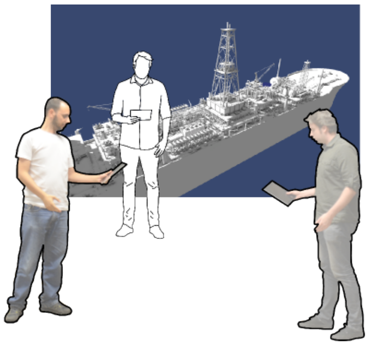

Remote Proxemics for Collaborative Virtual Environments

António Maurício Lança Tavares de Sousa

Thesis to obtain the Master of Science Degree in

Information Systems and Computer Engineering

Supervisors: Professor Doutor Joaquim Armando Pires Jorge
Professor Doutor Alfredo Manuel dos Santos Ferreira Júnior

Examination Committee

Chairperson:	Prof. Doutor Pedro Manuel Moreira Vaz Antunes de Sousa
Supervisor:	Prof. Doutor Joaquim Armando Pires Jorge
Member of the Committee:	Prof. Doutor Carlos Alberto Pacheco dos Anjos Duarte

November 2014

Acknowledgments

I would like to leave here some words of appreciation to the people who have proved important for the realisation of this work. First and foremost this thesis would have not been possible without the guidance and support of my advisors, Professor Joaquim Jorge and Professor Alfredo Ferreira. Secondly, i would like to show my gratitude to Bruno Araújo, Ricardo Jota Costa, Luís Bruno, Fernando Fonseca, Sergio Azevedo, Daniel Pires e João Guerreiro. I want to share this achievement with my dear colleague and friend Daniel Mendes for his patience, availability, help, guidance and cooperation in all crucial moments. To all those who agreed to participate in the various evaluation sessions owe my appreciation, and to all the people who contributed indirectly through the interest shown by them. Also, to Instituto Superior Técnico (IST), to the Visualisation and Intelligent Multimodal Interfaces (VIMMI) group and to the people who comprise it, for the opportunity and giving me the means that enabled this work. A special thanks to Helena Andrade, for all the dedication, support and understanding that helped, with no doubt, to realise this work. And Finally, to my brother and parents, for the unconditional support.

I would also like to mention the financial support from the Portuguese Foundation for Science and Technology (FCT), through the project CEDAR PTDC/EIA-EIA/116070/2009 and project TECTON3D PTDC/EEI-SII/3154/2012.

Thank you all,
António Maurício Sousa

Resumo

Com os avanços das ferramentas de video-conferência e de software colaborativo, as reuniões virtuais tornaram-se cada vez mais comuns, uma vez que permitem poupanças em tempo e recursos. No entanto, a sensação de presença ainda é diminuta. Na verdade, os participantes remotos queixam-se de ter uma presença reduzida, enquanto que os participantes locais têm dificuldades para perceber as atividades das pessoas remotas. Este trabalho introduz o conceito de Eery Proxemics, uma extensão dos Proxemics que visa trazer a sintaxe das interações proxémicas para reuniões virtuais e aumentar a consciência das atividades e situação dos participantes remotos. O nosso trabalho centra-se em reuniões virtuais facilitadas por várias superfícies interactivas, que vão desde écrans de grandes dimensões (Walls), tablets e smartphones. Portanto, o nosso objetivo é aumentar o conhecimento mútuo de participantes em locais diferentes, que não se conseguem ver uns aos outros, através de um espaço virtual comum. Nós chamamos este espaço virtual Eery Space. Através dele, é possível tornar a área de interação proxémica visível para que os participantes distantes consigam usar as interações proxémicas naturais e estabelecer intercâmbios de informação. Avaliações realizadas com pessoas, indicam que nossa abordagem é eficaz em melhorar o sentimento de presença mútua entre os participantes e suficiente para iniciar tarefas colaborativas independentemente da localização física, proporcionando uma interação contínua entre pessoas locais e remotas.

Palavras-chave: Reuniões Virtuais, Colaboração, Interações Proxémicas, Desenho de Interação

Abstract

Virtual meetings have become increasingly common with modern video-conference and collaborative software. While they allow obvious savings in time and resources, presence is still elusive. Indeed, remote participants complain about reduced presence away from the ”main meeting”, whereas local participants have trouble noticing remote peoples’ activities and focus. We present Eery Proxemics, an extension of Proxemics aimed at bringing the syntax of proximal interactions to virtual meetings and increasing awareness of remote participants’ activities and situation. Our work focuses on virtual meetings facilitated by multiple surfaces, ranging from wall displays to tablets and smartphones. Therefore our goal is to increase mutual awareness of participants, who cannot see each other from different locations, through a shared virtual space. We call this shared realm the *Eery Space*. Through it we are able to make proxemic interaction area visible to/from far participants to afford proximal interactions and exchanges among meeting participants. Evaluations carried out with people, indicate that our approach is effective at enhancing mutual awareness between participants and sufficient to initiate proximal exchanges regardless of physical location, while providing a seamless interaction between local and remote.

Keywords: Virtual Meetings, Collaboration, Proxemic Interactions, Interaction Design

Contents

List of Tables

List of Figures

Chapter 1

Introduction

Nowadays, business and engineering work teams are faced with the challenge of having their workforce geographically separated around the globe. Tight travel budgets and constrained schedules require team members to rely on virtual meetings. These conveniently bring together people from multiple and different locations. Indeed, through appropriate technology, it becomes possible to see others as well as to hear them, which means it becomes easier to communicate verbally and even non-verbally at a great physical distance.

The solutions available on the market allow face-to-face conversation and the overall access to broadband Internet connectivity, supply a good quality user experience. On the other hand, since nearly all of these solutions apply a conference table metaphor where the virtual meetings take place, it is difficult to create a collaborative environment for engineers who have the need to analyse and review large amounts of data, and at the same time, engage in conversation. Furthermore, the collaborative creation of content and sharing of information still imposes some obstacles to the normal flow of communication, and often, is necessary to use additional tools. One of the tools used is Virtual Environments laying out real-world engineering problems that can use massive and high quality graphics, forcing engineers to communicate with each other while looking for points of interest in the virtual world, creating annotations and sketches of the possible solutions to the problems they are debating.

1.1 Motivation

When people get together to discuss, they communicate in several manners, besides verbally. Hall [1966] observed that space and distance between people (Proxemics) impact interpersonal communication. While this has been explored to leverage collaborative digital content creation [Marquardt et al., 2012b], nowadays it is increasingly common for meetings to take place when the work team is not physically present in the same room.

The newest videoconferencing and telepresence solutions support both common desktop environments and the latest mobile technologies, such as smartphones and tablet devices. Notable examples include Skype[1] and FaceTime[2]. However, despite considerable technological advances bent on bringing people together, remote users in such environments often feel neglected due to their limited presence [Neyfakh, 2014]. Moreover, although verbal and visual communication may be easy in virtual meetings, other modes of engagement, namely proxemics, have yet to be explored. Yet, the work from Reeves and Nass [1996] suggests that this is not only possible, but desirable.

By placing users in the same common virtual space, albeit being geographically apart, new ways of interaction become possible. These new interactions take into account the personal space of each user. Despite their not being in the same physical space, the locus of a remote user must be accounted for, fostering interactions with local people as if the remote user were actually there. Unlike conventional systems which strive for eye-contact we focus on proximal interactions.

In addition, recent developments in technology fundamentally changed the core concept of the computer. Common computer devices range from smartphones, tablets and desktops to interactive tabletop surfaces, and even, large scale displays (or wall-sized displays). Smartphones and tablets have become ubiquitous, are equipped with several sensors to better understand the world surrounding them, and they hold a considerable storage capacity for large amounts of data and great processing power. Also, these mobile devices are almost exclusively personal and linked to one user. Therefore, handheld devices become proxies of their users and can be used as a personal identifier. In the other hand, large scale displays are vertical surfaces mostly built to be used as visualisation devices for large amounts of information in multi-user environments. Besides, their large size does not restrict the free movement of users around them. And combined with the usage of mobile devices, users can have a public viewing of the data shown in the wall display, as have another private view through their personal handheld devices.

1.2 Research Statement

In this work, we introduce *Remote Proxemics* as a tool to interact proximally with remote people. To this end, we explore the space in front of two or more wall-sized displays in different sites, where local and remote people can meet, share resources and engage in collaborative tasks using their handheld devices. We propose techniques that enable people to interact as if they were located in the same physical space, as well as approaches to enhancing mutual awareness.

With this dissertation, we intend to have our major contribution in validating the assumption that it is possible to use proximal interactions in the framework of collaborative work in virtual meetings without added complexity for local participants. And we intend to also minimise the still unresolved issue of the lack of remote people's presence in this type of environments. We can then highlight the research statement of this dissertation as follows:

> ***In distributed collaborative environments, proximity relationships can be extended to remote users by resorting to appropriate awareness techniques.***

[1] Skype: http://www.skype.com/

[2] FaceTime: https://www.apple.com/mac/facetime/

1.3 Contributions

Taking into account the obstacles exceeded in the development of a multi-device ecosystem that enables virtual meetings for design and review of virtual environments, and the problem of the limited presence of remote users, our work provides the two following contributions:

- **Definition of Remote Proxemics**
  This work introduces the concept of Remote Proxemics, within the scope of the virtual meetings, which is a logical extension of the Proxemic Interactions. To study the feasibility of this approach, interactions that exploit this new concept have been developed, as well as a set of techniques for mutual awareness. These approaches were tested with users, and the results of this evaluation show promise.

- **Solution for remote collaborative work for design and review of virtual environments**
  The prototype developed for the assessment of interaction techniques and mutual awareness of our approach has been taken beyond a proof of concept. This solution fits the reality of the meetings for design and review of three-dimensional engineering models carried out by the oil and gas industry. Includes not only the visualisation of engineering models and mediation of the flow of communication in brainstorming sessions, but also incorporates a strong component for interactions with remote people, a feature highly desired in this industry.

These being the main contributions of this dissertation, we also developed other aspects that may be useful for other related works. Thus, contributions to the community resulting from the development of this work are:

- **Eery Tracker Toolkit.**
  The Eery Tracker Toolkit overcomes a problem with a very specific focus, to resolve in real time, the people's positions within an indoors tracked area in front of a large scale display. It is a standalone application with the ability to be reused in many projects. Thus, our toolkit consists of a server that provides a stream of data that is interpreted by a client-side plugin.

- **ThumbCam: a camera manipulation technique for Virtual Environments**
  We present a novel single-touch technique for camera manipulation on 3D virtual environments that builds up from the limitations of multi-touch gestures on smartphones. With this navigational solution, the user is able to move and look around and circle points of interest, while interacting using only his thumb. This technique play an important role in our approach, in the way that enables each participant to navigate through the virtual environment subject of the meeting and zoom in to inspect details on the 3D model.

- **Technique to associate handheld devices to users.**
  Knowing the personal identity of people is crucial to proximity-aware environments. We propose a computer-based technique to bind handheld devices to their users in order to obtain their identity to enable cross-device proxemic interactions. Our approach takes advantage of built-in motion

sensors present in every mobile device to calculate a positive match with people's body motion, easily obtained from depth cameras.

1.4 Publications

The work developed in this work led to several publications evaluated by panels of experts and accepted in scientific conferences. These publications are listed below, sorted chronologically, from newest to oldest.

1. *Beyond Post-It: Structured Multimedia Annotations for Collaborative VEs*, João Guerreiro, Daniel Pires, **Maurício Sousa**, Daniel Mendes, Ismael Santos, Alberto Raposo and Joaquim Jorge, 24th International Conference on Artificial Reality and Telexistence (ICAT 2014) and the 19th Eurographics Symposium on Virtual Environments (EGVE 2014), December 2014.

2. *Eery Proxemics: Proximidade à Distância usando Múltiplas Superfícies*, **Maurício Sousa**, Daniel Mendes, João Madeiras Pereira, Alfredo Ferreira and Joaquim Jorge, Encontro Português de Computação Gráfica, November 2014.

3. *Enabling Remote Proxemics through Multiple Surfaces*, Daniel Mendes, **Maurício Sousa**, João Madeiras Pereira, Alfredo Ferreira and Joaquim Jorge, Collaboration meets Interactive Surfaces, ACM International conference on Interactive Tabletops and Surfaces, November 2014.

4. *ThumbCam: Returning to single touch interactions to explore 3D virtual environments*, Daniel Mendes, **Maurício Sousa**, Alfredo Ferreira, Joaquim Jorge, ACM International conference on Interactive Tabletops and Surfaces, November 2014.

5. *Binding an Handheld Device with its Owner*, **Maurício Sousa** and Joaquim Jorge, Collaboration meets Interactive Surfaces, ACM International conference on Interactive Tabletops and Surfaces, October 2013.

6. *Collaborative 3D Visualization on Large Screen Displays*, Daniel Mendes, **Maurício Sousa**, Bruno Araújo, Alfredo Ferreira, Hildegardo Noronha, Pedro Campos, Luciano Soares, Alberto Raposo, Joaquim Jorge, Powerwall-International Workshop on Interactive, Ultra-High-Resolution Displays, ACM CHI, October 2013.

1.5 Dissertation Outline

The remaining contents of this dissertation are organised as follows. In Chapter 2 we discuss related work that motivated our approach, as regards both in relation to existing solutions and interaction with large-scale screens, as well as proximity-aware interactions. The Chapter 3 describes our proposed solution, the Eery Proxemics. An environment for collaboration that brings people together in the same virtual space, so that they can interact with each other using remote proxemics. Next, Chapter 4 presents the technology and the apparatus developed to arrive at the solution. Chapter 5 reports the tests conducted to verify the feasibility of remote proxemics and validate our proposed solution. And finally, Chapter 6 concludes and discusses possible future work.

Chapter 2

Related Work

Engineering projects rely on the specific expertise from multiple team members. During the planning and construction stages, engineers often analyse three-dimensional models depicting the project at hands. It is then natural that during the virtual meeting, the focus is directed to one or more aspects of the virtual model, where the participants' attention is focused on the issues related to their expertise and knowledge, often creating separate working groups that will later be presenting and discussing their assessments with all present. For local work interactions, the natural formation of this groups of work follow the accepted social conventions of proximity (*Proxemics*). On the other hand, current virtual meetings' solutions add additional complexity when creating concurrent or separate work groups. Adding layers of communication protocol on top. Since the proliferation of personal mobile devices, this issue can be mitigated by incorporating an *Ubiquitous Computing* environment (*Ubicomp*) where each device has its role in the social interactions between the various participants in the virtual meeting. Starting from this assumption, all collaborative activities, communication, and even, the design and review of the virtual models can be achieved using those devices.

In our dissertation, we aspire to develop a prototype that enables remote collaboration using social interactions, by putting local and remote people side by side performing related tasks, and, in this way, break away from the layers of protocol generated by current virtual meeting solutions. For this reason, it was necessary to make an effort to research the most relevant works and key areas of study, to motivate and guide our approach. In this chapter we provide a comprehensive overview of the research related to our core areas of knowledge: *ubiquitous computing environments, social and proxemic interactions, remote collaboration and telepresence, and finally, virtual environment navigation on handheld devices.*

2.1 Ubiquitous Computing

Ubiquitous Computing (Ubicomp) was conceived by Mark Weiser which envisions the real world covered by computers. Starting with the observation of the evolution of devices' availability over time, Weiser [1991] foresaw, more than two decades ago, that everyone will have access to digital devices. Even more, technology would play a key role in our daily lives, by being everywhere and anywhere. This vision was extrapolated from the analysis of the evolution of information technology where a computer (*Mainframes*) originally served multiple people at the same time, moving to a paradigm where there is one computer per person (*Personal Computer* or *PC*), to the point where every person has access to multiple digital devices. Indeed, nowadays, information technologies are ubiquitous. Not only everyone has access to multiple devices, ranging from desktops, tablets and smartphones, but also, digital public devices are present in the real world in the form of street signs and public displays. But the idea of Ubicomp does not stop at the availability of information devices or portable devices that can go everywhere with its user. Weiser also describes Ubicomp environments where the integration of technology into the real world is such that normal day-to-day activities are seamlessly mediated by digital devices. Ubicomp is different form virtual and augmented realities, in the sense that the latter thrives in bringing the real world into a computer generated environment, and ubiquitous computing fills the real world with computers. In general, the Ubicomp environments show the following attributes:

- **Ubiquity**
  Access to computation is everywhere and interactions are channelled thought multiple digital devices linked in a network, distributed in space, but coordinated. Thus, technology should be around people, providing information when necessary. Resorting to the people's implicit input thought sensors and recognition software, taking into account the natural human environment. And moving away from traditional explicit input or WIMP interfaces (*Windows Icons Menus and Pointing Devices*) [Van Dam, 1997].

- **Transparency**
  Technology is invisible by blending into the background of the environment, remaining non intrusive and integrated with the arrangement of its surroundings. Thus, information should remain invisible until the moment when it is required by people [Weiser, 1991, Weiser and Brown, 2009].

Early works exploring Ubicomp environments [Weiser, 1991, Elrod et al., 1992], at Xerox Parc[1], arrived to a grouping of digital devices in three categories according to size and usability: small *inch-sized*, *foot-sized* and *yard-sized* devices. Each device shows information that correlates better with the task carried out by its user. Inch-sized devices are personal and small enough to be carried around all the time by people. Figure 2.1 (right) shows the Xerox ParcTab [Schilit et al., 1993], which displays private information to its user, and even, works as an identification badge. Foot-sized devices are portable and intended to be used as digital paper [Holman et al., 2005]. The Figure 2.1 (bottom left) demonstrates a seated person taking notes on a foot-sized Xerox ParcPad prototype. These devices provide digital content appropriate to small social group discussions, since their intended usage was to pass them around in an environment where many devices are available mimicking books or even paper notebooks. In the other hand, yard-sized devices are immovable interactive displays fitted for public digital content. Elrod et al. [1992] describes the Liveboard, in Figure 2.1 (left), a large interactive display to support group meetings. Liveboard is a CRT-based rear-projection system that allows pen interaction for input control and drawing.

[1] Xerox Parc: http://www.parc.com

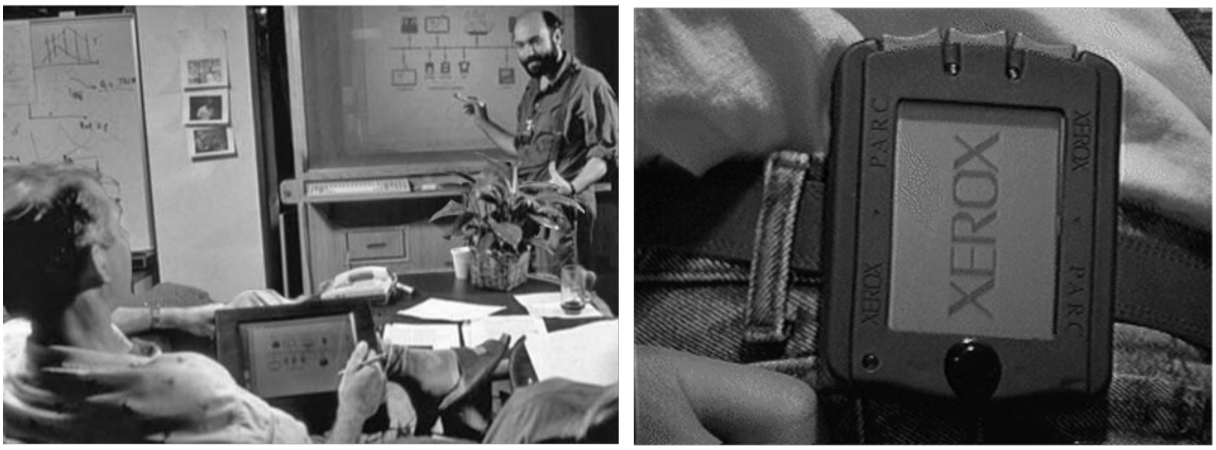

Figure 2.1: Early demonstration of a Ubicomp environment: (Left) Public yard-sized device, the Live-Board, and a person using a foot-sized handheld device, the ParcPad. (Right) Personal Inch-sized device, the Xerox ParcPad (Photos: Xerox Parc).

Transposing to the present day, these device categories are equivalent to current smartphones, tablets and large scale displays. While it is apparent that the vision of Weiser is very similar to the present day, in fact there are still considerable obstacles to effortlessly interact through these devices, since although they are connected with each other, they still do not work coordinately. Cooperstock et al. [1997] states that using multiple devices seamlessly can only be achieved with the yet to be seen ubicomp's transparency. Since nowadays, an enormous effort is required to make devices to intercommunicate and share resources between them.

Expanding the concept of ubiquitous computing, Dourish [2004] introduces *embodied interactions*, aligning himself with the importance of transparency in technology. The goal of embodied interactions is to design digital systems that exploit the normal human actions [Dourish, 2001, Harrison and Dourish, 1996]. To this end, Dourish [2004] emphasises that the seamless integration of technology with the environment involves the use of *tangible user interfaces*, or TUI [Ullmer et al., 1998].

2.1.1 Context-Aware Computing

Context-aware computing relates to Ubicomp systems that examine and react to people's state and surroundings, while adapting its behaviour [Schilit et al., 1994, Satyanarayanan, 2002] through sensors. Early research in Ubicomp context-aware systems, studied the measures needed to obtain the sufficient information to infer context [Dey et al., 2001, Antifakos and Schiele, 2002]. Coulouris et al. [2005] presents a context-aware mobile phone that notifies the user depending on his location, avoiding ringing in meetings. Studies shows that location can be inferred from sensed noise levels, temperature and light. Antifakos and Schiele [2002] propose sensor fusion strategies to retrieve context information from these measurements. Want et al. [1992] propose the *ActiveBadge*, a wearable device to determine people's location and consequently infer context, by transmitting and receiving infrared signals. Using this technology, Schilit et al. [1994] studied four techniques regarding location. First, the *proximate selection* technique to detect digital devices in the surroundings. The context reconfiguration technique to prepare nearby devices for interactions. Contextual information to provide visualisation devices with the capability to change the display information when new people enter their location. And finally, the context triggered actions to activate commands while entering a pre-defined locations. Other works explore the awareness of people's and devices' presence, and their movement, to create reactive environments [Buxton, 1997]. Cooperstock et al. [1997] suggests that, when sensing people's presence and movement, spaces can infer the context of the interaction and pro-actively adapt and perform actions. In fact, there is a considerable body of research related to Ubicomp systems that considers the presence and the spatial relations between people and devices. Greenberg and Kuzuoka [1999] introduces the *Active-Hydra*, a device that senses the proximity of people to control the fidelity of audio and video outputs in a virtual meeting environment. Using a similar approach, Ju et al. [2008] devises the *Range* system to divide the area in front of a digital whiteboard into four discrete zones and detecting approaching people using infrared proximity sensors. With this, the *Range* system is able to implicitly react to the presence of people and allow for content creation when a user is in close proximity. In the same manner, the *Medusa* tabletop display, [Annett et al., 2011] reorients its content towards a user by detecting their presence.

