haptic devices;
2. I will verbally complete survey questionnaires and will take part in interviews, and that my answers will be collected and analysed.
3. Audio recordings (interview) will be collected and analysed.
4. I reserve the right to withdraw this consent without the need to give any reason within 48 hours of signing the consent.
5. Any personalised data will be anonymized and used for research and will be publicly available.

Risks

☐ ☐

I am aware of the following risks.

- Unexpected motions, force jumps, instability caused by the haptic feedback devices.
- Nausea caused by the HMD

Use of the data

I understand that personal information collected about me that can identify me, such as [e.g. my name], will not be shared beyond the study team. ☐ ☐

I understand that all physiological data will be destroyed once it has been analysed. ☐ ☐

Consent to be Audio Recorded

I agree to be audio recorded during the interview. ☐ ☐

Compensation:

You will receive a 10 Euro bol.com voucher as compensation for your participation. You have the right to withdraw from the experiment at any point without having to give a reason and then you will receive the voucher

Signatures

______________________ ______________________ ________

Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Informed Consent Form

____________________________	_____________________	_________
Researcher name [printed]	Signature	Date

Study contact details for further information:

Principal Researcher:
Mrudula Kodihalli Shashikumar
+31 683230215
m.kodihallishashikumar@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee of the Faculty of EEMCS at the University of Twente by **ethics-comm-ewi@utwente.nl**.

C Appendix: User Materials

This section contains the materials provided to participants, including interviews and surveys utilized in the study.

C.1 Demographics Survey

Demographic Survey

Participants Personal Page Info

* Indicates required question

1. Participant Number (to be filled out be experimenter) *

____

2. What is your age? *

Mark only one oval.

○ 18-24
○ 25-34
○ 35-44
○ 45-54
○ 55-64
○ 65 and older

3. You identify yourself as: *

Mark only one oval.

○ Male
○ Female
○ Prefer not to say
○ Other: ______________________________

4. Do you practice a sport? *

Mark only one oval.

○ Yes
○ No

5. if you answered Yes, which which sport do you practice? If you answered No, write "none" in the space below. *

____

6. At what level? If you do not practice a sport, select "none" *

Mark only one oval.

○ Competitive level (8 or more hours of training a week)
○ Amateur level (less than 8 hours of training a week)
○ None

7. Do/Did you have medical conditions which affected your upper body muscles or nerves? *

Mark only one oval.

○ Yes
○ No

8. Is Handshake your first form of Greeting? *

Mark only one oval.

○ Yes
○ NO

9. Where are you from *

East part of the world: (Example like: India, Japan where handshake is not first form of Greeting) ; West part of the world (Example like: North America , Canada where Handshake is first form of Greeting) . please fill your country name if your comfortable in other section.

Mark only one oval.

○ East
○ West
○ Other: ______________________

10. How much do play video games on a weekly basis? *

Mark only one oval.

○ I don't play video games at all
○ Less than on hour
○ Between 1 and 3 hours
○ Between 3 and 5 hours
○ More than 5 hours

11. Have you experienced virtual reality with a head mounted display? *

Mark only one oval.

○ Never
○ Once
○ Sometimes
○ Regularly

12. Have you become nauseous in VR? *

Mark only one oval.

○ No, as I have never experienced VR before
○ Never
○ Once
○ Sometimes
○ Regularly

13. Have you experienced a telerobotic interaction before? *

Mark only one oval.

○ Never
○ Once
○ Sometimes
○ Regularly

14. End of the information

You have reached the end of the first section of the survey. Please follow the instructions of the experimenter.

Mark only one oval.

○ Submit

C.2 Sense of Embodiment Survey

The following question was displayed in HMD, utilizing a seven-level Likert scale where 1 signifies "strongly disagree" and 7 signifies "strongly agree." Each Statement of Experience (SoE) component have two questions, with one question serving as a control. These questions where dispalyed after each handshake.

- SoO: I felt as if the arm that I saw in the display was my arm
- SoO: At some point I felt as if my real arm was starting to take on the posture or shape of the robotic arm that I saw
- SoA: It seemed as if my hand was able to feel the researcher hand
- SoA: It felt like I could control the robotic arm as if it was my own arm
- SoS: I felt out of my body

Cognitive workload was also assessed using a rating scale ranging from 1 to 10, where a score of 1 indicated the task was perceived as very easy, and a score of 10 indicated it was perceived as very challenging. The following questions were used for this assessment:

- How mentally demanding was the task?
- How physically demanding was the task?posture or shape of the robotic arm that I saw
- How hurried or rushed was the pace of the task?
- How successful were you in accomplishing what you were asked to do?
- How hard did you have to work to accomplish your level of performance?

C.3 Interview Questions

The interview process adheres to a semi-structured format, organized into five distinct phases as outlined in reference [71]. Each phase serves a specific purpose and is accompanied by its corresponding objectives and questions. The breakdown of the interview phases is presented below:

C.3.1 Phase 1: Ice Breaker

Objective: Establish rapport and create a comfortable atmosphere.

Questions: 1. Can you briefly introduce yourself and share a bit about your background? 2. What sparked your interest in participating in this study?

C.3.2 Phase 2:Introduction

Objective: Provide an overview of the interview process and set expectations.

Questions: 1. What do you think on the overall handshake experience?

C.3.3 Phase 3: Key Questions

Objective: Explore the core topics related to the research.

Questions:

Did you ever think of temperature handshake?

What do you feel on visual playing role in the experience? How was the grip of the handshake? How do you feel about anatomical consistency of the hand? Did you feel that your hand was operating in a different environment? Are you able to guess the personality of the person through tele-handshake?

C.3.4 Phase 4: Cooling Off

Objective: Transition smoothly and ensure the participant is at ease.

Questions: 1. Is there anything else you would like to share about the experience that we haven't covered? 2. Do you have any questions or thoughts you'd like to discuss before we conclude this phase? 3. What would you improve in the system? What was diffcult part of Tele-handshake.

C.3.5 Phase 5: Warp Up

Objective: Summarize the interview and gather final insights.

Questions: 1. Based on our discussion, is there anything you'd like to emphasize or reiterate?

C.4 Detailed Interview Transcripts

The transcripts below show in-depth discussions between researchers and participants during a semi-structured interview process conducted between the researcher and the participant. The participants share their genuine thoughts, offering a firsthand account of their reactions and observations during the experiment. These transcripts offer a deeper understanding of the participants' perspectives and contribute to the exploration of the challenges and potentials of remote interaction technologies.

Participant 1 (P1): - For privacy reasons the participants name is not revealed
Researcher (R): Mrudula

The interview presented below is conducted after a brief introduction of the participant. In this phase, the researcher and participant engage in a candid conversation that delves into various aspects of the remote handshake experience.

R: Let's dive into the questions then. What are your thoughts on the overall handshake experience in the context of our study?

P1: I have to admit, I didn't quite expect the remote handshake experience to be what it turned out to be. It was good and quite different from what I had imagined.

R: Interesting, let's dive into the interview process. In this second phase, I'd like to provide you with an overview of what to expect throughout the interview. We'll be discussing various aspects of the handshake experience,Before we delve into those topics, what are your initial thoughts on the overall handshake experience in a telecommunication setting?

P1: It was good, as I said very different. Honestly, I'm skeptical. Handshakes are supposed to be physical and personal. Trying to replicate that with wires and gadgets sounds like a stretch, but hey, I'm curious to see if it can be pulled off.

R: Yeah, your doubts are, totally okay. Let's explore the core topics, First off, did you, ever think about, like, a temperature handshake?

P1: Temperature? Never crossed my mind. But if they can, like, simulate warmth somehow, it could make the experience more, like, real. But I'm not sure.

R: You're challenging the possibilities. How do you feel about visual cues influencing your perception of a tele-handshake?

P1: Visual cues matter a lot. You can tell so much from, other person expressions,body language. It was very nice that I could see him.

R: Now, about the grip during the handshake, did it, feel convincing to you? Can you really, like, feel the grip through?

P1: Grip? I did not feel it, It felt like I was closing hand in air. There was nothing to hold on it. Also I felt slight force but yeah it did not make sense.

R: Interesting, Jumping to anatomical consistency, how crucial is it for the remote hand to match your own hand's anatomy during a Tele-handshake?

P1: Consistency is, like, important. But it's not a deal-breaker, I guess. As long as it's not, like, too weird, our brains might just, you know, ignore the small differences.

R: yeah, true. Did you feel that your hand was operating in a different environment?

P1: Absolutely. There's this disconnect when you're not actually feeling the touch. It's like puppeteering your hand from afar. But if they can make that puppeteering seamless, it might just work.

R: Lastly, gauging personality through a tele-handshake—do you think you can still get a sense of someone's personality from the interaction?

P1: It's a stretch, I think. A confident handshake could still show confidence, but you miss those, like, tiny cues. Hard to say, really.

R: Your perspective is, pretty insightful. So, as we wrap up, is there anything else about the handshake experience that we, um, didn't cover? Anything you'd like to share?

P1: Nah, we've covered quite a bit. But what about the technical glitches? I did felt on and off disconnect to the system.

R: That's a valid concern. Technical glitches did pop up during the experiment—mainly around haptic feedback. It's a challenge we're tackling to ensure a smoother experience.

P1: Got it. And, um, to close things off, based on our chat today, is there anything you'd, like, really want to emphasize or, you know, say again?

R: Absolutely, Your candid opinions have been gold. We're grateful for your straightforward input.

P1: Happy to provide it. Looking forward to seeing where this research leads. Keep pushing those tech boundaries!

R: We definitely will. Thanks again for your time and insights. It's been a pleasure discussing this with you. Feel free to let me know if you'd like any further adjustments or variations in the conversation!

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