Much research has been done in order to obtain users personal identity. Some works make use of intrusive devices to obtain the identity information [Marquardt et al., 2011b, Meyer and Schmidt, 2010, Roth et al., 2010]. However, various techniques are non-intrusive. Some use biometrics [Schmidt et al., 2010], some explore what users wear [Piper et al., 2006], and others rely on computer vision [Ramakers et al., 2012]. Within the work related to computer vision, there is a consensus on the usage of data fusion between body movement signals captured by cameras and data from inertial sensors [Mayol et al., 2005, Bahle et al., 2013, Tao et al., 2007]. Teixeira et al. [2010] proposes the use of inertial sensors that are within mobile devices in combination with a network of surveillance CCTV cameras to locate personnel, track people inside buildings and locate intruders. On a similar note, Rofouei et al. [2012] exposes a similar problem regarding identity in user interactions on touch-enabled surfaces.

2.1.2 Discussion

In this session, we reviewed related work regarding ubiquitous computing, relevant to the scope of this dissertation. Providing that indoors' environments environments can sense people, and even, sense their handheld devices, context-aware computing can improve collaboration in telepresence systems, in the way that, new inexpensive sensing technologies, such as the Microsoft Kinect depth camera, can provide relevant information to track and infer people's actions. Thereby, the more information we can detect from the tracked environment, easier it will be to transfer that data to create virtual representations in a remote setting.

2.2 Telepresence in Remote Collaborative Environments

In virtual meetings, technology plays a decisive role in providing the necessary means for people to communicate and collaborate with each other while not being physically present in the same space. Wolff et al. [2007] argues that systems that enable virtual meetings can be categorised into *audioconferencing*, *groupware*, *videoconferencing*, *telepresence* and *collaborative mixed reality systems*. In this section, we will review the related work from those domains related to collaborative work to computer-supported cooperative work (CSCW) [Johansen, 1988].

There are several research addressing the interpersonal space of the people involved in the virtual meetings, by providing a broadcast of a single user to the group. This is the actual paradigm for virtual meetings adopted by common commercial solutions. These systems do enable communication and even eye contact [Ishii and Kobayashi, 1992, Chen, 2002, Vertegaal et al., 2003, Nguyen and Canny, 2005]. In the early days of videoconferencing and telepresence, Buxton et al. [1997] suggested a system where remote people were represented by individual video and audio terminals, called *HIDRA*. Morikawa and Maesako [1998] follows the concept of the shared space and introduces the *HyperMirror*, a system that displays local and remote people on the same screen, Preserving each participant's singular interpersonal space. Although this approach enables communications, the focus on the interpersonal space renders the user experience not appropriate related tasks. People need to meet in a shared space to perform collaborative work [Buxton, 1997]. Thereby, Buxton [1992] argues that these virtual shared workspaces, enabled by technology, are required to establish a proper sense of shared presence, or telepresence.

Using a shared virtual workspace, people can meet and share the same resources, allowing for joint collaboration and creation of shared content. Following this concept, Tanner and Shah [2010] proposes a side-by-side system that exploits multiple screens. One for content creation and another one displaying a side view of the remote user. Side-by-side interactions allows people to communicate and transfer their

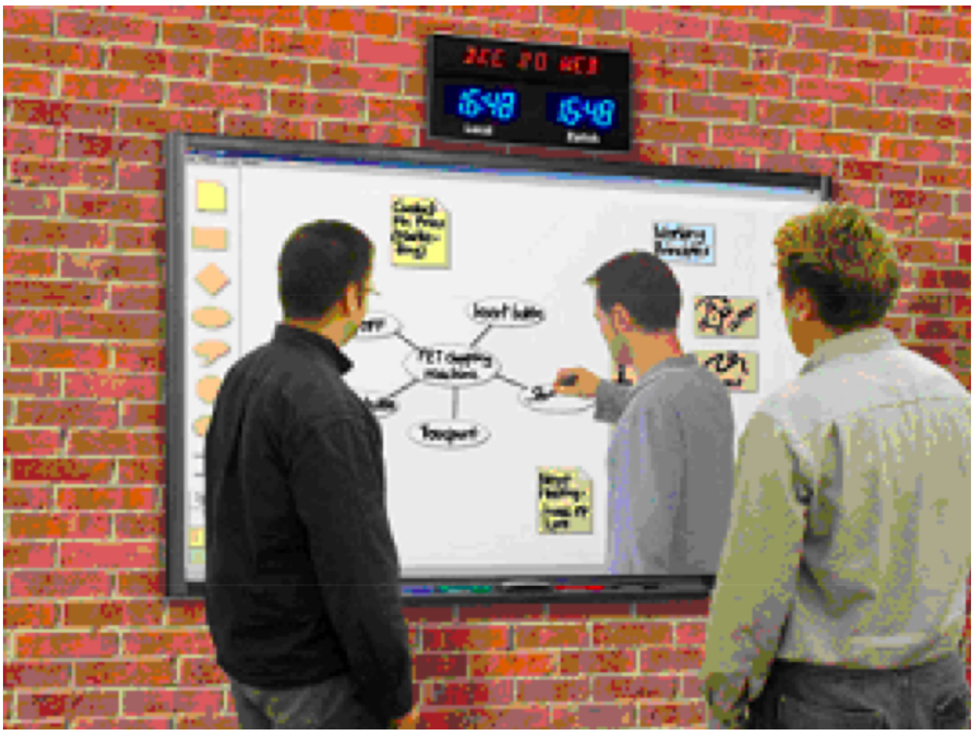

Figure 2.2: CollaBoard, a collaborative whiteboard for remote interactions, overlaying the remote people's video reprentation on top of the common workspace.

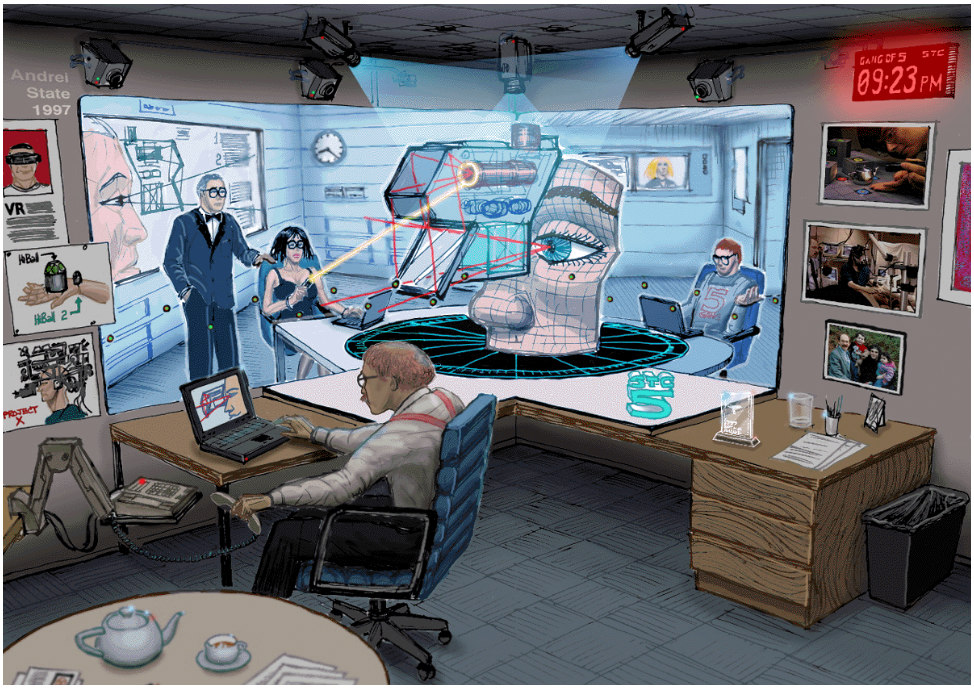

Figure 2.3: Office of the Future: four users are engage in collaboration in a virtual meeting.

focus naturally between the others and the collaborative work [Tanner and Shah, 2010]. In addition, efforts in integrating the interpersonal space with the shared workspace, resulted in a improvement of the work flow, enabling a seamless integration of live communication with joint collaboration. Ishii and Kobayashi [1992] introduced the *Clearboard*, a videoconferencing electronic board that connects remote rooms to support informal face-to-face communication. With this system, users can draw on a shared virtual surface. Using a different approach, Tang et al. [2007] introduces *VideoArms*, an embodied technique to collaboration that reproduces remote people's arms around an interactive surface. With VideoArms, local users have the clear awareness of the remote people's actions. In a different manner, Kunz et al. [2010], with the *CollaBoard* system, employ the life-size video representation of remote users on top of the shared workspace. Figure 2.2, shows *CollaBoard* with two local users collaborating with another remote user.

Shared immersive virtual environments [Raskar et al., 1998] provide a different experience from "talking heads" in that people can explore a panoramic vision of the remote location.In [Raskar et al., 1998] vision of the Office of the future, as depicted on the conceptual sketch of the Figure 2.3, participants in a virtual meeting can collaboratively manipulate 3D objects while seeing each other as they were in the same place, by projecting video on to the walls of the room, and thereby, virtually joining all remote places into one shared workspace. Following the same principles, Benko et al. [2012b] introduce the *MirageTable*, a system that exploits the concept of bringing people together as if they were working in the same table. By projecting a 3D mesh of the remote user, captured by depth cameras, into a table curved upwards, the local user can rely on the virtual representation of the other to perform collaborative tasks.

The most suitable systems for collaboration are spatially immersive, either via large scale-, tiled-

Figure 2.4: Immersive Group-to-Group Telepresence: a distributed group of people can meet each other and navigate through the virtual environment.

or, even CAVE-like- displays. These systems provide the necessary size for all people in a meeting to see others and support the physical space needed for collaborative work in two remote rooms. As an example, Cohen et al. [2014] present a video-conferencing setup with a shared visual scene to promote co-operative play with children. The authors showed that the mirror metaphor could improve the sense of proximity between users. Following a different metaphor, Beck et al. [2013] presented an immersive telepresence system that allows distributed groups of users to meet in a shared virtual 3D world. Participants could meet front-to-front and explore a large 3D model, as depicted in the Figure 2.4.

2.2.1 Discussion

The body of work described above, relates to the state-of-the-art of the current research in telepresence environments. As described, current solutions rely on the depiction of video [Ishii and Kobayashi, 1992, Morikawa and Maesako, 1998], avatars or, even, representations of remote people projected onto surfaces or displayed in large scale immersive displays [Beck et al., 2013, Benko et al., 2012b]. Also, attempts have been made to virtually extend the local environment with a faithfully representation of remote places [Benko et al., 2012b, Raskar et al., 1998]. Although exploiting a shared workspace, local users have been made aware of the presence of remote people through digital barriers, always suggesting the physical distance between the two people, creating distinctive groups. Regarding that, splitting people across different spaces, can have a negative effect on the the group dynamics [Kraut et al., 1988]. Therefore, in the work presented in this dissertation, we argue that to create the feeling of remotely being there together, local people must be made aware of the presence of remote people around them, sharing awareness of both task and person [Buxton, 1992], by making the remote people's occupied space felt by the local ones. Furthermore, we argue that videoconferencing technologies do not have to play any role in collaborative virtual meetings, since people can relate to other people's proxies and representations as if they were the same [Reeves and Nass, 1996].

2.3 Social Interactions

When people get together, they communicate in several manners, besides verbally. People often implicitly adapt their physical distance and orientation when interacting with each other. It is also normal for people, in a room, to gather in groups during conversation. Consequently, this behaviour also occurs in business meeting settings and work gatherings. In his seminal work, Edward Hall [Hall, 1966] observed that space and distance between people impact interpersonal communication. In this section, we present the related work regarding *Proxemic* interactions, a field of study under nonverbal communication that explores the people's use of space beetween them.

2.3.1 Personal Space Theory and Proxemics

Initially from zoology, personal space was used to describe the behaviour of animals [Katz, 1937]. Hediger et al. [1950] sugests that animals use their spatial relationships with other animals to determine if they are in danger situations. Later, personal space was applied to the study of human interpersonal relationships. Sommer [1959] states, from observation in his studies, that personal space is the distance people placed themselves among others. Personal space is also described as an invisible bubble surrounding a person [Altman, 1975]. In psychology [Aiello, 1987] the concept of personal space serves a protective function and its usage is dictated by social norms. Thus, people react to violations of their personal space [Altman, 1975, Ciolek, 1983]. Behaviour and neuropsychological studies suggest that humans constructs three basic segments of space [Holmes and Spence, 2004]. The *Personal Space*, occupied by our bodies [Beschin and Robertson, 1997, Coslett, 1998, Vaishnavi et al., 1999]. The *Peripersonal Space*, defined as the space immediately surrounding our bodies until the extent of our limbs [Làdavas et al., 1998]. And the *Extrapersonal Space*, consisting of the space beyond the reach of our limbs [Previc, 1998]. In another way, Edward Hall [Hall, 1966] while introducing the concept of Proxemics, notes that interpersonal distance relationships between people are also a form of nonverbal communication, going beyond the personal space. Thereby, Hall conceptualises a model of interactions between people which highlights interpersonal implicit communication.

Hall's Proxemics

Edward Hall [Hall, 1966] in his anthropological studies, coined the term Proxemics, referring to his observations of the usage of distance and space on interpersonal relationships. Hall also refers to it as a silent language, since it is a form of non-verbal and implicit communication device. Hall's observations in proxemics interactions, were later confirmed by empirical studies [Aiello, 1987]. By correlating physical distance to interpersonal communications, the theory of proxemics can implicitly distinguish how people interact with each other. Proxemics also shows how people perceive, interpret and use distance cues to mediate their relationships. Hall proceeds in categorising proxemics distances into four discrete zones, each devided into the *close* and *far* phases, and describes the activities and interactions occurring inside them, as illustrated in the Figure 2.5.

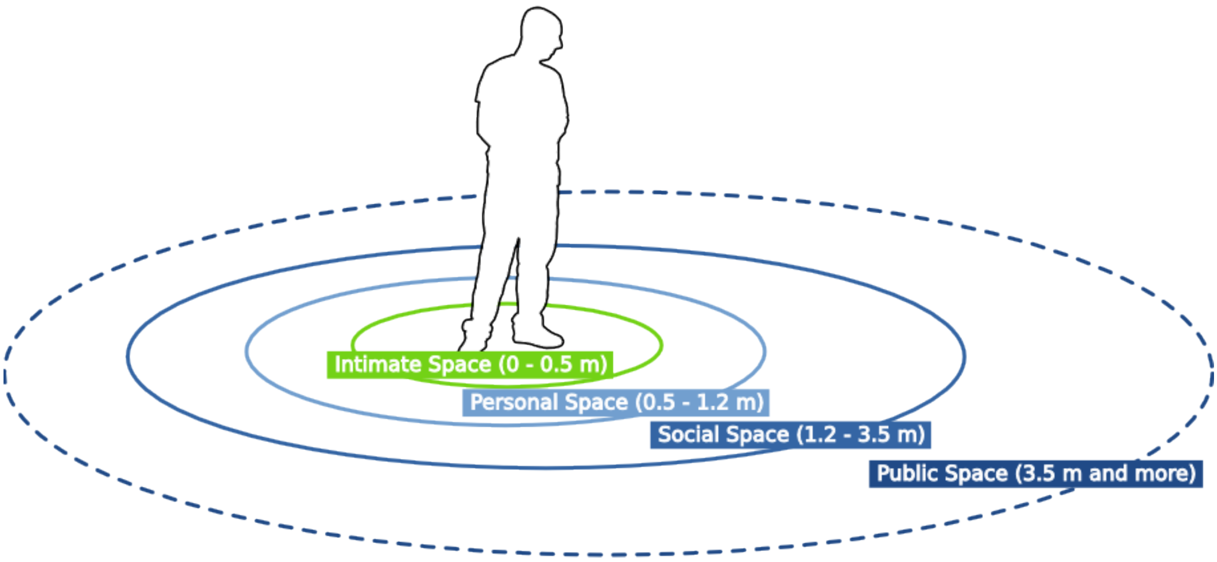

Figure 2.5: Hall Proxemic distances

- **Intimate Space (0 to 0.5 m)**

  This area encompasses the body of the person and extends to a distance of 50 centimetres. Normally, only intimate people can occupy the intimate space of another person. At this distance, people can whisper and touch. This space contains a close phase between 0 to 15 centimetres and a far phase between 15 and 50 centimetres.

- **Personal Space (0.5 to 1.2 m)**

  This space is reserved for friends and family relationships. At this distance, people can engage in close conversation at a lower volume and it is still possible to touch the other person. The personal space is the one that varies the most according to the culture and background of the people involved. It has a close phase between 50 and 76 centimetres, and a far phase between 76 centimetres and 1.2 meters.

- **Social Space (1.2 to 3.5 m)**

  This is the most common space used in day-to-day conversations with work colleagues and while meeting new people. In this space, interactions are more formal. In general, this space is used between acquaintances that don't know each other particularly well. It is still possible to maintain conversations in a comfortable volume, but the voice is louder. The close phase is between 1.2 and 2.1 meters, and the far phase is between 2.1 and 3.5 meters.

- **Public Space ($>$ 3.5 m)**

  At this distance, people have to speck louder to address others. Normally specking to an audience or simply passing others while walking in the street. This space is in the domain of public interactions. The close phase is between 3.5 to 8 meters, and the far phase is beyond 8 meters.

Despite representing in a discrete way the relations of proximity between people, these proxemics zones are invisible and imaginary. In addiction, the distances noted by Hall are not static. Other studies suggests that these distances or proxemics zones vary depending on several factors [Hayduk, 1985]. The environment is one factor that impacts people's use of proxemics, in the form of room size and room density [Evans et al., 1996]. Also, high illuminated settings can cause less discomfort to people in close proximity [Adams and Zuckerman, 1991]. Aiello [1987] shows the culture background is another factor, since people from Mediterranean and Latin backgrounds sit and stand closer than Anglo Saxon cultures. Female often stand closer that males [Price and Dabbs Jr, 1974] and the interpersonal distance increases with age [Aiello and Aiello, 1974]. Furthermore, the shape of personal space is not circular. Petri et al. [1974] suggests an elliptical shape, with longer distance at the front and smaller distances at the sides. Also, experimental studies from Adams and Zuckerman [1991] notes that reactions from infractions by entering peoples' personal space also suggests an elliptical shape. Finally, Sommer [2002] describes an hour-glass shape with wider areas in the front and back, and narrower sides.

Proxemics Fixed and Semi-Fixed Features

Hall describes proxemics further by defining types of spaces according to the way people behave around objects and also to the organisation of the space indoors. As such, these spaces are:

- **Fixed features spaces**
  Comprised by the layout of buildings and rooms. This spaces are composed of objects that cannot be moved. Such as, architectural details, or even, large scale displays.
- **Semi-fixed features spaces**
  This spaces are comprised of the spatial layout of objects that can be moved, including furniture, chairs and tabletop devices.

Focused Encounters or F-Formations

Interpersonal relationships are not only described by the proxemic distances introduced by Hall [Hall, 1966]. In general terms, Proxemics study the impact of distance on the formation of these relationships. On the other hand, the study of F-Formations considers the disposition of people when they are engaged in conversation encounters and describes the dynamics of small group interactions [Kendon, 1990, 2010, Ciolek and Kendon, 1980]. Typically, people cluster into circular arrangements that best suit the focus of their conversation. Therefore, an f-formation consists of a group of two or more people engage in a joint activity. The inner space of the invisible circle formed by them, *o-space*, is reserved for the focused activity of the conversation, and is comprised of the area between them that can be reached by their hands [Kendon, 1990]. The *p-space* is the ring of space outside the o-space that is occupied by the members of this close encounters. Surrounding the p-space is the *r-space*, which represents the world outside the conversation. People in the r-space do not take part in the encounter. Still, people in r-space approaching the f-formation can arrange arrange themselves into formation by aligning with the others in the p-space. The structure of f-formations can also be affected by semi-fixed features in the environment. Kendon [2010] states that people's group formations adapt to presence of objects, specially if those

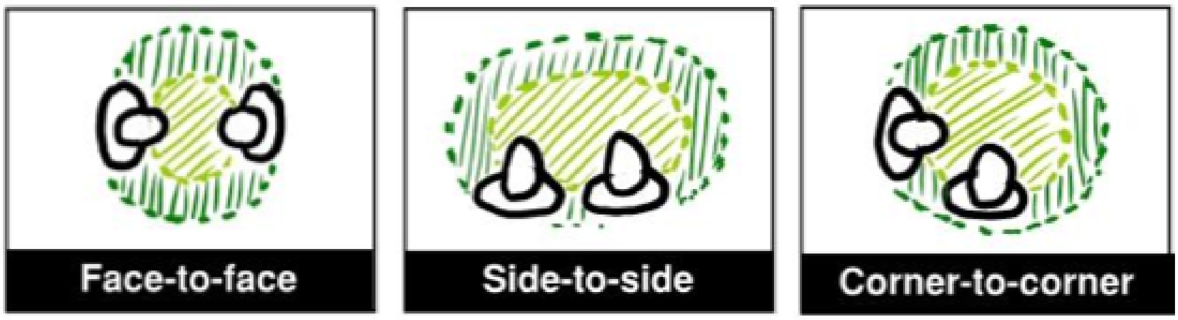

Figure 2.6: F-Formations. While engage in conversation people usally meet face-to-face, side-to-side or corner-to-corner.

objects are the main focus of the encounter (e.g., a large display or a tabletop). Figure 2.6 depicts the three kinds of observed f-formations relative to body orientation. People arrange themselves instinctively accordingly to the task that made them get together [Sommer, 1959]. A *face-to-face* formation, imply that people are performing in a competitive activity. *Side-to-side* formations occurs when people are engaged in a collaborative task, usually interacting with the same object in the o-space. In the other hand, *corner-to-corner* formations are mainly communicative and signify openness for other people to join.

2.3.2 Proxemics in Ubicomp

The theory of Proxemics describes that interpersonal relationships are mediated by distance. Also, people adjust their spatial relationships with other accordingly to the activity they are engaged on, whether simple conversation or performing collaborative tasks. Greenberg et al. [2011] argues that proxemics can help in the mediation of interactions in Ubicomp environments. After all, the vast majority of devices that make up modern ubicomp environments are virtually blind to the non-computational aspects of their surroundings, the fixed and semi-fixed features. Furthermore, even connected to each other by means of Wi-Fi of Bluetooth networks, these devices may recognise one another but they usually do not cooperate as a single and transparent system, rendering interactions between them tiresome and difficult to setup. Figure 2.7 illustrates a common indoors situation, depicting an ubicomp ecology of people carrying personal devices and coexisting with digital surfaces and other information appliances. Thereby, Greenberg et al. [2011] proposes that the same natural social behaviour carried out by people, can be transposed to Ubicomp environments to deal with interactions between people and devices, and even, devices with each other. In this section, we will report how the integration of social interactions can be made in ubicomp environments, also, we will review recent related works that adopt proxemic interaction in multiple device environments.

Proxemic Dimensions

Greenberg et al. [2011], while exploring the benefits of proxemic interations in ubicomp, identified the essential proxemic measures that need to be considered in order to make ubicomp environments react to

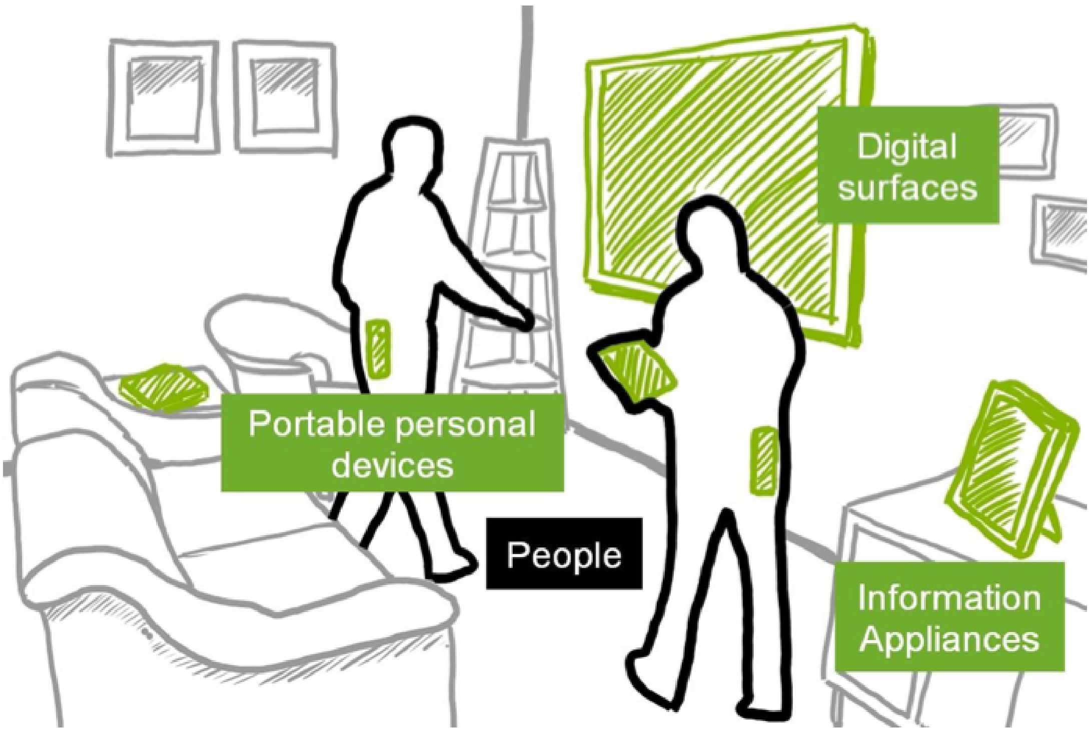

Figure 2.7: Depiction of Ubicomp environment comprised of people, personal devices, digital surfaces and information appliances.

social interactions. These measures are comprised of five dimensions, as depicted in Figure 2.8, which should be sensed and calculated by the ubiquitous network of devices. The five proxemic dimensions are:

1. **Distance**

   The measure of distance between people, fixed and semi-fixed environmental features and digital devices. Distance can be use to infer possibilities for interactions. Large wall displays can react when a person is in close proximity. Also, distance is the main measurement to determining in which proxemic zone a person lies against another, thus making it possible to classify their relationships.

2. **Orientation**

   Orientation is the relative angles between entities. This proxemic dimension captures nuances that

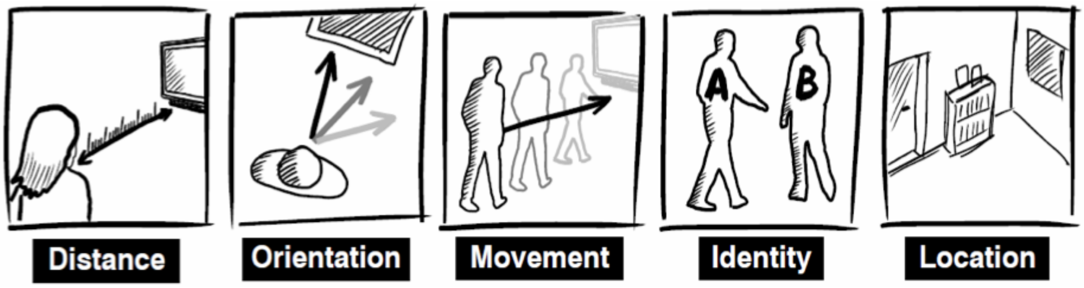

Figure 2.8: Proxemic dimentions that should be considered while designing Ubicomp environment.

cannot be achiever by observing distance alone. Although, orientation can provide information on the attention of people [Shell et al., 2003], it also is critical to detect and classify F-formations [Marquardt et al., 2012b].

3. **Movement**
   This measure consists in the changes of position and orientation of an entity over time. With movement, it is possible to calculate velocity and acceleration, revealing the intention of people to interact with others. Regarding digital objects, visualisation appliances can than predict when information could be requested.

4. **Identity**
   Knowledge about the identity of a person or the ownership of handheld devices, is critical when displaying personal information in ubicomp environments. Also, it is necessary for digital devices to know and understand the identity of entities in the environment when it needs have different reactions regarding the presence of people or other devices.

5. **Location**
   The setup of the environment and the distribution of fixed and semi-fixed features, since these features do play an active influence in the people's behaviour indoors. Also, location can be the context of the environment, ranging from private to public, or even the available area reserved for social interactions.

Proxemic Interactions

When Ubicomp systems are able to measure proxemics dimensions, digital devices can mediate interactions accordingly to the theory of Proxemics. Still, even if sensing digital devices are available in the ubicomp environment, information captured from the real world is difficult to process in a system's developer point of view [Marquardt et al., 2011a]. Recently, Marquardt et al. [2011a] introduced the *Proximity Toolkit* to deal with this process, leaving developers to build ubicomp systems on top of the interactions intended to be used. Therefore, the *Proxemics Toolkit* simplifies the access of proxemic information. Despite this, there is a great body of related work that takes advantage of proxemic information to build ubicomp ecologies and interactions between people and digital objects. Furthermore, many of the innovations concerning proxemics exploit current digital devices which nowadays have become ubiquitous. Smartphones and mobile devices have been equipped with the capability to interact with each other. Kortuem et al. [2005] demonstrates how mobile devices can establish a peer-to-peer connection and support interactions between them by measuring their spatial relationship. Proximity can also be used to pass information to co-located devices automatically or using gesture [Hinckley, 2003].
With the GroupTogether system, Marquardt et al. [2012b] explores the combination of proxemics with *micro-mobility* to support co-located interactions. *Micro-mobility* relates to the orientation and repositioning of physical artifacts. In close encounters, changing the relative position of handheld devices, suggests the intention to share or not share information [Luff and Heath, 1998]. Thus, tilting or moving

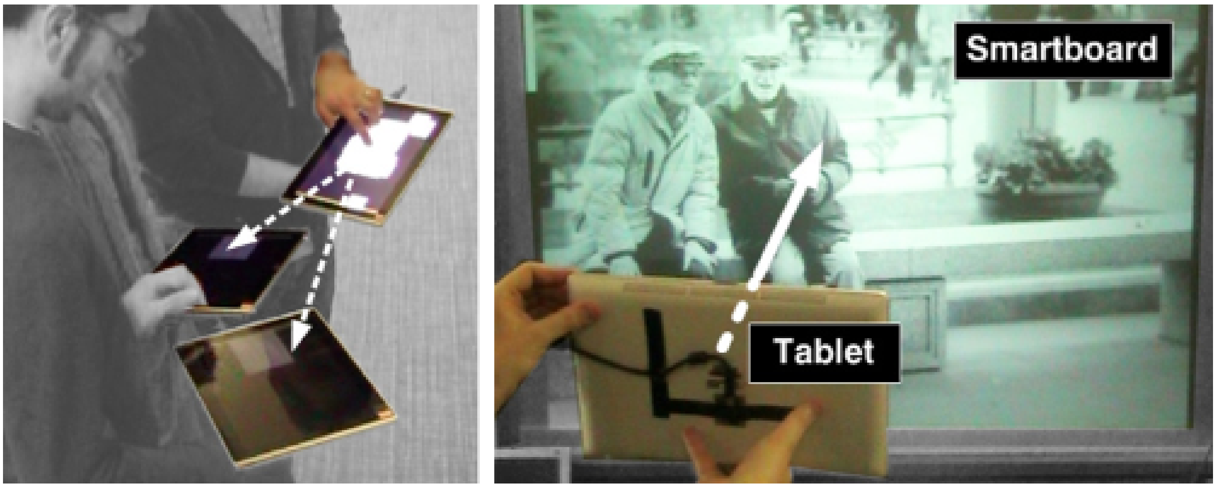

Figure 2.9: GroupTogether system Marquardt et al. [2012b] that uses a combination of F-formations and *micro-mobility* to share and propagate content. (Left) A user shares the content on his handheld device with another member of his F-formation, by tilting the device. (Right) Tilting the handheld device forward in direction of the smartboard, users can implicitly propagate content.

closer handheld devices towards others, indicates the intention to share the displayed content. Marquardt et al. [2012b] then, proposes interaction techniques based on these concepts. By selecting content and tilting the handheld device, this same content is transmitted to other devices in proximity, as shown in Figure 2.9. By tilting the device to an extreme of an angle larger than 70 degrees, content is mirrored in fullscreen in both devices. Also, iconic edges are displayed while devices are at close proximity in the same F-formation. Serving as portals to transfer content. Pinch-to-zoom gesture is used to explicitly propagate content over the surface of devices' displays. Marquardt et al. [2012b] also considered interactions with large displays. Since the proxemics distances can implicitly encompass fixed and semi-fixed environmental features, by orienting the handheld device's screen to a large scale display, content is propagated to a more public setting. Providing the measurement of proxemic dimensions, large scale and wall displays can dynamically adjust the shown content and how people can interact with them. Vogel and Balakrishnan [2004] developed design principles for interactive public displays that support the transition from implicit to explicit interaction with both public and personal information. By segmenting the space in front of the display, into *Personal*, *Subtle*, *Implicit* and *Ambient* interactive zones, the display content changes from public to private and different interactions become available. Similarly, Ju et al. [2008] applied implicit interactions using proxemics distances to augmented multi-user smartboards, where users in close personal proximity can interact using a stylus pen, while users at a distance are presented with ambient content. Also, Ju et al. [2008] noted that the closest user to the display is the one driving the main interaction. More recently, Marquardt et al. [2012a] address the issue of connecting and transfering information between personal and shared digital surfaces using interactions inspired by the theory of proxemics. Marquardt et al. [2012a] propose different techniques to transfer data, such as, pointing gestures and portals for interactions at a distance, and direct drag manipulation when in close proximity. In this environment, digital devices are aware of the user's situation and adapt by reacting to different interactions accordingly to the context. [Ballendat et al., 2010] introduces a home media player that exploits the proxemic knowledge of nearby people and digital devices, including their position, identity, movement and orientation, thus, mediating interactions and triggering actions in the media player. The primary interface allows for browsing, selection and playback of videos on a wall display. However, using an attentive behaviour, the media player pauses the playback functionality when the user directs his attention to other semi-fixed features in the environment, when the user picks up magazine or answers a call on his mobile phone. Additionally, the media player react to the presence of other approaching users and displays the title of the current featured video. If both users engage in conversation, the media player also pauses the playback.

2.3.3 Discussion

During informal brainstorming sessions, people do use normal social interactions while engaging in collaborative tasks. In his seminal work, Edward Hall [Hall, 1966] encapsulates those interactions into a social model that can help ubiquitous computing systems to infer people's actions and their desire to engage in communication. In fact, several works use the Proxemics theory, not only to infer the intentions for people to start interactions with each other, but also, to mediate interactions with physical digital objects [Roussel et al., 2004, Ju et al., 2008, Marquardt et al., 2012b]. Despite that, no attempts to extend proximity-aware interactions to remote people in virtual meeting environments, have been made. It is our belief that remote collaborative environments have much to gain by employing Proxemics to mediate tasks between remote people, by transposing the way people work in a co-located fashion, to telepresence environments. And through it, alleviate the constraints imposed by current technologies for computer supported collaborative work.

2.4 Navigation on Handheld Devices

The task of navigation in virtual environments consists of controlling the transformations applied to the virtual camera within the 3D scene. Despite this area of study is not the focus of this dissertation, navigation in virtual environments, especially on handheld devices, is essential for the design and review of 3D engineering models. Today's multi-touch technologies proliferate in almost all mobile devices. Thus,Hancock et al. [2009] proposes different techniques for direct and indirect manipulation of 3D models. Yet, there is a great concern to create interfaces that permit direct manipulation [Martinet et al., 2012, Reisman et al., 2009, Yu et al., 2010, Butkiewicz and Ware, 2011], this is due to the fact that this type of interaction to facilitate use by inexperienced users [Yu et al., 2010] and enable the completion of tasks more quickly [Knoedel and Hachet, 2011]. On the other hand, the indirect manipulation gives better results in terms of accuracy in tasks [Knoedel and Hachet, 2011]. But while allowing the usage of multiple contact points, difficulties arise in performing multitouch gestures when the interactive surface do not provide a large area, this is the case of mobile devices. Aware of the limitation of using both hands while interacting with smartphones, Boring et al. [2012] proposed the FatThumb technique, which allows users to interact with a 2D map using the thumb's contact size. Considering 3D Virtual Environments, Hachet et al. [2008] introduced Navidget for camera placement, that uses sketched circles to obtain the point of interest (POI) representing the end point of the desired camera's trajectory and position. ScrutiCam [Declec et al., 2009] implements a manipulation technique to move the camera around objects by moving an area of interest to the center of the screen, using a single touch. In Drag'n Go [Moerman et al., 2012] the user controls the camera progression in the VE by combining target acquisition with touch input gestures. Move&Look [Marchal et al., 2013] extends the Drag'n Go method in the sense that it uses single-touch interactions to move around the VE and multi-touch to manage the camera's orientation. Jankowski et al. [2014] compared several techniques and concluded that a stroke-based method can achieve better results for street level navigation tasks.

2.5 Summary

In this Chapter, we provided an overview of the literature containing the body of knowledge that guided our work. Firstly, we reviewed the seminal work regarding Ubiquitous computing and context-aware environments. Secondly, we described the state-of-the-art regarding telepresence in collaborative environments. Thirdly, we provided an analysis of the research related to proximity-aware and proxemics interactions. Finally, a brief description of recent works on navigation techniques for virtual environments on handheld devices was provided. Following this chapter, we describe our proposed approach to deal with the collaborative work in virtual meetings. This includes the core concepts developed to achieve proximal interactions with remote people, and the awareness techniques to support those interactions.

Chapter 3

Eery Proxemics

Our work focuses on the mediation of collaborative work in virtual meetings between geographically dispersed people, in order to tackle the issue of the remote people's lack of physical presence. In this chapter, we argue that we can study a technique that enables local and remote people to meet and engage in collaborative work using proximal interactions. Our proposed solution, exposed below, succeeds at bringing geographically distant people together at the same space, and provides the necessary devices and feedback for participants in the virtual meeting to be able to proximally interact with each other at the distance. Therefore Eery Proxemics[1] is our proposed solution that exploits Remote Proxemics and allows local people to improve the level of awareness of the remote participants' presence. Figure 3.1 maps out the scope of our solution. Eery Proxemics exploits normal social interactions to improve remote collaboration in virtual environments. By bringing proxemic interactions to a remote setting, local and remote participants in virtual meetings can naturally relate to the presence of one another and engage in collaborative tasks as if they were co-located. Providing that they are aware of one

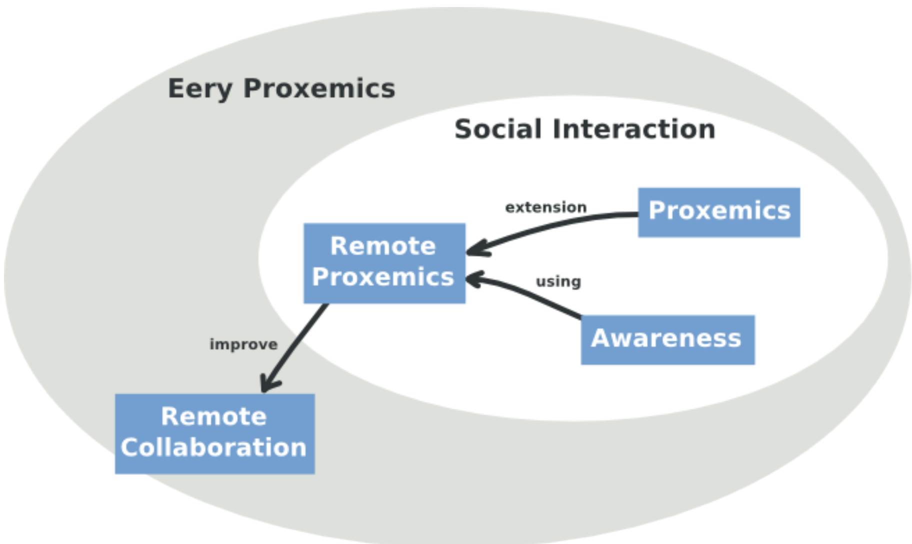

Figure 3.1: Eery Proxemic's scope diagram.

[1]Eery: same as eerie, meaning mysterious and peculiar.

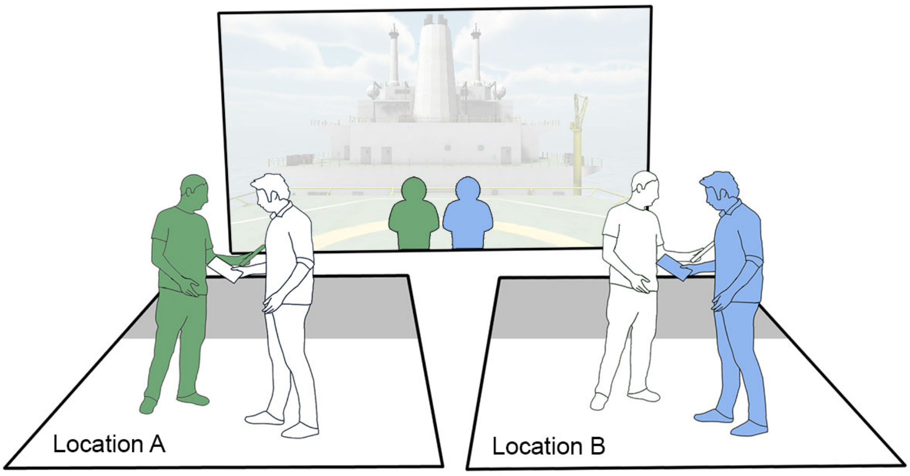

Figure 3.2: Eery Space: Two people in different locations interacting in the Eery Space. Wall displays are the common element in both locations and show the same information.

another's situation and actions (Awareness).

As a way to better address our research statement, we propose a design review tool to support collaborative tasks from the oil and gas industry field. In oil and gas industry settings, large teams usually gather to review and discuss around large 3D CAD models, which are often difficult to visualise and to navigate due to their complexity. These teams typically include field engineers working at different remote locations. Maintenance in specific infrastructures inside an oil platform is very frequent and technical staff have to plan how to access them beforehand. Furthermore, changes to these installations are frequent, removing and installing new components. It is common to use large scale screens to support engineers' cooperative work by allowing them to promptly visualise the procedures needed to repair devices while assessing possible interferences reflected in the 3D model.

We begin this chapter by introducing the fundamental concepts of Eery Proxemics and describe the set of featured interactions necessary to support the collaborative work. Subsequently, we present the presence awareness techniques which renders Remote Proxemics possible.

3.1 Eery Space

To explore proxemic interactions between physically apart users, we created a common virtual space, to overcome the physical distance separating them. We call this shared virtual locus *Eery Space*, where people equipped with personal handheld devices can meet, collaborate and share resources in front of a wall display, as depicted in Figure 3.2. The Eery Space assumes that people are distributed in several similar rooms merged together in the same virtual space. Also, every room is outfitted with a wall screen display. Instead of placing users in front of each other, as typical of commercial applications and other research works [Benko et al., 2012a, Beck et al., 2013], we place both remote and local people side-by-side, similarly to Cohen et al. [2014], maintaining their positions in front of the wall display. We consider both a user's position alongside the wall and their distance to it. Contrarily to the common interactions with remote people using the mirror metaphor, we provide for a sense of remote participants

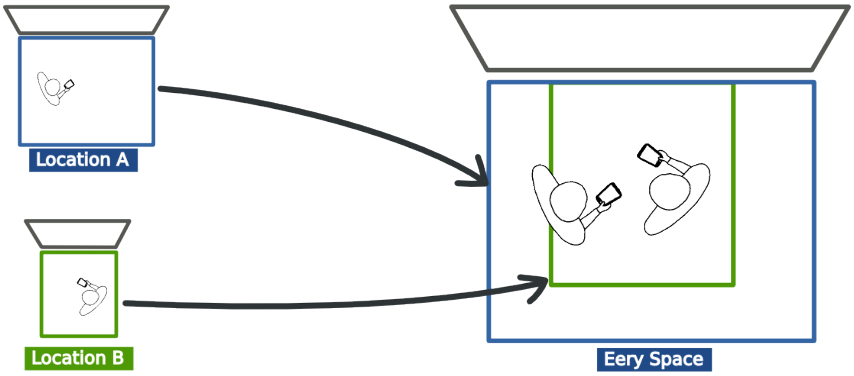

Figure 3.3: Eery Space, merging two different sized rooms into the same virtual space.

being around the local ones in the same shared space. This creates and reinforces the model of a shared meeting area where interactions can take place. Furthermore, all wall displays show the same perspective to make shared references plausible. Eery Space also takes into account that no room is like the other, thus this virtual space spans over the area of the larger room, as depicted in Figure 3.3. Though people are confined to the area that is provided by their physical space, which can be less than the total of the Eery Space, its distance relationships with the others are kept in the same proportions. Nevertheless, there is a limitation in this model to the extent that people in the the extremities of the larger room are not reachable by the people in the smaller rooms. This limitation is a detail that alone does not preclude the study of remote proxemics in the context of this dissertation.

3.2 Social Bubbles

The Eery Space features wall-sized displays. Due to their large dimensions, such displays have the characteristic of providing a visualisation surface capable of serving multiple people at the same time. Also, they do not restrict people to a single position. Wall users can freely move alongside the surface to better reach the displayed information, move forward to glimpse more details, or move further back to get a general view.

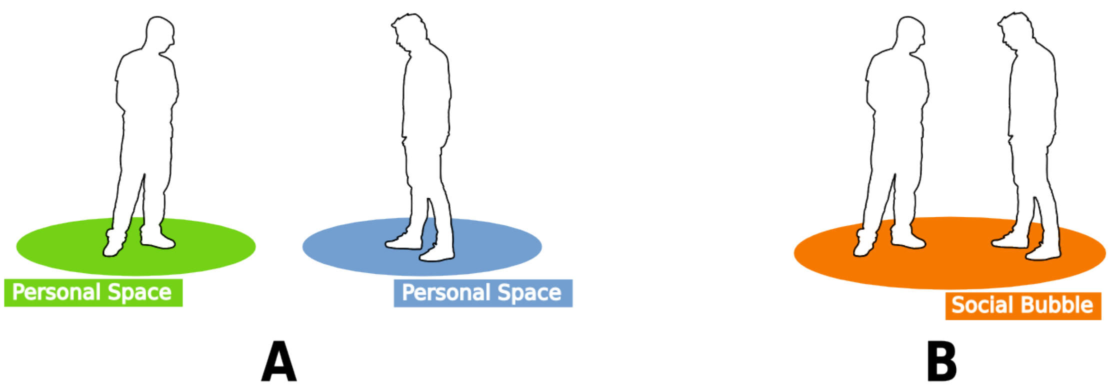

Figure 3.4: Social Bubbles: (A) Two people placed outside the personal space of one another. (B) A social bubble is formed when people's personal spaces intersect.

In a meeting, it is natural for various different working groups, people performing related tasks, to appear when participants move in front of the wall display. To identify and deal with these groups of people, we devised a novel model of proxemics. We call this model **Social Bubbles**. Hall's [Hall, 1966] model for proxemic distances dictates that if people are close to each other is because they are interacting in a certain way. Within the social space, people are interacting in a formal way, a normal professional relationship. In contrast, personal space is reserved for family and friends, and people can use a comfortable low volume to talk. Yet, as described by Hall [1966], these distances are dynamic, friendship and professional acquaintanceship decreases interpersonal distances [Sommer, 2002]. Social bubbles embody these concepts and is an adaptation to the collaborative work environment that takes place in Eery Space.

Inside the Eery Space, interactions are initiated by analysing the distribution of people in space. The intention of the people to perform a collaborative task is implicitly detected when they create a social bubble around them. Since we are in a working environment, people do not need to enter the personal space of each other, because they can be neither family nor friends. Instead, a social bubble is created through the intersection of the personal spaces, as depicted in Figure 3.4. Thereby, people can interact with each other using a distance that has the maximum initial portion of the social space. This formulation of the model of social bubbles, allows people motivated by the collaborative work, able to create proximal interactions without violating the personal space of others. Since, people are aware of their personal space, behaviours that violate their social boundaries may prove uncomfortable.

In general, this approach ensures encapsulation of the actions arising within each of the bubbles that are formed during the meeting. People are in a social bubble because they are having a closed conversation or because they are involved in a same task. Therefore, bubbles are created implicitly by distance. To create a bubble, people have to naturally go near to each other. The destruction of bubbles is analogous to its creation. Social bubbles cease to exist when people move apart.

To summarise, we define the concept of social bubbles as follows:

> ***Social Bubble*** *is the virtual space that results from the intersection of the personal space of two or more people, where people can meet, share resources and engage in closed conversation.*

3.3 Remote Proxemics

We devised remote proxemics to be able to capture the natural interactions that occur between co-located people and make them available to the meeting participants who are not physically in the same room. Thus, all interactions in Eery Proxemics described here have the ability to work the same for local and remote people. The success of our approach is to ensure that the local and remote people are always present and side by side within the Eery Space, so participants can create social bubbles in the same way, regardless of their physical presence in the room. These social bubbles can encompass

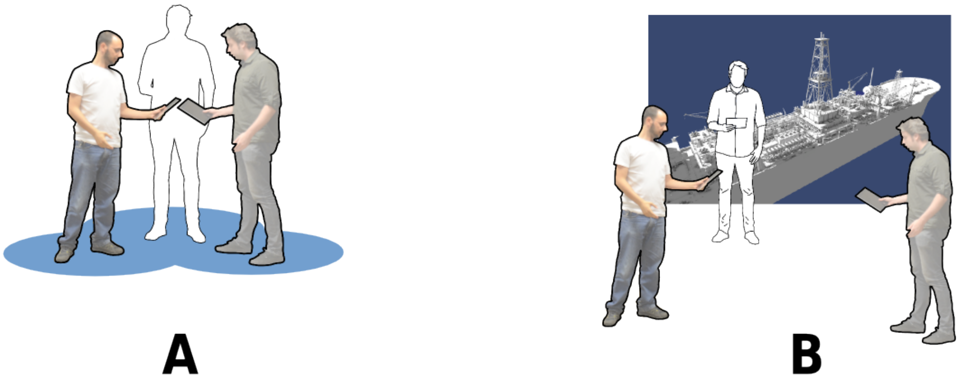

Figure 3.5: Remote Proxemics: (A) Two local people and one remote (white) formed a social bubble and are engaged in collaborative work. (B) The remote participant, closest to the wall display, is the moderator. In Eery Space,anyone can grab the control of the visualisation by moving inside the moderator space.

two or more users, either local or remote. When located in the same bubble, users can engage in collaborative activities.

Once the Eery Proxemics implements an environment with multiple people and devices, we have grouped these interactions into two groups: person-to-person, for interactions involving people and their mobile devices; and person-to-surface, for interactions between people and the wall display.

3.3.1 Considering Person-to-person Interactions

Within Eery Space when people come together and create a social bubble, a set of tools are made available to them to support collaborative tasks, in the form of person-to-person interactions. These interactions, here described not only include the participants but also their mobile devices, which in this case are smartphones. When people establish a social bubble, their smartphone devices automatically opens a channel of communication between local and remote participants. Since verbal communication is also a key element for the success of virtual meetings, participants can talk and hear the other people in their bubble. This channel of communication is then closed immediately when the bubble is destroyed. Similarly and simultaneously, for participants in the same social bubble, their handheld devices are synchronised with the common visualisation on the wall display. At this stage, participants can engage in a collaborative session of brainstorming sketches. Users can draw sketches around points of interest on top of the 3D model and see the others sketches in real-time.

3.3.2 Considering Person-to-Surface Interactions

The wall display serves the purpose of relaying the information under analysis to all meeting's participants. When a proximity relationship with the wall display is established, the participant turns to the role of moderator. In Eery Space, the moderator is a person that has special authority to take control of the common visualisation on all wall displays, by mirroring actions made on the handheld device. This authority is granted to whom gets closest to the display, inside the moderator space (as illustrated in

Figure 3.5) (right), taking advantage of person-to-surface proxemic interactions. Also, when a meeting participant becomes the moderator, a channel for speech communication is opened so that they can address the meetings attendees. His speech is relayed to the participants that in relation to him are remote through their handheld devices, since local participants already can hear him. The current moderator relinquishes his role when leaving the moderator space. If this happens and another person is standing in that space, then they become the new moderator. Otherwise, the moderator role will be open for anyone to take.

3.4 Providing Awareness

While becoming and staying aware of others is something that we take for granted in everyday life, maintaining this awareness has proven to be difficult in real-time distributed systems [Gutwin and Greenberg, 2002]. Previous research indicated that people can respond socially and naturally to media elements [Reeves and Nass, 1996]. Thus, we allow remote users to interact through appropriate virtual proxies, by making both the shared space and actions mutually visible. When trying to keep people conscious of other people's presence, an important design issue is how to provide such information in a non-obtrusive, yet effective manner. Following the collaborative guidelines proposed by Erickson and Kellog [Erickson and Kellogg, 2000], we used the techniques described bellow to increase visibility and awareness of other users, namely for remote participants, either through the wall display, the projected floor or via individual handheld devices.

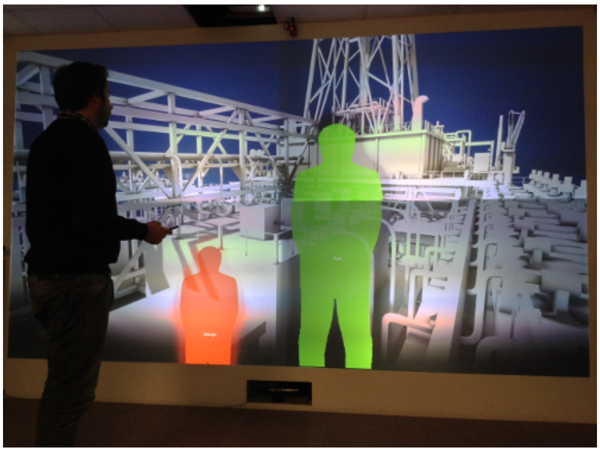

Figure 3.6: Users' shadows depicting two participants on the wall display. The larger shadow indicates that the remote person had the moderator role (in green). Local participants (on the left) also have a shadow representation.

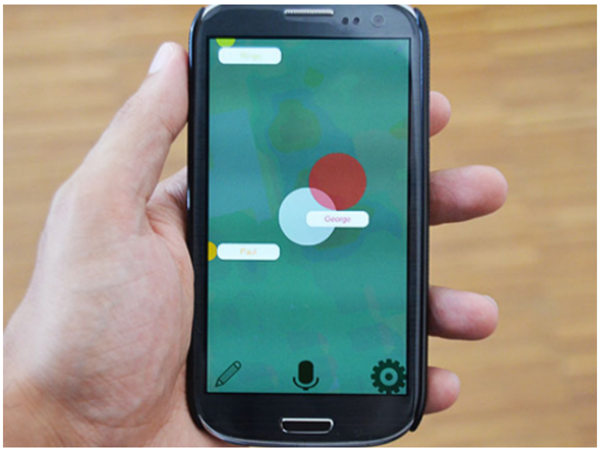

Figure 3.7: Participants's bubble map. The large white circle in the center represents the device's owner. The large red circle on its right represents a user in the same bubble. The two small circles on the screen edge are users outside the device's owner bubble.

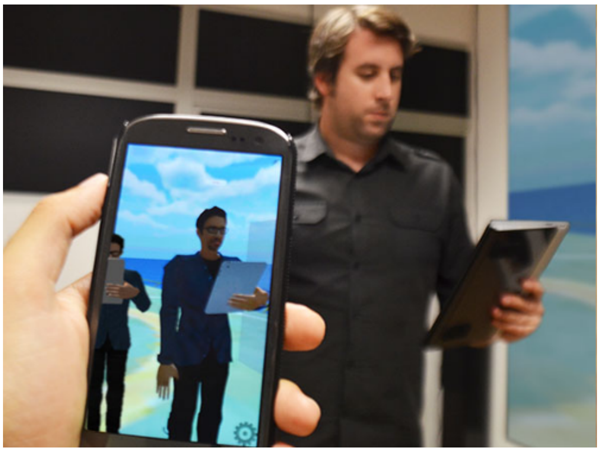

Figure 3.8: Virtual window offers a personal view to the virtual world, showing users' avatars with their position and orientation accordingly to the wall, from the device owner's point of view. In this case two users are shown, one local and one remote.

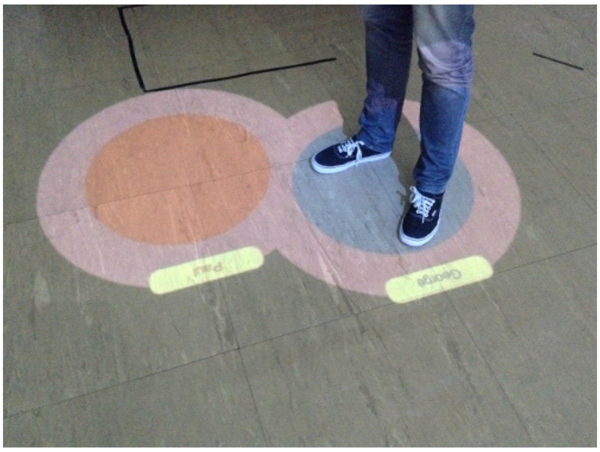

Figure 3.9: Floor shadows depicts the location of people in the Eery Space. In this case, a remote and a local user are establishing a social bubble. The inner circle represents the participant's intimate space and the outer ring, the personal space.

3.4.1 Wall Shadows

Every person has a representative shadow on the wall display, distinguished by a name and a unique colour, as shown in Figure 3.6 similarly to the work of Apperley et al. [2003]. The location of the shadow reflects distance from the person to the wall to give a sense of the spacial relationship between the people and the interactive surface. Wall shadows takes in consideration an imaginary directional light source at the infinity and towards the wall display. Thus, the nearest person to the wall display, will have the shadow with more coverage area than the others. A much larger shadow also makes it clear who is the moderator. Furthermore, each user has a coloured aura around their shadow. When two or more people share the same aura colour, this means they are in the same social bubble and can initiate collaborative tasks.

3.4.2 Bubble Map

Whenever a user tilts their handheld device to an horizontal position, a partial top view of the Eery Space is displayed, as depicted in Figure 3.7. In the center of the screen, its owner is represented by a large white circle. Other users who are close enough to lie in the same Interactive Bubble as the device owner's are also portrayed as large circles, painted with the colour of each user. Users outside the bubble are considered off-screen. Resorting to an approach similar to Gustafson et al. Gustafson et al. [2008], we place these circles (smaller than users in the same bubble) on the screen edge, indicating their direction according to the device owner's position.

3.4.3 Virtual Window

Virtual Windows provide a more direct representation of other users' position and orientation. These depict a view into the virtual world, in a similar manner to the work of Basu et al. Basu et al. [2012]. Using the combined information of users' position and the orientation of their handheld device, we calculate the user's own perspective, allowing them to point the device wherever they desire. The virtual window shows both local and remote users (Figure 3.8), represented by avatars within the virtual environment. For the purpose of this dissertation, we used a 3D model of a generic clothed human.

3.4.4 Floor Shadows

In Eery Space, every local and remote participant has a representative projected shadow on the room's floor, as depicted in Figure 3.9. All floor shadows are unique to its corresponding person and are distinguished from each other by a name (the participant identity) and the user's unique colour, analogous to the wall shadows. In addition, these shadows move in accordance with the person's position within the Eery Space to visually define the participant's personal space and makes people aware of each other. The Floor Shadows provides the necessary spacial information for participants to initiate proximity interactions. When people come together to start a social bubble, the shadows on the floor inform on the status of their Social Bubble, by displaying a coloured aura around the bubble's members. The projected aura gets its colour by the computation of the social bubble's members colour difference. This makes that new colour unique and unmistakably different from the other shadows on the floor.

3.4.5 Intimate Space

We designed Eery Space keeping each person's personal locus in mind. Every user has their own space assured, even if they are not in the same physical room as the others. To prevent users from invading another user's intimate space, we provide haptic feedback by vibrating their handheld device, when this happens. In this way, participants can quietly adjust their positions without interrupting the main meeting, since this technique does not use audio or visual cues.

3.5 Binding users to handheld devices

The Eery Space strives on the mediation of interactions using proximity, aided by handheld devices. A common issue in ubiquitous computing environments, comprised of multiple devices, is the association of these devices with the people using them. The interactions described in this chapter, not only have the need for the knowledge of the people's actions within the Eery Space, but also, their handheld devices must retain the knowledge of who is holding them. While not having that kind of information, the handheld device cannot change its presentation accordingly with the user's actions, and cannot display the relevant feedback, in the form of our proposed awareness techniques. Furthermore, identity is one of the dimensions necessary to perform proxemics interactions, either local or remote. And since, normally, handheld devices are personal and not transmissible, they are proxies of their users and can be used as a personal identifier by binding devices with people.

In this section, we describe the two approaches studied in the course of this dissertation. The first one being an acceleration based algorithm to match people's hand movements with mobile devices'

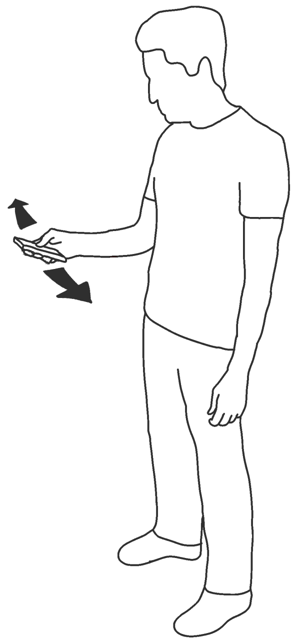

Figure 3.10: User, holding an handheld device, performing the horizontal gesture to initiate a session.

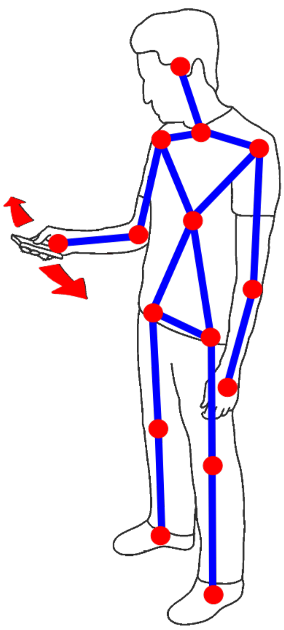

Figure 3.11: User Skeleton Model obtained with Microsoft Kinect depth cameras

accelerometer data. And the second one, a simple but effective solution to aid in the development and evaluation of Eery Proxemics.

3.5.1 Acceleration-based approach

Mobile devices have become ubiquitous and are equipped with several sensors to better understand the world surrounding them, also, they hold storage capacity for large amounts of data. In a certain way, mobile devices are, almost exclusively, personal and linked to one user. In this section, we describe our acceleration-based approach consisting in computing the resulting accelerations from hand movements of all people in order to find the relationship of resemblance with accelerometer data obtained from their mobile devices. To ensure unambiguous data, we devised a gesture to indicate the intention to bind

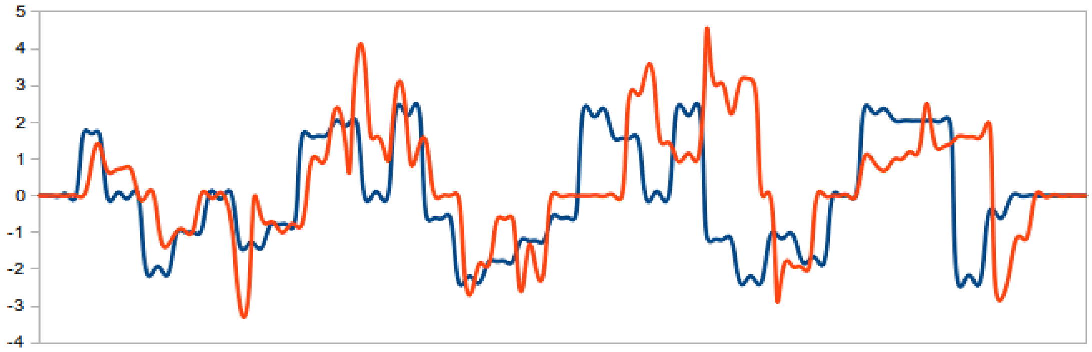

Figure 3.12: Plot representing the data set for the computer vision tracked accelerations(in orange) and handheld device accelerometer(in blue) from the same hand, during the horizontal pairing gesture.

a user with his phone and to add a new device to the Eery Space. The gesture corresponds to an horizontal movement of the hand holding the mobile phone, as depicted in Figure 3.10, which creates a signal of the acceleration data, given by the handheld devices accelerometer hardware, within a set time interval.

Simultaneously, we use all users' joints information, from a *Skeleton Model* supplied by one Microsoft Kinect depth camera, to calculate similar acceleration signals from the instantaneous speed given by a change in hands position. Figure 3.11 shows a representation of the three-dimensional data of the obtained *Skeleton Model*. Since the values derived from the handheld device accelerometer sensor are calculated using the Earth's gravity, hand tracked values are divided by $1g$ ($g = 9,8m/s^2$) so they can both be at the same scope.

The Figure 3.12 shows two acceleration signals plotted as waveforms, where the blue signal corresponds to data collected from the accelerometer sensors, and the color orange corresponds to the calculated accelerations of the users' hand. It is thus apparent that although the signals are similar, there are substantial differences in the amplitude and there is an offset on the time axis. Moreover, the second signal contains some noise due the nature of the hardware chosen to track the users' hands. While a binding action is preformed, a signal, generated from the mobile device's accelerometer, is compared to the all captured accelerations of every user's hands, in the attempt to find a match. Thus, to find the corresponding pair we use the *Cross-correlation* algorithm that, given two waveforms, returns a degree of similarity between them, the *correlation coefficient*. In pattern matching, *Cross-correlation* is a standard method of finding the measure to which two signals are correlated. In our case, we use the definition for discrete functions, Equation 3.1, where f^* is the complex conjugate of f.

$$(f \star g)[n] = \sum_{t_0}^{t_n} f^*[m]g[n+m] \tag{3.1}$$

For every users' hand signal h, with N being the number of observed hands, and $a_{handheld}$ the signal with accelerometer data, we apply the matching algorithm ($h_N \star a_{handheld}$). The pair that returns the highest *correlation coefficient* is chosen. Ultimately, this algorithm can easily find the corresponding pair, as the calculated *correlation coefficient* stands out with much higher numerical value than the coefficients for incorrect signals. The *Cross-correlation* method allows the signals to have shifted values in time, different amplitudes, as well as producing positive results with noisy signals.

Despite showing good results in a controlled environment, evaluation trials show that it fails to acquire the person performing the hand gesture while the other people are freely moving in front of the wall display, due to the significant depth camera's noisy signal created while in these multiple user's environments. Furthermore, studies must be perform in order to determine if this approach can be applied to a multiple depth camera setup.

3.5.2 GUI approach

For the purpose of this dissertation, we developed a Graphical User Interface (GUI) approach to bind people with their handheld devices. This approach consists in a display of a map picturing all people

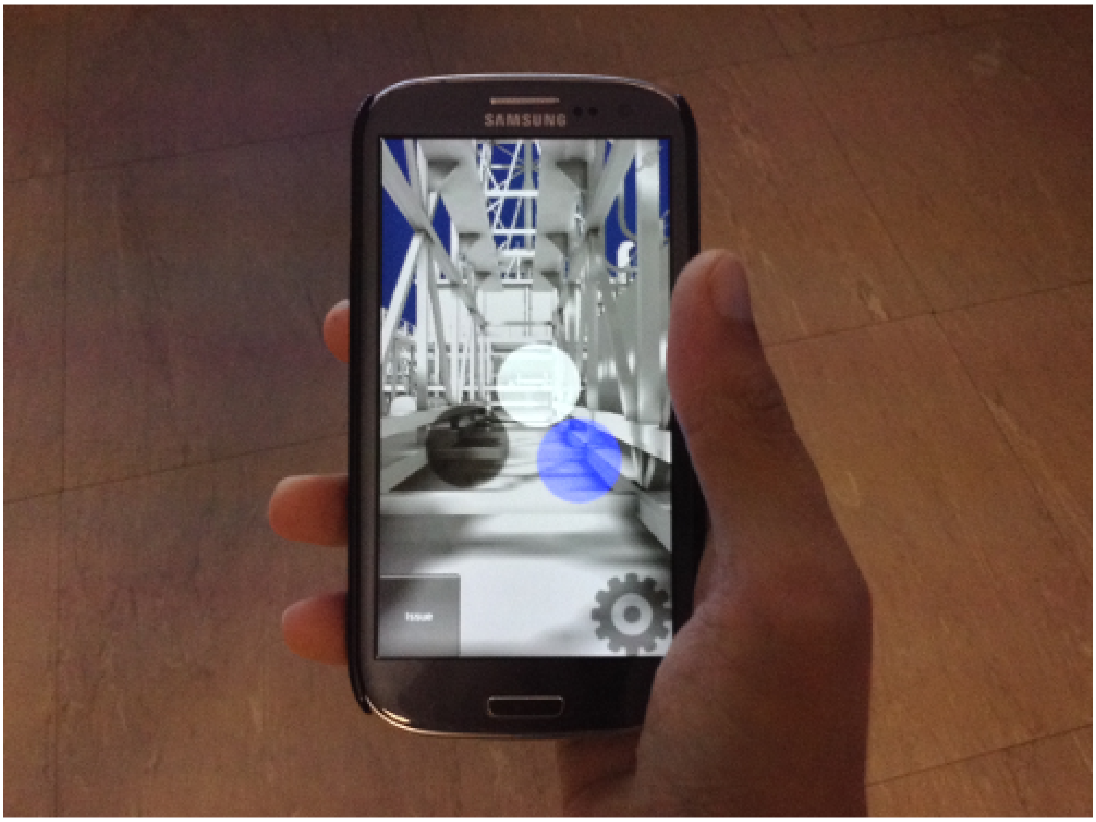

Figure 3.13: GUI approach to associate people with their devices. The dark circle represents a traced user that is yet to be associated with a device. The blue circle is a currently authenticated user and the white one is a authenticated user from a remote location.

currently present in that local portion of the Eery Space, while not associated with anyone, as depicted in the Figure 3.13. The map depicts the position of each person present in the room and shows associated and unassociated users. Thereby, when entering the Eery Space, the participant is required to select his representative icon on the handheld device screen before initiating any task. Although effective in binding and identifying participants in the virtual meeting, this GUI approach is prone to user errors and its easy for a person to pose as another. Despite that, it remains appropriate for the evaluation of Eery Proxemics in the scope of this thesis.

3.6 Navigation in Virtual Environments

Within the context of the collaborative meeting, participants need to analyse points of common interest in the virtual model. Camera manipulation is a very important task within 3D virtual environments. Whether it is a design review task or a virtual tour, it is often necessary to explore both the virtual scene in general and have a detailed look on specific objects.

In Eery Space the moderator retains the ability to guide the common visualisation on the wall display, by controlling the virtual environment's camera point of view. For this he has to be in a position to not cause occlusions in the viewing angle of the other participants in the virtual meeting. Several approaches were studied to empower the moderator with the ability to grab control of the visualisation. These

Figure 3.14: Navigation using a Brain Computer Interface. Pointing gestures combined with electroencephalographic data results in a forward movement of the virtual environment's camera to the point of interest

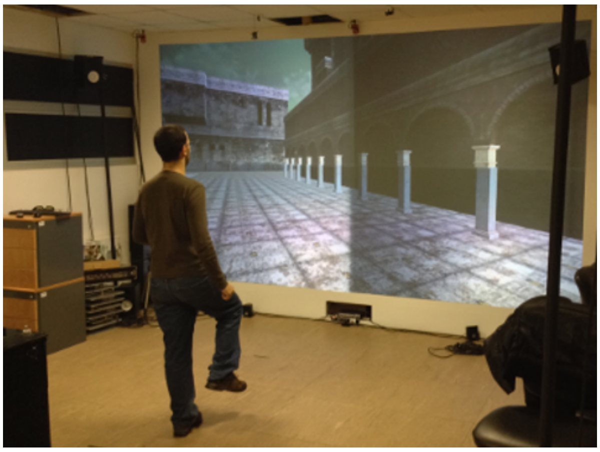

Figure 3.15: Walking-in-Palace approach. Using the lower limbs' natural movement, the user can control the navigation in the virtual environment.

approaches consisted of the use of a combination of a Brain-Computer interface (BCI) combined with pointing, the use of a Walking-in-Place technique driven by the kinect depth camera, and a touch based approach for the required handheld devices present in the Eery Space.

3.6.1 Brain-computer interface approach

Though still in its infancy, BCI through the analysis of electroencephalography (EEG) data, are becoming accessible by the emergence of inexpensive solutions like the Emotive Epoc EEG headset[2]. This device has the capability to detect several facial expressions (blink, smile, laugh, smirk, etc.) "out of the box", and prerecorded brain patterns. Therefore, we decided to study the feasibility of combining this device with the gesture of pointing, to set camera trajectories to a point of interest in the virtual environment. The detection of the intention to move to a specific location on the 3D scene was triggered by a predefined brain pattern and the resulting ray-cast of the pointing gesture on the surface of the 3D model, as shown in Figure 3.14. Once detected the intention and the target destination set, the virtual camera on the displayed virtual environment would perform a displacement animation until it reached its destination.

Either way, this approach proved to be inadequate for the navigation tasks required. Since it it necessary to register the brain patterns for that action for each participant in the meeting, and triggering actions are rather difficult and requires a large amount of training. Furthermore, this approach do not allow for multiple camera transformations required by the nature of the virtual meetings in the scope of this work. Also, the usage of this device is too intrusive and uncomfortable, and does not always work with everyone.

[2]Emotive Epoc EEG headset: http://www.emotiv.com/

3.6.2 Walking-in-place approach

The Walking in Place (WIP) is a navigation technique that enables people to control their linear position in a virtual environment, and try to mimic the real walking movements [Liu et al., 2012]. Unlike unrestricted real walking, the WIP technique allows users to operate in small areas of interaction, and also frees the subject's hands, making them available to perform other interaction tasks on their mobile devices. Figure 3.15 shows a navigation session, were the user is strolling through the virtual environment using our WIP technique. The lower limbs are the most determinant and expressive body parts that contribute to the WIP control. Our WIP approach resorted to a Microsoft Kinect depth camera to obtain the lower limbs' movements for gait speed control, and the rotation of the torso for directional control.

Similarly to the previous approach, the WIP technique showed to be inadequate for the use in conjunction with Eery Space. The proximity of the moderators to the wall display makes it difficult for a comfortable visualisation and navigation control, and also restricts the needed mobility for the meeting's participants to engage in proximity-aware interactions. Furthermore, this technique only supports navigation at a ground level which contrasts with the need to reach details on the 3D model that may only be visible in extreme viewing angles.

3.6.3 ThumbCam

In Eery Space, participants are required to resort to handheld devices not only to be an identification tool, but also to engage in co-located collaborative tasks. Naturally these devices can also be used to navigate through the virtual environment. Small interactive devices, such as tablets and smartphones, are getting ever more computational power, starting to rival traditional computers in some tasks, such as design and review of 3D engineering models [Campos and Noronha, 2013]. Today's common solutions for interacting with virtual environments with touch enabled devices mainly rely on multi-touch gestures or buttons to apply different camera transformations. It has already been shown that multi-touch gestures can surpass button based interactions [Fiorella et al., 2010]. When considering smartphones, multi-touch gestures imply that the user needs to hold the device with both hands, which can be tiresome and not always possible [Boring et al., 2012]. Also, smartphones' small screens offer little space for multi-touch gestures, which may occlude a significant part of the imagery displayed. Moreover, studies [Hoober, 2013] have shown that users tend to interact with their smartphones using a single finger, being the thumb the more often used finger.

In this section we present ThumbCam, a camera manipulation solution that allows users to move, look and circle around within a virtual environment (VE) using only one thumb. Aiming for a touch solution that could enable users to manipulate the camera in 3D Virtual Environment using a single contact point, we developed ThumbCam. With our solution, it is possible to look and move freely in the virtual scene and to circle around specific points of interest, without occluding too much of handheld devices' small screen. To support these different types of interaction with only one touch, we resorted to a state machine (Figure 3.16) to decide which behaviour should be followed at any given moment. We have three states that modify the current view: Rotate, Drag and Move, which are described below.

These states are selected depending on user's inputs: tap (a very brief touch without any significant movement - we consider less than 0.3 seconds between touch begin and end); touch begin (longer than a tap); touch move; and touch holding (we consider a touch in the same place for longer than 0.5 seconds).

This approach is aligned with the need for mobility within the Eery space. At anytime a participant in the virtual meeting can become a moderator and its visualisation in mobile phone is mirrored in the wall display. Ensuring that each participant continues with their private analysis of the virtual environment.

We will follow the concepts of move around, look around and circle around, as described by Marchal et al. [2013]. We also resort to the notations used by the same authors for camera translations (*Tx*, *Ty*, *Tz*), look around rotations (*Rx*, *Ry*) and circle around transformations (*Ox*, *Oy*).

Rotate

When the user starts an interaction by placing and moving a touch, we enter the Rotate state. We support two modes of camera rotation: look around (Figure 3.17) and circle around (Figure 3.18). Two sequential taps while in the Idle state toggle between these two modes. When transitioning from the look around to circle around mode, a ray from the second tap is casted into the scene, and the intersection with the nearest object defines the POI and the orbit's center. In circle around mode, a target is shown to indicate the POI being orbited. Horizontal movements of the user's touch will then rotate the camera around a vertical axis (*Ry* in look around mode or *Oy* in circle around mode). Likewise, vertical movements of the touch will rotate the camera around a horizontal axis (*Rx* in look around mode or *Ox* in circle around mode).

Drag

Touching and holding the screen will enter the Drag state, showing two vertical arrows to inform the user (Figure 3.19 left), which disappear as the user moves the finger. The behaviour of this state follows the Drag'n Go technique [Moerman et al., 2012]. The intersection of the ray casted from the touch start position with the scene will define the target of the movement. Dragging the touch downwards translates

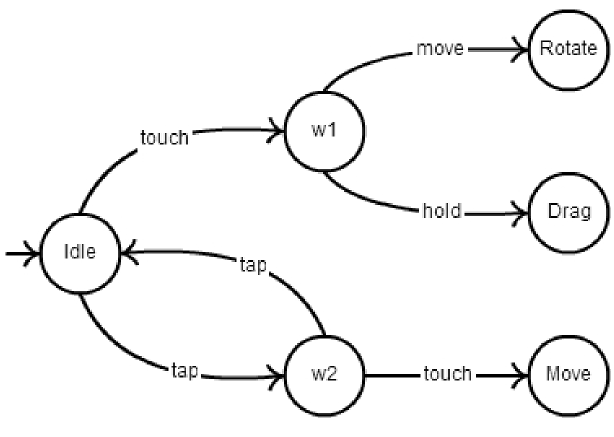

Figure 3.16: Simplified view of our state machine. States w1 and w2 are waiting for another input to decide which transition to make (they do not modify the current view).

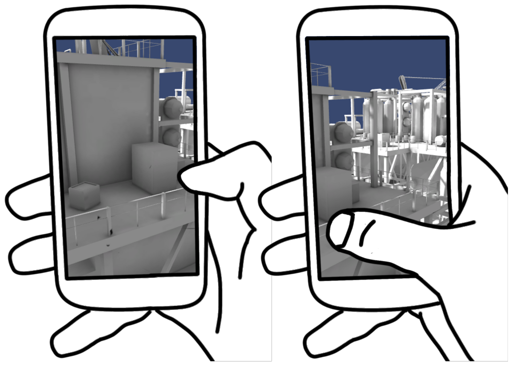

Figure 3.17: Looking around in the VE (*Rx* and *Ry* simultaneously).

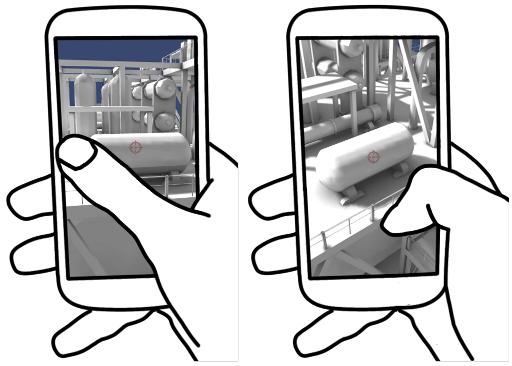

Figure 3.18: Circling around a point-of-interest in the VE (*Ox* and *Oy* simultaneously). The red target indicates the orbit's center.

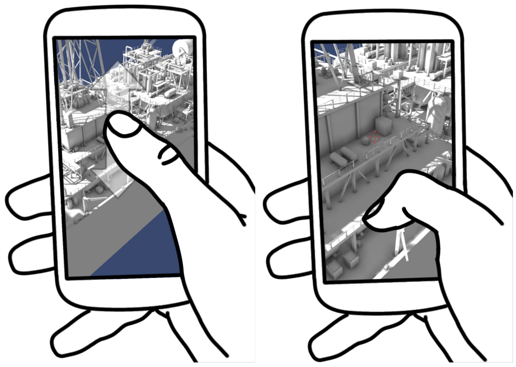

Figure 3.19: Moving towards a POI (indicated by the red target) using the Drag'n Go technique (*Tz*).

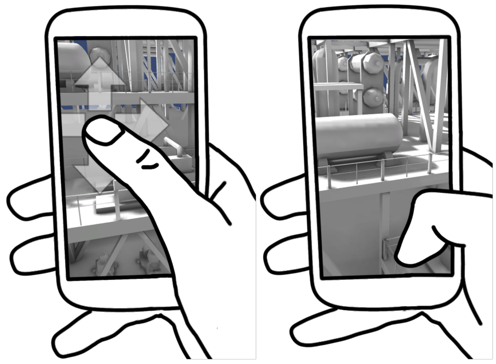

Figure 3.20: Moving around in the VE (*Tx* and *Ty* simultaneously).

the camera towards said target along the path defined by the ray casted (Figure 3.19), while upward movements of the touch will translate backwards along the same path (*Tz*). The distance between the start position of the touch and the bottom of the screen is mapped to cover the entire length of the path from the camera's start position and the target. While traversing the path, horizontal movements rotate the camera sideways (*Ry*). These horizontal movements do neither affect the camera position nor the previously defined path.

Move

The Move state can be achieved by tapping and immediately touching the screen, i.e. a quick sequence of touch begin, touch end and another touch begin actions. In this state, users can translate the camera sideways (*Tx*) with horizontal movements, and upwards and downwards (*Ty*) using vertical movements of the touch (Figure 3.20). In a similar fashion to the Drag state, four arrows are displayed on the screen upon entering the Move state (Figure 3.20 left), to inform the user of the action he is now performing.

Comparison with Other Techniques

In Table 3.1 we show how ThumbCam compares to the most relevant state-of-the-art techniques for camera manipulation. Navidget offers only POI based navigation, being not possible to look around. Scruticam focus solely on object visualisation, offering no actual scene exploration. Drag'n Go, although making move around interactions possible, neither allows looking up and down nor circle around points of interest. Move&Look is a more complete solution than the previous, but lacks *Tx* and *Ty* transformations and resorts to two touches interactions, which have been shown being not always possible. Our proposed technique, ThumbCam, offers more camera transformation than the remainder, and all actions can be done within reach of the user's thumb.

Moreover, the hand grip on a smartphone, although not being static, renders impossible the thumb to reach all screen real state, which hinders targets' acquisition. ThumbCam was designed in a way that all targets can be acquired by the user's thumb when in range, and the rotation gesture is available to relocate the target on the screen, when it is out of reach.

3.7 Summary

In this chapter we explained the concepts of Eery Space and Remote Proxemics. These two novel concepts play a key role in the overall solution, Eery Proxemics, with the ultimate goal of bringing social interactions to the scope of the collaborative work in virtual environments. Our intention is to open a new perspective onto how virtual meetings can benefit from the natural people's social interactions. To make Remote Proxemics possible, we described a set of awareness techniques to increase the level of presence of remote users, fostering social interactions with proxies of people that actually are not there. In the next chapter, we describe a set of tools developed to build a prof-of-concept prototype that materialises and mediates the interactions exposed in this chapter.

Technique	Move Around	Look Around	Circle Around	# Contact Points
Navidget [2008]	Tx, Ty, Tz	-	Ox, Oy	1
ScrutiCam [2009]	Tx, Ty	-	Ox, Oy	1
Drag'n Go [2012]	Tz, Ry	Ry	-	1
Move&Look [2013]	Tz, Ry	Rx, Ry	Oy	2
ThumbCam	Tx, Ty, Tz, Ry	Rx, Ry	Ox, Oy	1

Table 3.1: Comparison of the most relevant techniques and our ThumbCam.

Chapter 4

The Prototype

Our prototype was built in order to prove our assumptions that, not only remote proxemic interactions are possible, but also Eery Proxemics is an effective mean to achieve the level of presence as if they were in the same room. The developed environment materialises the Eery Space and is comprised of an ecosystem of multiple running modules communicating to each other using local networks and the Internet. Essentially, two large software packages were implemented: The *Eery Tracker Toolkit*, to pinpoint people inside a tracked area in a room; and the *Eery Proxemics Environment*, to mediate remote interactions and provide the tools for people to collaborate using multiple surfaces. The Eery Proxemics Environment also includes features to move around and review the virtual environment which is the focus of the meeting. Our Eery Space thrives in merging together multiple physical rooms into one unique virtual space. For this, there must be an instance of Eery Tracker Toolkit and another of the Eery Proxemics Environment in each physical room. Thus, the number of instances of these two modules is proportional to the number of rooms in connected in Eery Space.

In this section, we describe the prototype's architecture and its implementation details. In the end, we describe the setup used in the development and evaluation of this work.

4.1 Virtual Environment

For the purposes of this research, we have created a virtual environment aligned with the work that has been developed by teams of engineers in the oil and gas industry. These engineers perform tasks for design and review of 3D models which are faithful representations of actual oil and gas infrastructures deployed in remote offshore locations. Thus, they can study and adapt new solutions without interfering with the daily functioning of these infrastructures, also, the access to these remote sites is expensive and dangerous,. Typically, engineering teams focus on planning escape routes, simulating the construction cycles of projects and defining inspection checkpoints. Therefore, these 3D models must have a level of detail as close to reality as possible.

Our prototype takes into account these real usage scenarios and implements a virtual environment with a model of a vessel for offshore oil production, storage and offloading, the *FPSO Noble Seillean*,

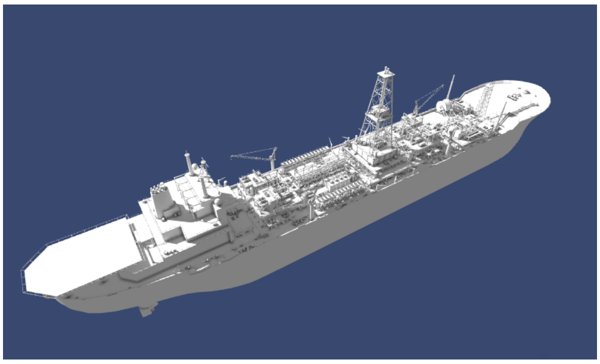

Figure 4.1: Virtual Environment: Global overview of FPSO Noble Seillean.

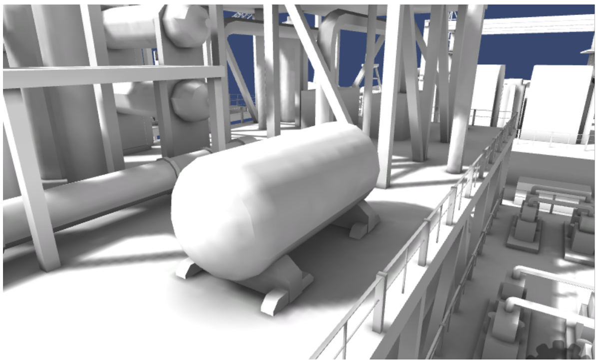

Figure 4.2: Virtual Environment: Detailed view of a part of the FPSO Noble Seillean 3D model.

as shown in Figure 4.1. This vessel is currently part of the Brazilian oil company Petrobras[1] fleet. The virtual environment was developed in Unity 3D [2] engine. In regard to the rendering of the 3D model, we followed an approach with light textures, casted shadows and ambient occlusion to highlight the relevant engineering features for design and review purposes. This approach was also a way to optimise the virtual environment to run seamlessly both in the wall display and the user's smartphones. This virtual environment supports navigation ThumbCam technique, developed in the context of this dissertation and referred above in section 3.6.3. Figure 4.2 shows a detailed view of the virtual world resulting from ThumbCam's drag action.

4.2 Eery Tracker Toolkit

The Eery Tracker Toolkit is a set if tools with the single task of locating people indoors, in a non-intrusively fashion using computer vision. It is a standalone module that acts as a server of the user's positioning data gathered from Microsoft Kinect depth cameras. By separating this single task software package, from the main solution, we eliminated any unnecessary complexity, and the toolkit's encapsulated nature encourages reuse and allows for future parallel evolution.

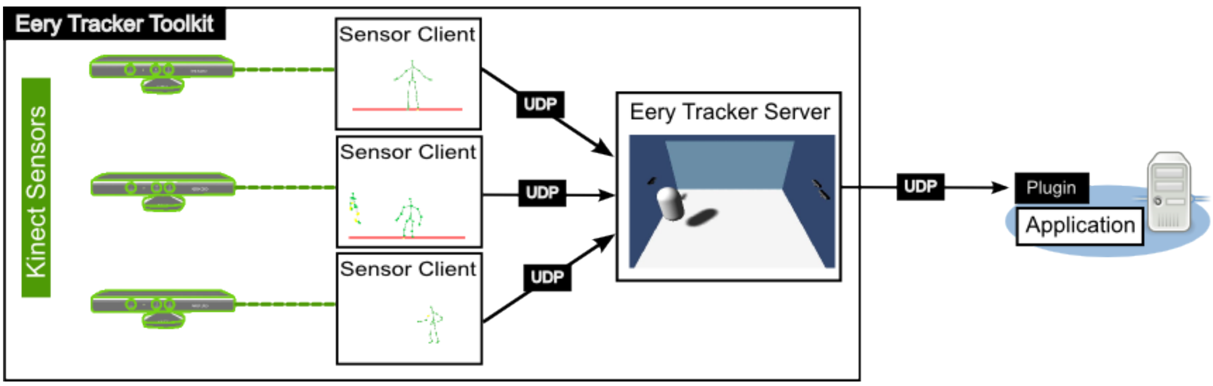

Figure 4.3: Eery Tracker Architecture.

[1]Petrobras: http://www.petrobras.com
[2]Unity3D: http://www.unity3d.com

This toolkit provides support for multiple depth cameras, by means of a scalable architecture of add-on camera modules that can be added in run-time. The ability to support multiple cameras arises from the need to deal with user's body occlusions that are naturally created when people get themselves ahead of others in the field of view of the cameras. The toolkit is comprised of a main application, the *Eery Tracker Server*, multiple Kinect camera handlers, the *Sensor Clients* and a client-side plugin. Figure 4.3 outlines the overall architecture, where the Sensor Clients collect depth camera data and send them in parallel, to the server. In its turn, the server makes the merged data accessible to the software plugin installed in front-end application. This plugin not only knows how to deal with the reception of data messages but also provides an Application Programming Interface (API). The plugin is a single file programming library that can be added to any project based on top of people's position tracking, in our case, the Eery Proxemics environment. The flow of data passing through the various components of this process are time-sensitive and dropping data packets is preferable to waiting for delayed packets that would certainly be wrong. Therefore the toolkit architecture follows data streams over the User Datagram Protocol (UDP).

4.2.1 Sensor Client

This module uses the Microsoft Kinect for Window SDK[3] to capture skeleton data, more specifically, people's position in relation to the camera's own coordinate space. We also calculate a value of confidence(q) for each captured skeleton. This value is calculated by relating the number of joints tracked with the inferred ones, and this value ranges between 0 and 20. Skeletons with $q < 14$ are discarded, so that false positives and erroneous joints can be ignored. It also is a way to identify the best skeleton which best represents the tracked person, since, sensors in extreme angles can reconstruct a less faithful skeleton model of a person. The number of running instances needed, matches the number of depth sensors capable to cover the desired area, as shown in the Figure 4.4. In the end,

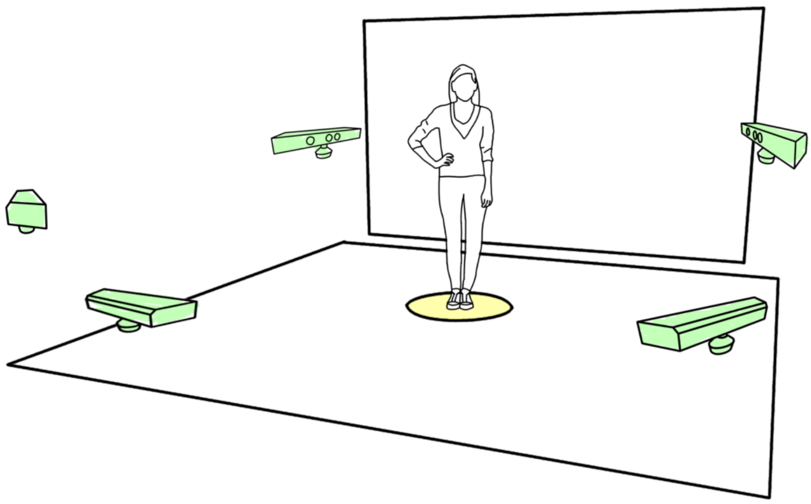

Figure 4.4: Eery Tracker camera's setup: Normal Setup for positioning the sensor cameras around the intended tracked space.

[3]Kinect for Windows: http://www.microsoft.com/en-us/kinectforwindows/develop/default.aspx

at each camera's frame processing cycle, the data is encapsulated in a UDP text message and is sent to the Eery Tracker Server. Each Sensor Client generates at startup an unique identity to ensure the traceability of the output data. This identity is comprised of the universal hardware identity of each kinect camera, concatenated with the desktop computer's name running the Sensor Client.

4.2.2 Eery Tracker Server

The Eery Tracker Server is the main component of the toolkit. It maintains the information about tracked people and the depth camera's position and orientation in the real world. Since this toolkit is intended to be a complementary tool to the overall prototype, this module is also responsible to maintain a virtual representation of the real space in front of the wall surface, for debug purposes only. The processing of the data passing through the server are subjected to four stages. **(1)** Firstly, a single UDP port is used to obtain the raw positional data, in the form of a set of skeleton models, from all Sensor Clients over the local network. **(2)** The Eery Tracker Server, then proceeds to transform that data from each camera's coordinate space into the virtual area's coordinate space, matching the real world. For each captured skeleton in each camera, a **TrackedPerson** entity is instantiated and its position in the virtual space is updated continuously whenever new messages are received from the sensors. If there is a person within the field of view of n cameras, then that person will have n corresponding TrackedPerson entities. **(3)** The server proceeds to group all TrackedPerson entities into a **MergedPerson** according to the closeness of their positions. Therefore, a MergedPerson is the main proxy of the real person and is defined by set of TrackedPerson entities that are spatially distributed within a diameter of 30 cm. The MergedPerson's final position is then calculated through the geometrical barycenter of the positional values of each TrackedPerson. Then, the stability of the final values are ensured using the multipurpose Kalman Filter [Kalman et al., 1960]. **(4)** At the end of each processing cycle, the server unites the entire positional information of each MergedPerson into a data packet which is then sent to the plugin in the final application. Not only the Eery Tracker Server sends the user's position but also provides the full Skeleton Model by adding to the packet the skeleton from the TrackerPerson with the highest value of confidence.

4.2.3 Sensor Calibration Method

In each captured frame, data from the kinect depth cameras are processed by the Sensor Clients into the tracked people's skeleton data. The skeleton data contains 3D positions, of each skeleton joint, stored as (x, y, z) coordinates. This is a right-handed coordinate system that places the camera at the origin of its axis. Actually, the Sensor Client can only know where the detected people are relatively to its depth camera, completely ignoring the position of the people in the room. For this it is necessary to know the exact location of each kinect. It was then necessary to develop a calibration method that could calculate their distribution in the real world, through a common point of reference to all the cameras.

The calibration method developed in the Eery Tracker Toolkit uses the position of a single person to determine the location of the kinect cameras. But that person's position alone is not enough, it is first

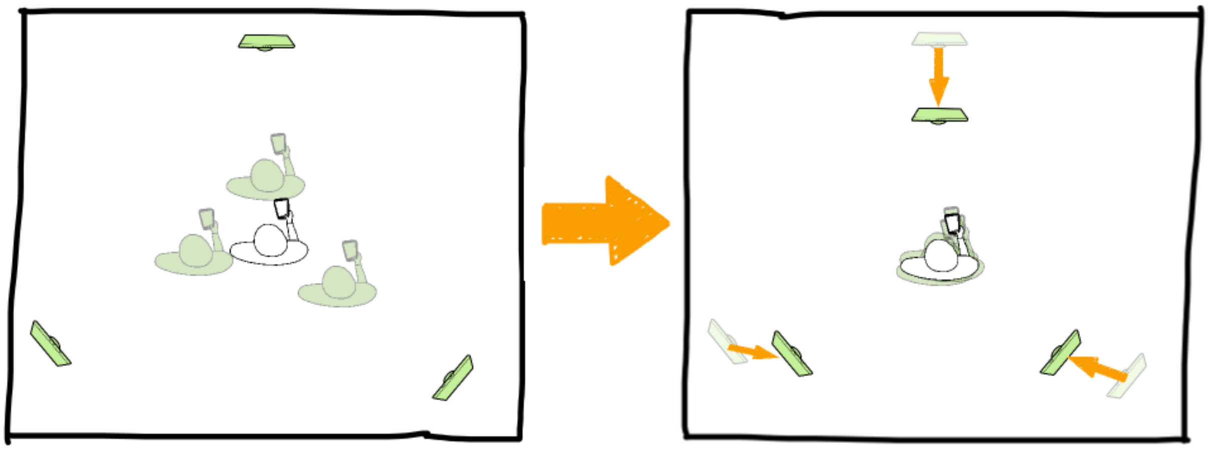

Figure 4.5: Depiction of the Eery Tracker Toolkit calibration method.

necessary to know the cameras' orientation. The Eery Tracker allows to manually input the orientation of each camera before starting the calibration method. This orientation corresponds to the rotation of the camera relative to the wall display. Therefore, the kinect facing the wall has an orientation of 180° . To start the calibration process, it is first necessary to ensure that all sensors are sending data to the Eery Tracker Server and that the orientations are properly configured. From here, one person should be directed to the center of the area to track. Then, the process starts when a calibration command is triggered on the server through a push on the "calibrate" button. Figure 4.5 (left) depicts the setup before the calibration method. At this time, although a person is in the middle of the room (depicted in white), the tracker detects three (in green), ie the number of cameras connected. During the calibration process, the tracker adjusts the virtual position of all cameras to bring it equal to the actual setup. As can be seen in the Figure 4.5 (right), all kinect cameras have undergone a virtual shift so that all tracked entities overlap to match the position of the real person.

Whenever the tracker is installed in a new room, the calibration method must be performed. Also, whenever it is necessary to add a new depth camera or the setup's layout needs reconfiguring, the tracker must be calibrated to ensure the quality of its output.

4.2.4 Features and Requirements

The Eery Tracker Toolkit provides the position of people inside a tracked area in real-time, using depth cameras. Therefore, the characteristics of the tracked area are provided by the hardware setup. The Microsoft Kinect camera range of optimal values are between 0.8 to 4 meters, which, when multiple depth cameras are placed in a circular distribution, the tracked area can hold a diameter of 6.4 meter. Since a Kinect depth camera requires at least 50% of the USB bandwidth available, it cannot share the computer's USB controller with any other devices. Not all computers have more than one USB controller. In the worst case, it is necessary to use a different computer for every instance of the Sensor Client. Despite this, the Sensor Client is able to send data packets to the Eery Tracker Server at a send rate of one packet in each 100 milliseconds. Likewise, the server broadcasts the merged data at a rate of 60

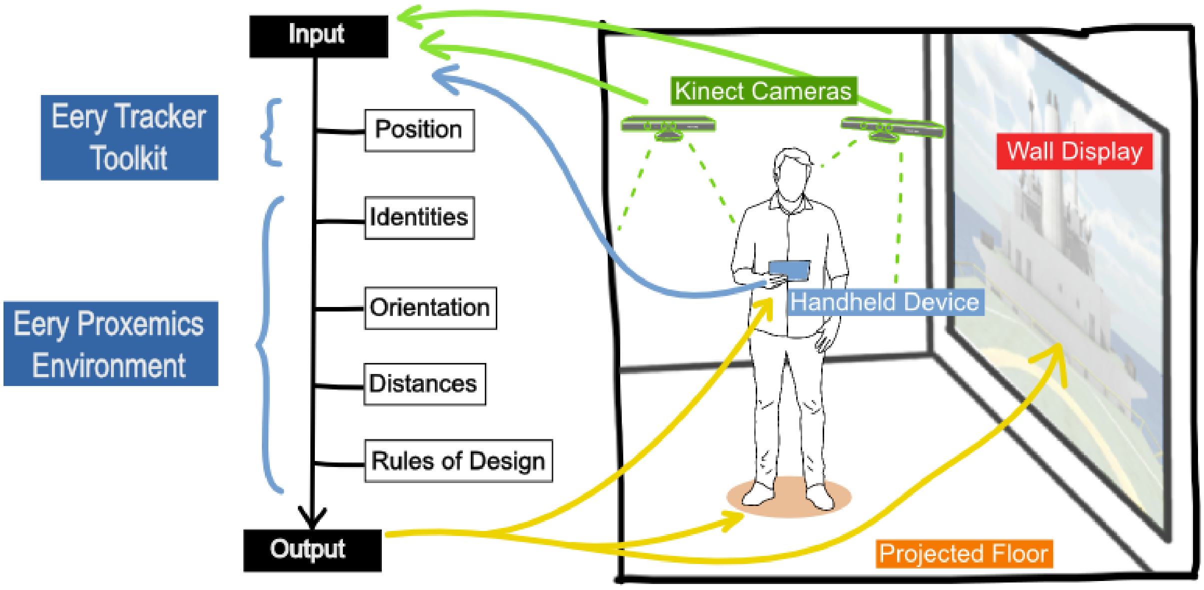

Figure 4.6: Eery Proxemics Environment's processing cycle of the real world data.

frames per second (approximately 1 in each 18 milliseconds);

4.3 Eery Proxemics Environment

In this section, we describe the Eery Proxemics Environment, the software package that implements Eery Space and the set of interactions necessary for the operation of Remote Proxemics and supports the awareness techniques mentioned earlier in Chapter 3. Furthermore, this package is responsible for the virtual meeting, the management of its participants, the flow of communication and the individual devices present in this environment.

The Eery Proxemics Environment is a distributed system, in the sense that all its components are connected over the network while communicating with each other in real time to coordinate actions. It is comprised of a root server and multiple clients for each device. Since our solution aims to join various rooms in a single virtual space, each component of the environment is aware of its location in relation to each of the rooms' large scale display. Nevertheless, these components behave as if they are always in the same common virtual area in accordance with the Eery Space. Thereby, the Eery Proxemics Environment behaves like a system that adapts its features after analysing the real world, which in this case are the people and their personal handheld devices present in the virtual meeting.

In the Figure 4.6 we depict the sequence of processing stages that the data, captured from the real world, undergoes in order to be transformed into information which the system can use to mediate interactions. Firstly, the Eery Proxemics Environment uses the Eery Toolkit to receive the data from the depth cameras that are installed around the room and in front of the the wall display, in the same way as previously shown in Figure 4.4. This data includes information on how many people are present and their positions. At the same time, clients running on the handheld devices send data from the built-in gyroscope that will later be interpreted as the orientations of each individual person. Our system, then, continues to identify each person detected by the depth cameras. For participants in the meeting with an active login, resulting from the procedure previously described in section 3.5, their positions are updated and the newest orientations given by their handheld devices are also associated with them. Otherwise, the system interprets these people as anonymous and awaits their login. By calculating the distances between each participant, the system now has the information needed to infer the intentions of each person. Following the rules of design, participants are grouped into social bubbles and, if applicable, someone is chosen as moderator. In the end, the Eery Proxemics Environment updates its presentation in all its displays and applies the awareness techniques throughout Eery Space.

4.3.1 Overall Software Architecture

The Eery Proxemics Environment is a set of executable tools and programming libraries built using the Unity3D and written in `C#`. Unity3D is a game engine and it is ideal to build collaborative virtual environments, since it is able to import external programming libraries and has support for developing for multiple platforms whether these are desktop computers or mobile devices. All components are built from the same base software. The Eery Proxemics Environment contains the introspective capability for the running software to know their platform. Eery Proxemics clients can adapt by changing their presentation and role in the ecosystem accordingly to the device, causing each client to show different views according to their function. In general, there is a software client for each device in the Eery Proxemics Environment.

As demonstrated in the Figure 4.7, the Eery Proxemics Environment follows the Client/Server network model. Each client has its own version of the data model, a representation of what happens in Eery Space, which is synchronized using messages that pass through the root server. The communication between the various components of the architecture and the server is made by invoking Remote Procedure Calls (RPC) over UDP protocol, except the Eery Tracker that uses common UDP data streams.

4.3.2 Server

The Eery Space combines in itself all the actions that occur in the different rooms that are geographically remote, which means that the various instances of Eery Proxemics environment may not be on the same local network. The server uses a public address over the Internet to create a link between the various system components. Its main function is to synchronise all events by relaying messages between all clients, including the participants actions, positions and the orientations of their smartphones. In addition, the server also maintains a data model of all tracked entities present in the environment. This model contains information on individuals within the Eery Space, as well as all connected devices and the current camera's point of view in the virtual environment displayed on the wall. Therefore, as shown in the Figure 4.8, the server also serves as a tool for helping developers to see in real-time what entities are being tracked.

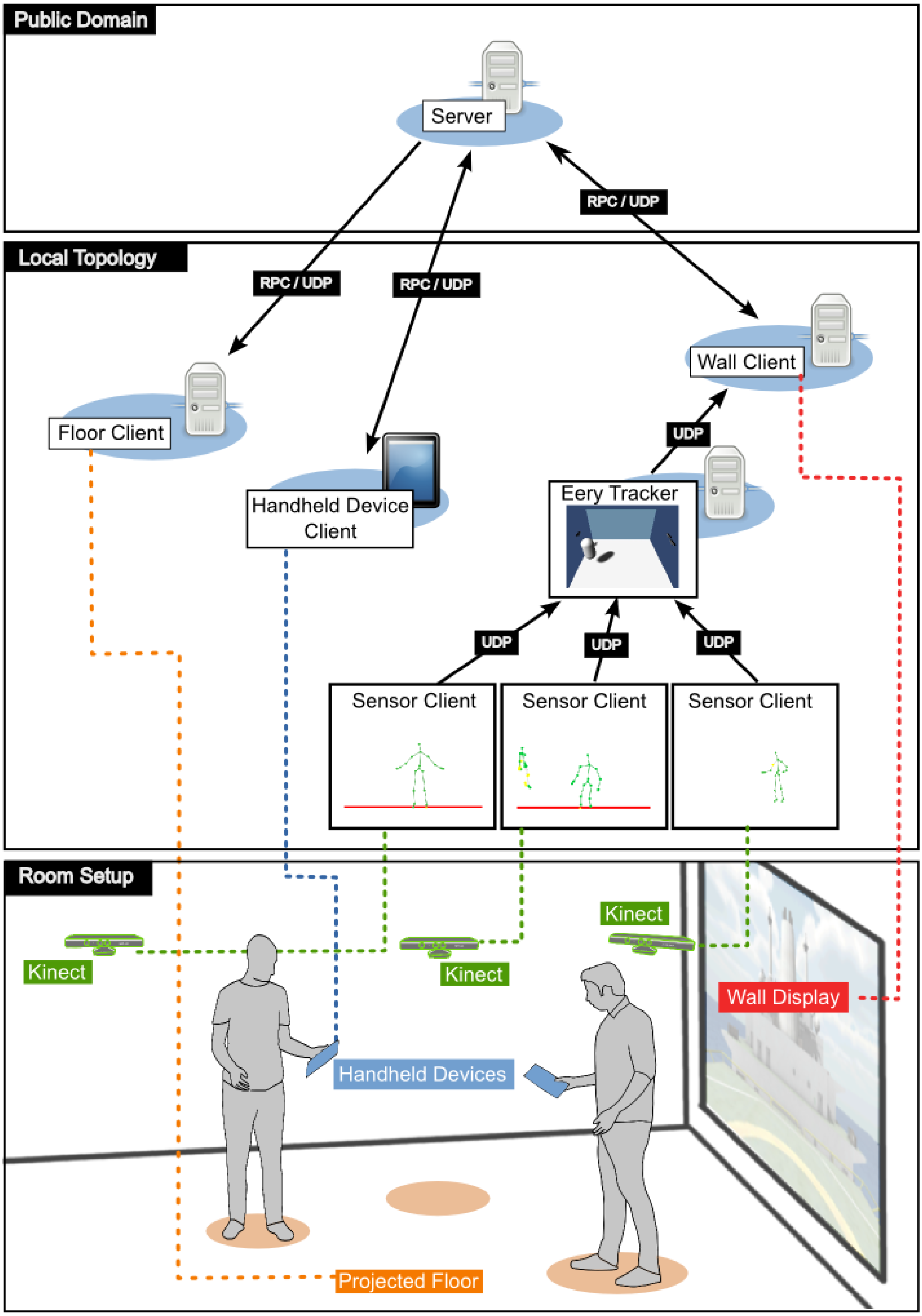

Figure 4.7: System's architecture for the Eery Proxemics Environment.

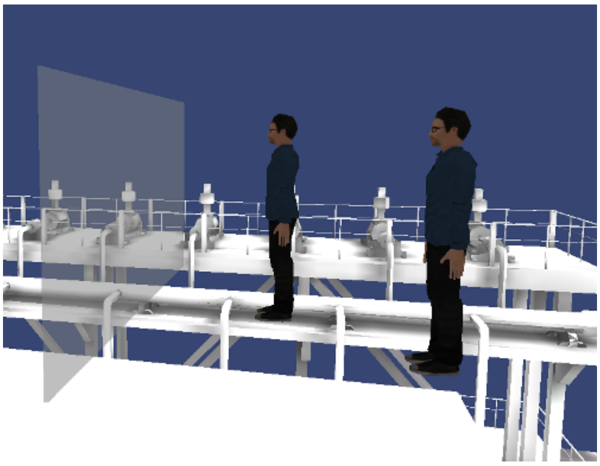

Figure 4.8: The Eery Proxemics server displays the current state of the Eery Space. In this case, two participants are engaged in the virtual meeting in front of the wall screen display.

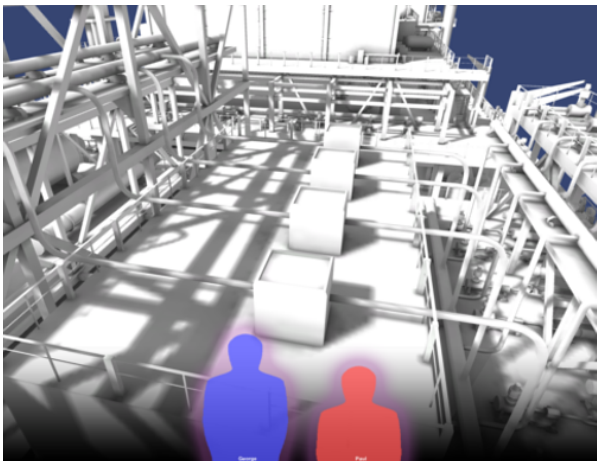

Figure 4.9: Wall Client. Displayed information shows the wall shadows of two participants currently in the Eery Space.

4.3.3 Wall Client

The Wall Client is the main visualisation tool for the virtual environment. For every room that makes up the Eery Space, there is a Wall Client instance. These instances behave as one, in the sense that they need to show the same information to all participants of the virtual meeting. Following the Eery Space's rules of design, the only person able to grab control of the wall is the moderator. During a moderation session, the virtual environment's camera on the wall moves in accordance with the moderators own camera on his handheld device. This mirroring is achieved via communication through the server. The visualisation on all the others wall displays, is also, maintained in sync by the server.

Regarding the techniques of mutual awareness, the Wall Client displays the wall shadows of all participants. Wall shadows are GUI textures depicting the silhouette of generic human beings and are programmatically manipulated to match the people's movements and positions in the Eery Space, as shown in Figure 4.9. The scale changes accordingly to the people's distance to the wall. In the case of moderator, the scaling factor is much larger than the other. Also, the shadows maintain the colour identity of the participants they are a proxy for.

4.3.4 Floor Client

The Floor client is a visualisation tool for the sole purpose of materialising the floor shadows awareness technique. This module takes advantage of a ceiling-mounted projector, above and aligned with the center of the wall display, to cast shadows of the people in the Eery Space, whether local or remote. As shown in Figure 4.10, the Floor Client output consist in depicting bright colours in a black canvas. The canvas being black means that a negligible amount of light is projected onto the areas where floor shadows are not, maintaining the illusion that nothing is being projected beyond the shadows. The Floor Client is connected to the server and the shadows move according to the movement of the people, and are kept under their feet.

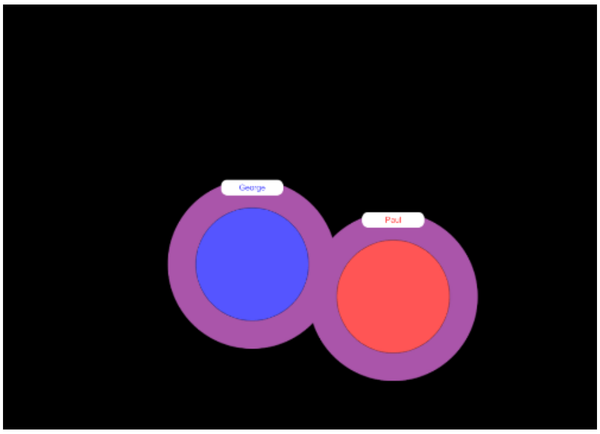

Figure 4.10: Floor Client. Floor shadows are projected into the floor on top of a dark background.

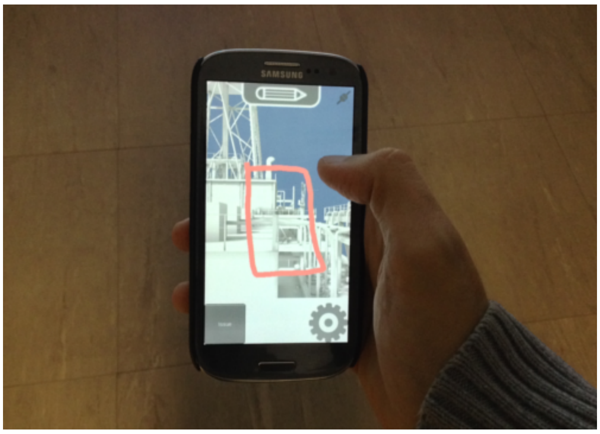

Figure 4.11: Handheld Client. User engaged in a sketch collaborative task.

4.3.5 Handheld Device Client

The Handheld Device Client provides a private window to the virtual environment. It supports the interactions mediated by the formation of social bubbles. And, also employs the ThumbCam technique for navigation. The data model of the events occurring in the Eery Space, is kept up to date thought RPC communication with the server over a local wireless network. It is also the provider of the identity of its user in the Eery Space. Currently, the identification protocol uses a GUI-based login method. Also, the handheld client sends a continuous stream of gyroscope data to the server. The gyroscope data is used to infer the orientation of each person in the Eery Space. Assuming that the user started the session in the virtual meeting facing the wall, this data becomes acceptable for the context of this dissertation. But due to hardware limitations, these data do not accurately represent the actual orientation of the person, only an approximation.

The Handheld Device Client follows the state of its user and change its behaviour during the performance of person-to-person and person-to-surface interactions. Since the handheld client knows the position and the state of all participants, while its user is the moderator, the client send to the server the user's virtual environment camera point of view, to be synchronised with all wall displays. Once the user is not the moderator, he can engage in collaboration with the other participants using proximity-aware interactions. When a social bubble is formed, the Handheld Device client lock the virtual environment's camera with the wall's point of view, and people can start a sketch session. During this session, people within the same social bubble can draw on the same view of the virtual environment. Users can see the scribbles of each other at this time because their devices are synchronised, sending the strokes of its users and to drawing the strokes of others. In summary, people are virtually the same sketch annotation.

The Handheld Device Client also implements a voice-over-ip (VOIP) solution for communication between local and remote people. This is achieved using a third-party software package and API, uSpeak[4]. This feature takes advantage of microphones embedded in the mobile devices and earphones to privately ear remote people. Thus, when forming a social bubble, local people can establish a bidirectional channel for conversation while involved in a collaborative task. In return, the moderator's mobile device,

[4]uSpeak, now known as DFVoice: http://daikonforge.com/dfvoice/

Figure 4.12: Main Setup, comprised of a large scale display, Kinect depth cameras and a ceiling-mounted projector

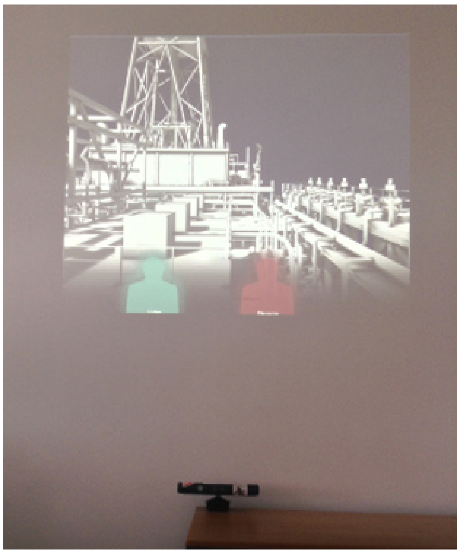

Figure 4.13: Remote Setup, built to evaluate remote collaboration, it is comprised of a simple setup of one projector and one depth camera.

sends the audio of his speech to all the people that in relation to him are remote.

The handheld device client contains an abstraction layer to access the device's motion sensors and hardware. This makes it run on Android[5], iOS[6] and Windows Phone[7] devices. Also, the abstraction layer is able to detect if the device is a tablet or a smartphone. If is a smartphone, it users the vibration hardware to provide haptic feedback whenever a person steps in the intimate space of another. For the purpose of this research, the handheld device client was evaluated in Android smartphones. The Figure 4.11 shows the Handheld Device Client running on an Android smartphone and depicts the user's virtual environment point of view.

4.4 System's Setup

The majority of the work presented in this thesis was conducted in the *João Lourenço Fernandes* Laboratory, at Campus Tagus Park of the Instituto Superior Técnico, in Figure 4.12. Consisting of a room devised to supply the resources needed for research projects in the fields of Interaction Design, Multimodal Interfaces, Visualisation of Information and Virtual Reality. In this lab, we highlight the presence of a large wall display, a ceiling-mounted projector for floor interactions, multiple Kinect depth cameras installed around the room, and a 6x6 square meters area that supports up to 6 users in front of the wall display. Nevertheless, in order to evaluate our proposed solution, a second space was set up to serve as a remote location.

[5] Android: http://www.android.com
[6] iOS: https://www.apple.com/ios/
[7] Windows Phone: http://www.windowsphone.com/

4.4.1 Main Setup

With the aim of creating an environment favourable for virtual meetings and remote proxemics, we built our main setup in the *João Lourenço Fernandes* Laboratory. This served as the main space for carrying out the solution evaluation with test subjects. In addition, this media lab contains the necessary resources and devices to sustain the awareness techniques explored in this dissertation. Apart from the wall display and the ceiling-mounted projector, six kinect depth cameras were installed along the boundaries of the room. Two of these cameras remain in place with the use of tripods.

Wall Display

The wall display is a rear-projection system composed by a projection screen and a support structure to hold the projectors. The display is a flexible screen of 4x2.25 square meters in a 2x2 tiled system of four Optoma EW775 projectors. The mosaic generates 3.6 megapixel images thanks to a small overlap (64 px horizontal and 19 px vertical) blending at each projector. The visualisation system is driven by a HP Z820 Workstation coupled with two NVIDIA Quadro 5000 behaving as a single desktop and thus simplifying the development and deployment of applications. The projectors are kept in place by an aluminium structure. For image calibration purposes, each projector rests on top of a mechanism that allows for precise adjustments along 6 degrees of freedom.

Floor Projection

The projection on the floor surface serves the need for the visual feedback provided by the floor shadows' awareness technique. To achieve this, we built a rigid wooden board where the projector was screwed

Figure 4.14: Ceiling-Mounted Projector, installed above the wall display to display the floor shadows awareness technique.

on. The board was then placed on the ceiling and held statically by two beams drilled into the concrete, as shown in Figure 4.14. The projector is a short-throw Benq MP780 ST+, and by placing it over the center of the wall display, it can project a total of 4x4 square meter of displaying area on to the floor.

4.4.2 Remote Setup

The remote setup was installed in an office space in the same building and near the main setup. Its purpose was to provide the second room to be added in to Eery Space environment. It was also used as a tool for development and evaluation of our proposed solution. Therefore, it consists of a cut-down version of the main setup. As shown in Figure 4.13, this remote setup is comprised of an emulation of the wall display by a normal projector, and it employs an Eery Tracker Toolkit instance with only one kinect depth camera. Also, this environment contains instances of the Eery Proxemics Environment connected to the main server.

4.5 Summary

In this chapter we introduced the Eery Proxemics Environment that enables social interactions between local and remote people in the same virtual meeting. Firstly, we described our developed virtual environment and its closeness to the actual requirements of the work in the oil and gas industry. The Eery Proxemics Environment succeeds in supporting Eery Space and Remote Proxemics, described in Chapter 3. In this chapter, we describe its inner workings and the overall software architecture, comprised of a distributed system developed to support multiple devices and platforms. The Eery Tracker Toolkit provides the necessary hardware abstraction and hides the method of sensor fusion into one single source of positioning data. We envision this toolkit to be used even in a wider purposes, outside the scope of proxemics interactions, in many future and different projects. Finally, we describe the lab setup and apparatus that supported our prototype. In Chapter 5, we report the tasks and methodologies performed to evaluate both the feasibility of remote proxemics and the overall Eery Proxemics solution.

Chapter 5

Evaluation

In the previous chapter we presented the developed prototype and apparatus to support the Eery Space and create a favourable environment for Remote Proxemics to take place. During the work of this dissertation, the solution developed has undergone two phases of evaluation that included the presence of users, in order to integrate their preferences and opinions to the end result. Following our proposed evaluation metodology, it was possible to meet the expectations of users, highly relevant to the process of identifying the most suitable awareness techniques. The first phase consisted of a preliminary evaluation to assess the feasibility of Remote Proxemics. The awareness techniques, regarding the wall display and mobile phones, were also evaluated at this stage, to assess whether our techniques provide enough feedback for people to remotely interact. This first stage was used to determine whether our approach was successful in bringing remote people together in the same virtual space and, at the same time, maintain their presence noticeable to each other. The second phase of the evaluation was comprised of an experiment with users, in which the overall solution was subjected, now taking into account the presence awareness feedback from the floor plane. These evaluation sessions took into account the context of virtual meetings, since audio communication channels were maintained between the test user and the remote person, during each interaction using social bubbles. In both trials, users were provided with a smartphone running the handheld device client before entering the evaluation environment.

In this chapter, we present the methodologies followed during these test sessions, as well as an account of the results obtained. We describe the tasks created to evaluate the interactions within Eery Space. Finally an analysis of the results obtained in these tests will be presented.

5.1 Preliminary Evaluation

This evaluation session aimed to test the proximity-aware interactions within the Eery Space, both with a local and with a remote person. It also served to evaluate the role of the moderator, by grabbing control of the wall display using the person-to-surface interaction method. For this experiment, the test user was placed in with one local and one remote person, scattered through the two rooms described in 4.4. In this case, the user was invited into the room with the Main Setup. This assessment phase had the

#	Stage	Time
1	Introduction	10 minutes
2	Evaluation tasks	15 minutes
3	Filling in the questionnaire	5 minutes

Table 5.1: Remote Proxemics' preliminary evaluation stages

initial prototype built with the Eery Tracker Toolkit, the Eery Proxemics Environment, and the awareness technique for wall shadows, bubble map, virtual window and intimate space haptic feedback. Again, we highlight the fact that during this evaluation session, the floor shadows were not present in the prototype. With this, the user was encouraged to move freely in the space in front of the wall display and look for others to establish social bubbles in order to be able to do the collaborative tasks required.

5.1.1 Methodology

In this section, we describe the methodology performed to evaluate the feasibility of proximity-aware interactions in a remote virtual meeting setting. The expected duration for each session with users was about thirty minutes and was divided into three stages (Table 5.1):

1. **Introduction**
   First of all, an explanation of the objectives and the context of the virtual meeting, were given to the test subject, followed by a demonstration of the prototype's features with a description of all available awareness techniques.
2. **Evaluation Tasks**
   The evaluation tasks were performed in an informal way. The local participant, acting as the evaluation session moderator, gave out commands to the test user, while engaging in conversation. Approximately, five minutes into this stage, the remote participant was signaled to enter the Eery Space environment.
3. **Filling in the questionnaire**
   At the end, the user was then asked to fill out the questionnaire. The questionnaire was comprised of a user's profile section and another section with nine questions in a *Likert* scale form of 6 values. The questionnaire is available in the Appendix section A.1.

5.1.2 Performed Tasks

Despite having been done informally, the set of evaluation tasks followed a strict order. Below, are listed the tasks performed by the test users during this stage of the evaluation.

1. **Associate user with mobile device**
   At first, the user was presented with a detailed description in how to become associated with the handheld device provided. This explanation was accompanied with a description of the Eery Tracker and the depth cameras in the setup environment. Then, the user was asked to log into the system.

2. **Change role to moderator**
   This task started with a demonstration of the navigational technique on the handheld device and a demonstration of grabbing the control of the wall's common visualisation. While exploring the virtual environment on the handheld device, the test user was encouraged to assume the role of moderator and share the point of view of the his device's virtual camera.

3. **Collaborative task with local participant**
   At this stage, the user was asked to establish a social bubble with the local participant and start a collaborative sketch annotation. During this task, the test user was made aware of the visual changes provided by the awareness techniques.

4. **Collaborative task with remote participant**
   Finally, the test user was encouraged to find the remote participant and start a collaborative sketch annotation.

5.1.3 Participants

This first evaluation session was attended by eleven users, two of them females. With ages ranging from 25 to 60 years, and the large majority below 35 years. Also, all had at least a bachelor's degree and revealed different backgrounds, mainly in Engineering and Architecture. The user's profile obtained from the questionnaire is available in the Appendix A.2.

5.1.4 Results and Discussion

The main objective of this preliminary evaluation was to study the feasibility of remote proxemics by exposing people to the concept. Therefore, the evaluation tasks were designed to expose the test users to local and remote proximal interactions, in order to correlate these two user experiences.

In the Table 5.2, are listed the answers from questionnaire in the form of median and the *interquartile range*, the measure of statistical dispersion of the data values. Since the beginning, the main driver of this work was to present a solution to mediate interactions between local and remote people seamlessly. Since the values obtained from the tasks are two related samples and come from the same population in an ordinal scale, we applied the *Wilcoxon Signed Ranks test* to highlight possible statistically significant differences between local and remote interactions. Accordingly to the *Wilcoxon Signed Ranks test* there are no significant differences ($Z = -1.414$, $p = 0.157$) between the making a sketch with local and remote participant. Nevertheless, establishing a social bubble, using the same test, shows a statistically significant difference between local and remote ($Z = -2.000$, $p = 0.046$), evincing a degree of difficulty while engaging in remote collaborative tasks, which brings us to the conclusion that the awareness techniques employed were insufficient and not adequate. In fact, from observation, test users were reluctant to utilise the virtual window and the bubble map awareness techniques and restricted their attention to the more expressive information from the wall shadows.

Question	Median (IQR)
1. It was easy to see who is present at the meeting.	5 (1)
2. It was easy to see where each participant is.	5 (0.5)
3. It was easy to see how I become moderator.	6 (0)
4. It was easy to see who is the current moderator.	6 (0.5)
5. It was easy to see who is in my social bubble.	6 (0.5)
6. It was easy to join the social bubble of another local participant.	6 (0.5)
7. It was easy to join the social bubble of another remote participant.	5 (1)
8. The task of making a sketch with a local participant was simple to perform.	6 (1)
9. The task of making a sketch with a remote participant was simple to perform.	5 (1)

Table 5.2: Questionnaire's results of the preliminary evaluation (median and interquartile range).

5.2 Solution Evaluation

Since with the preliminary evaluation we can conclude that it is possible to interact with remote people using proxemics, this test session focused on the study of the overall developed solution. In general, this phase of evaluation is comprised of a proxemics interactions and awareness overview, as well as, a comparison of the awareness techniques employed in the final solution. Once the conclusion of the first preliminary study, the prototype had been altered. Accordingly to the noted low usage of the virtual window and bubble map awareness techniques, these features were discarded at this stage. Nevertheless, the floor shadows technique was developed and added to the final prototype, providing the precise information of the location of each remote participant. Similarly to the preliminary evaluation,

Figure 5.1: Test user interacting with the local participant during the an evaluation session.

#	Stage	Time
1	Introduction	10 minutes
2	Evaluation tasks	20 minutes
3	Filling in the questionnaire	5 minutes

Table 5.3: Solution's evaluation stages

a single user, for each session, was invited into the main setup environment and asked to interact with a local and another remote participant. Every test user had no previous experience with work in question. In this section we describe the methodology and the performed tasks employed in this evaluation stage. Also, we provide a discussion about the results obtained.

5.2.1 Methodology

The solution evaluation phase maintained a similar methodology to the previous phase to guarantee the consistency of the data obtained. Table 5.3 demonstrates the three stages of each session with users. In total, each session lasted approximately thirty-five minutes. Below, we describe each stage of this session:

1. **Introduction**
   At the start, the new user was greeted with an explanation of the objective for this evaluation session, and with general consideration regarding the prototype. Firstly, was a description of the motivating aspects of our project, the design and review of 3D CAD models in virtual meetings and social interactions with remote people. The user was made aware that they would be interacting with another remote person. Secondly, the user was introduced in the basic features of the prototype, how to be associated with the handheld device and log on into the system. Thirdly, a brief description was made about the nature of the Eery Space and the awareness techniques. Fourthly, the concept of proxemics were discussed, accompanied with a demonstration on how to become the moderator and how to perform a collaborative task by forming a social bubble, emphasising the concept of intimate and personal space. This was followed with a demonstration of the haptic feedback by stepping on the user's intimate space. Finally, the user was encouraged to explore these concepts for a few minutes.

2. **Evaluation Tasks**
   The user was accompanied by both the local and the remote experienced participant. Thus, the user was receiving verbal commands for the tasks it should perform. Since this evaluation requires an honest reaction from the test users, any posed questions were responded with another formulation of the commands, avoiding influences on the user's behaviour.

3. **Filling in the questionnaire**
   Upon completion of the tasks, the user was asked to fill out a questionnaire, not only to define the profile of the user, but also to gain an appreciation of the various components of our solution. This questionnaire is available in the Appendix B.1.

5.2.2 Performed Tasks

The set of evaluation tasks was designed with the intention to check if there is any significant difference between local and remote interactions. Therefore, users were asked to perform a collaborative task, firstly with the local participant, following with the remote participant. Also, to verify if people do react to the presence of other remote people, even only being aware of the representation of their presence. Below, we describe the set of tasks performed by the test users:

1. **Interaction with Wall Screen Display**
   Since navigation in the virtual environment is beyond the context of this evaluation, which focuses on awareness and proxemic interactions, a button was placed on the prototype that automatically redirects the virtual camera to a specific point of interest in the model. This point of interest, common to all users, corresponds to an engineering detail in the virtual environment, and highlighted in red. Thus, the test user were encouraged to press the button and then displaying it on the wall display, by willingly assuming the role of moderator.

2. **Interaction with the local participant**
   To perform this task, user was asked to jointly create a collaborative sketch. For this, he had to physically move to establish a social bubble with the local participant and wait for instructions. Then, the local participant promptly drew a square around the point of interest in the virtual environment, and instructed the test user to draw a circle inside.

3. **Interaction with the remote participant**
   This task is essentially the same as that described with the local participant. The particularity of this task is that the test user was asked to create a collaborative task with the remote participant. To this end, the user had to move to establish a social bubble with the remote participant and wait for instructions. Similarly to the interaction with the local user and with the remote proxemics-enabled communication in the handheld device, the remote participant, then, instructs the test user to draw a cross inside his circle. At the same time, the remote participant intentionally steps in the test user's intimate space so as to arouse a reaction. Ideally, an adjustment in the position by the test user, demonstrating that he acknowledged the importance of preserving remote people's space in the meeting and also realising that he was interacting with another person.

4. **Intimate space invasion**
   For this task, the test user was instructed to watch the action performed by the remote user as moderator. The remote user moved into position and started to control the navigation on the wall display. At this stage, a computer generated remote user starts pursuing the test user in attempt to invade his intimate space. Again, this task is intended to observe the reaction of the user against an intrusion of their intimate space.

5. **Pathway between remote participants**
   This task was designed to realise if the test user had realised the concepts exposed in this evaluation. The user was instructed to move to a target location while considering the presence of four

computer generated remote participants. At no point in this evaluation, the user was informed that the computer generated remote users were in fact artificial.

6. **Stress test with multiple participants**
   The final task served as thanks to the test users for their participation in the evaluation session. This task was designed purely as a game and was not considered in the final analysis of the results. Therefore, the final task consisted of six computer generated remote users pursuing the test user in the attempts to invade his intimate space.

5.2.3 Participants

The participants in this trial were invited randomly and were mainly students attending our educational institution. Thereby, the set of test users was comprised of 12 participants, one of which was female, and all with a college degree. In regard to their age, the majority of the test users were between 18 years old and 24, remaining one of them between 35 and 55 years old. Nearly all reported having experience using smartphones in a daily base, except one of them that did not own a smartphone. The test users profile gathered from the questionnaire is available in the Appendix B.2.

5.2.4 Results and Discussion

In this section, we present an analysis of the data obtained from the evaluation of the overall solution. The data gathered of the user's preferences were obtained from the *Likert* scale of 6 values, presented previously. Also, data from the observation of the performed tasks is considered in this analysis.

The main objective of this evaluation was to demonstrate the feasibility of remote proxemics by maintaining an adequate level of awareness of the people that are remote, since the main premise of this work was that remote proxemics is possible provided that local participants have the awareness of the location and status of the remote ones. Furthermore, this evaluation provides a study of each awareness technique present on the final solution. Therefore, the analysis of the results is divided into a *Proxemics Overview*, an *Awareness Overview* and a comparison between the awareness techniques employed. A discussion of the final results is also provided along this section.

Proxemics Overview

The user's preferences regarding proxemics interactions are related to their easiness to perform proximal interactions with both local and remote people, and also the ability to interact with the wall display. The latter, poses a conscious decision to become the moderator of the virtual meeting. In Table 5.4 are depicted the responses obtained from the questionnaire regarding those interactions, in the form of median and interquartile range. The presented data suggests that it was easy to assume the role of moderator. According to the *Wilcoxon Signed Ranks* test between the first and second questions ($Z = -1.890$, $p = 0.059$), there are no statistically significant differences between starting a interaction with the other participants, despite their local or remote statuses. What leads us to conclude that interacting with

Question	Median (IQR)
1. It was easy to control what is shown on the wall display.	6 (1.25)
2. It was easy to start an interaction with a local participant.	6 (0)
3. It was easy to start an interaction with a remote participant.	6 (1)

Table 5.4: Questionnaire's results of the proxemics overview (median and interquartile range)

remote people is no different than local interactions. This result is encouraging insofar as it can prove that remote proxemics are in fact possible and do not add obstacles in the course of virtual meetings. In the trials, users did not demonstrate any difficulty in repositioning themselves to establish social bubbles in the collaborative tasks, although three users took up to five seconds to remember how to become the moderator while in the first task.

Awareness Overview

Regarding awareness, Table 5.5 summarises the data obtained from the test trials. In general, the presented data shows that people in the virtual meeting can relate to the presence of remote participants. User's preferences suggests that, despite exhibiting a slight dispersed data (Table 5.5, question 2), the absolute location of remote people is always visible. We can safely deduce that participants in the virtual meeting are always aware of the people involved. One of the requirements of our approach is the preservation of the intimate space of remote people. This design principle is required to impose their presence, while fostering remote interactions by establishing social bubbles. The *Wilcoxon Signed Ranks test* applied to the questions 6 and 7 ($Z = 0.000$, $p = 1.000$) shows no statistically significant difference between local and remote people, suggesting that test users were aware when their intimate space intercepted the others. Curiously while performing the collaborative task, three test users made a point of informing the remote participant of his infringement on their personal space during the smartphone-enabled conversation before readjusting their position. While during the intimate space invasion task every one of them changed their positions, responding to the haptic feedback from the handheld device. Despite that, four users complained that the remote participant was invading their intimate space, and then proceeded to readjust their positions. In the final task, the pathway between remote participants, only one user did not take into account the presence of the remote participants and walked right thought them, suggesting that almost every one accepted the presence of remote people and walked accordingly by dodging the floor shadows while walking to the destination. It is then safe to say, that in general, were aware of the presence of the remote participant and reacted accordingly. Nevertheless, one of the test subjects expressed the need to be aware of the others orientation in the meeting.

Awareness Techniques Comparison

To provide a model for future remote proxemic interactions, we compared the awareness techniques employed in the final solution to understand their decisive role in providing awareness of the presence of remote people. Not just presence in general, but also location and status. In out final approach, the awareness techniques encompass multiple devices and surfaces. Wall shadows provide the where-

Question	Median (IQR)
1. It was easy to see who is present at the meeting.	6 (0)
2. It was easy to see where each participant is.	6 (1.25)
3. It was easy to see who is controlling the wall display.	6 (0.25)
4. It was easy to see that I'm interacting with other people.	6 (0.25)
5. It was easy to see which participant I'm interaction with.	6 (1)
6. It was easy to see that I'm in the intimate space of another local participant.	6 (0)
7. It was easy to see that I'm in the intimate space of another remote participant.	6 (0)

Table 5.5: Questionnaire's results on the awareness overview (median and interquartile range).

abouts of all users, in the meeting, on the wall screen display. The projected floor surface displays representative shadows of the absolute location of each person in the Eery Space. And handheld devices provide haptic feedback when the participants intersect their intimate spaces. In the Table 5.6 we show the results from the questionnaire regarding the awareness techniques. First of all, by design, the handheld device client do not provide awareness of the meeting's participants or their location. Also, the handheld device is not able to show who is the moderator. For this, we applied the *Wilcoxon Signed Tanks test* in every question between all awareness techniques. There was no statistically significant difference in providing the information of who was present in the meeting, between the floor and the wall shadows. This was the only question that the *Wilcoxon Signed Tanks test* did not demonstrated a statistically significant difference. Although the floor shadows has scored higher (median) in the questionnaire, we believe that this is due to the remote participant entering the Eery Space from the side and not from the rear, which could invert these results. Regarding the location of each participant, the floor shadows proved to be better at this task ($Z = -2.456$, $p = 0.014$). In return, the wall shadows proved to be more efficient in showing who is controlling the wall display ($Z = -2.966$, $p = 0.003$). In fact the representation of the moderator changes on the wall display, while the floor shadows only shows him at close proximity. Wall shadows proved insufficient to provide awareness of the formation of social bubbles while interacting with other people, against the floor shadows ($Z = -2.595$, $p = 0.009$) and the handheld device ($Z = -2.122$, $p = 0.034$). We believe that the auras on the wall shadows are not that expressive and the information on the floor and on the handheld device is more prone to hold onto the participants attention. In a similar note, the floor shadows ($Z = -2.956$, $p = 0.003$) and the handheld device ($z = -2.958$, $p = 0.003$) both proved to be effective in providing the awareness while stepping in the intimate space of another participant. And finally, according to the *Wilcoxon Signed Tanks test*, the projected floor depicts a better representation of the people involved in a collaborative task, against the wall shadows ($Z = -2.461$, $p = 0.014$) and the handheld device ($Z = -2.958$, $p = 0.003$). Thereby, it is safe to conclude that the wall screen display is necessary for the tasks of design and review of 3D models, but proved to be somewhat irrelevant to the functioning of the social interactions in the Eery Space.

The final results clearly show an improvement in the awareness of the remote people's presence, in the way that local and remote interactions are virtually the same. We would not have gotten this result if we had not done the preliminary evaluation. The first evaluation trials, suggested the need for a more expressive awareness technique to depict the exact location and status of remote participants. With that, the projected floor has filled this requirement and presents a favourable acceptance by the test users.

5.3 Summary

In this chapter we presented the two phases of the evaluation developed throughout this dissertation. The preliminary evaluation with test users was performed in hope that our first assumption was true, the possibility to include proxemic social interactions to remote collaborative environments. In fact, the assumption proved to be feasible, but the awareness techniques employed were insufficient, rendering the user experience at one step from achieving our initial motivation of a seamless interaction between local and remote participants in a virtual meeting. To this end, we employed the floor shadows technique which verified to be, in the final solution's evaluation, overwhelmingly decisive for the seamless interactions within the Eery Space. Next, we conclude the work reported in this dissertation and list the possible future work to follow.

	Median (IQR)		
Question	**Wall**	**Floor**	**Handheld**
1. Helped to realise who is present at the meeting.	5 (1)	6 (1.25)	-
2. Helped to realise where each participant is.*	5 (0.25)	6 (1)	-
3. Helped to realise who is controlling the wall display.*	6 (0)	4 (3)	-
4. Helped to realise that I'm interacting with other participants.*	4 (1.25)	6 (0.25)	6 (1.25)
5. Helped to realize with whom I'm interacting with.*	4 (2.25)	6 (0.25)	3.5 (1.25)
6. Helped to realize that I'm in the intimate space of a remote participant.*	2.5 (1.25)	6 (1)	6 (0.25)

* There are statistically significant differences

Table 5.6: Questionnaire's results on the awareness techniques comparison (median and interquartile range for techniques available on the wall display, floor and handheld device).

Chapter 6

Conclusions

Nowadays, virtual meeting environments play an important role in bringing geographically separated people together, and are broadly used in business and engineering settings were experts around the world engage in collaborative tasks. Furthermore, it is usual to resort to virtual environments depicting real world problems in the form of 3D CAD models, to jointly and remotely discuss solutions. However, remote people feel a lack of presence in the meetings, rendering a feeling of not really being there. The outcome is an inefficient communication, which can hinder the collaborative work. As a matter of fact, current videoconference and telepresence solutions do enable verbal and visual communication between all participants. On the other hand, other forms of non verbal communication, namely social interactions through proxemics, have not been explored to their full potential.

In this dissertation we introduce Remote Proxemics, by bringing social interactions to virtual meetings, to provide the tools for a seamless interaction between local and remote people as if they were in the same space, and with that, assure the level of presence of remote people required to perform these proximity interactions. In extending virtual meetings with proximity-aware interactions, this work adds a new dimension to Hall's Proxemics [Hall, 1966], thus expanding the field. For this we created the Eery Space, a shared virtual space where people can meet and interact proximally with each other.

In the Eery Space, everyone, despite of being local or remote, have their place and intimate space assured, to maintain their availability to establish interactions. Also, several presence awareness techniques are contemplated in this shared locus. Using a large scale display, a projected floor and personal handheld devices, people can see each others representation and quickly realise their location and status on the virtual meeting. As a matter of fact, these awareness techniques that render Remote Proxemics even possible, since they highlight the presence of remote people. Furthermore, the Eery Space is build on top of the requirements of the design and review of collaborative 3D models. By devising in itself a multi-surface environment to support the visualisation and navigation of virtual environments, either through a large screen display, or through a personal view on the people's handheld devices, while fostering the collaborative through person-to-person interactions and with the common visualisation on the large display.

In the context of this dissertation, we developed a prototype in order to study the concepts of Remote

Proxemics and the Eery Space. Our prototype is a distributed system composed by two main modules and encompasses different devices and platforms. First of all, we developed a user tracker, the Eery Tracker, based on depth camera's computer vision to track people's position to infer the intentions to start interactions based on the social model introduced by Hall's Proxemics [Hall, 1966]. The use of commodity kinect depth cameras is a reliable way to track people's location and movement in an non-intrusive fashion. It is our belief that in the near future and with the proliferation of ubiquitous computing, such sensors will be broadly available. Second of all, we developed the Eery Proxemics Environment, the software package to mediate social interactions, supports the awareness techniques and provides the means for people to communicate in the virtual meeting.

Throughout this dissertation we relyed on the presence of users, to evaluate our proposed solution, in two different occasions: a preliminary evaluation and an overall solution evaluation. The aim of the preliminary evaluation was to study the possibility of extending remote proxemics to remote people. This led us to conclude that remote proxemics can be achieved if the awareness methods employed are expressive enough to provide the absolute location and status of the remote people in the virtual meeting. Therefore, we extended our solution to highlight the presence of everyone into the projected floor that covers the Eery Space. In our final evaluation sessions with users, results show the promise of remote proxemics, since we were able to achieve seamless interactions between local and remote people.

Finally, we believe that the work here described brings proxemic interactions a little further by bringing remote people together as if they were in the same space. Also, our innovative approach and awareness techniques can be used in virtual meetings for different kinds of purposes and scenarios, from engineering to architectural projects.

6.1 Future Work

In this dissertation, we present an innovative way to look at collaborative work in virtual meetings. We believe that Remote proxemics opens a door in the field of remote interactions in the same manner that proximal interactions did to co-located and cross-device interactions. Therefore, there are some aspects in need of further study, which have not been the focus of this thesis, that could lead to an interesting future work. Some related to the eerie nature of Eery Proxemics, and some related to a more technical aspect of the prototype. Below is the list of possible future work:

- **Evaluation of collaborative work with real world tasks**
  The scope of this dissertation focused on the possibility of remote proxemics and the level of awareness of the remote people's presence. However, it would be interesting to evaluate tasks related to collaborative editing and manipulation of 3D models. And finally, verify if the results correlates with the findings presented in this thesis.

- **Study F-formations in Remote Proxemics**
  Another possibility is to evaluate the impact of F-formations in the context of Remote Proxemics in

order to understand whether the use of these natural positions can improve collaborative work. It would therefore be interesting to identify the impact of the formation of various types and shapes of social bubbles.

Bibliography

L. Adams and D. Zuckerman. The effect of lighting conditions on personal space requirements. *The journal of general psychology*, 118(4):335–340, 1991.

J. R. Aiello. Human spatial behavior. *Handbook of environmental psychology*, 1:389–504, 1987.

J. R. Aiello and T. D. C. Aiello. The development of personal space: Proxemic behavior of children 6 through 16. *Human Ecology*, 2(3):177–189, 1974.

I. Altman. The environment and social behavior: Privacy, personal space, territory, and crowding. 1975.

M. Annett, T. Grossman, D. Wigdor, and G. Fitzmaurice. Medusa: a proximity-aware multi-touch tabletop. In *Proceedings of the 24th annual ACM symposium on User interface software and technology*, pages 337–346. ACM, 2011.

S. Antifakos and B. Schiele. Beyond position awareness. *Personal and Ubiquitous Computing*, 6(5-6): 313–317, 2002.

M. Apperley, L. McLeod, M. Masoodian, L. Paine, M. Phillips, B. Rogers, and K. Thomson. Use of video shadow for small group interaction awareness on a large interactive display surface. In *Proc. of AUIC '03*, 2003. ISBN 0-909925-96-8. URL `http://dl.acm.org/citation.cfm?id=820086.820107`.

G. Bahle, P. Lukowicz, K. Kunze, and K. Kise. I see you: How to improve wearable activity recognition by leveraging information from environmental cameras. In *Pervasive Computing and Communications Workshops (PERCOM Workshops), 2013 IEEE International Conference on*, pages 409–412, 2013. doi: 10.1109/PerComW.2013.6529528.

T. Ballendat, N. Marquardt, and S. Greenberg. Proxemic interaction: designing for a proximity and orientation-aware environment. In *ACM International Conference on Interactive Tabletops and Surfaces*, pages 121–130. ACM, 2010.

A. Basu, A. Raij, and K. Johnsen. Ubiquitous collaborative activity virtual environments. In *Proc. of CSCW '12*, 2012. ISBN 978-1-4503-1086-4. doi: 10.1145/2145204.2145302. URL `http://doi.acm.org/10.1145/2145204.2145302`.

S. Beck, A. Kunert, A. Kulik, and B. Froehlich. Immersive group-to-group telepresence. *Visualization and Computer Graphics, IEEE Transactions on*, 2013. ISSN 1077-2626. doi: 10.1109/TVCG.2013.33.

H. Benko, R. Jota, and A. Wilson. Miragetable: freehand interaction on a projected augmented reality tabletop. In *Proc. of CHI '12*, 2012a.

H. Benko, R. Jota, and A. Wilson. Miragetable: freehand interaction on a projected augmented reality tabletop. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 199–208. ACM, 2012b.

N. Beschin and I. H. Robertson. Personal versus extrapersonal neglect: a group study of their dissociation using a reliable clinical test. *Cortex*, 33(2):379–384, 1997.

S. Boring, D. Ledo, X. A. Chen, N. Marquardt, A. Tang, and S. Greenberg. The fat thumb: Using the thumb's contact size for single-handed mobile interaction. In *Proceedings of the 14th International Conference on Human-computer Interaction with Mobile Devices and Services*, MobileHCI '12, pages 39–48, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1105-2. doi: 10.1145/2371574.2371582. URL `http://doi.acm.org/10.1145/2371574.2371582`.

T. Butkiewicz and C. Ware. Multi-touch 3d exploratory analysis of ocean flow models. In *OCEANS 2011*, pages 1–10. IEEE, 2011.

W. Buxton. Telepresence: Integrating shared task and person spaces. In *Proceedings of graphics interface*, volume 92, pages 123–129, 1992.

W. Buxton. Living in augmented reality: Ubiquitous media and reactive environments. *Video Mediated Communication. Hillsdale, NJ: Erlbaum*, pages 363–384, 1997.

W. A. Buxton, A. J. Sellen, and M. C. Sheasby. Interfaces for multiparty videoconferences. *Video-mediated communication*, pages 385–400, 1997.

P. Campos and H. Noronha. On the usage of different work analysis methods for collaborative review of large scale 3d cad models. In *Human Work Interaction Design. Work Analysis and HCI*, volume 407 of *IFIP Advances in Information and Communication Technology*, pages 12–21. Springer Berlin Heidelberg, 2013. ISBN 978-3-642-41144-1. doi: 10.1007/978-3-642-41145-8_2. URL `http://dx.doi.org/10.1007/978-3-642-41145-8_2`.

M. Chen. Leveraging the asymmetric sensitivity of eye contact for videoconference. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 49–56. ACM, 2002.

T. M. Ciolek. The proxemics lexicon: A first approximation. *Journal of Nonverbal Behavior*, 8(1):55–79, 1983.

T. M. Ciolek and A. Kendon. Environment and the spatial arrangement of conversational encounters. *Sociological Inquiry*, 50(3-4):237–271, 1980.

M. Cohen, K. R. Dillman, H. MacLeod, S. Hunter, and A. Tang. Onespace: Shared visual scenes for active freeplay. In *Proc. of CHI '14*, 2014. ISBN 978-1-4503-2473-1. doi: 10.1145/2556288.2557117. URL `http://doi.acm.org/10.1145/2556288.2557117`.

J. R. Cooperstock, S. S. Fels, W. Buxton, and K. C. Smith. Reactive environments. *Communications of the ACM*, 40(9):65–73, 1997.

H. Coslett. Evidence for a disturbance of the body schema in neglect. *Brain and cognition*, 37(3): 527–544, 1998.

G. F. Coulouris, J. Dollimore, and T. Kindberg. *Distributed systems: concepts and design*. pearson education, 2005.

F. Declec, M. Hachet, and P. Guitton. Tech-note: Scruticam: Camera manipulation technique for 3d objects inspection. In *3D User Interfaces, 2009. 3DUI 2009. IEEE Symposium on*, pages 19–22, March 2009. doi: 10.1109/3DUI.2009.4811200.

A. K. Dey, G. D. Abowd, and D. Salber. A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications. *Human-computer interaction*, 16(2):97–166, 2001.

P. Dourish. Seeking a foundation for context-aware computing. *Human–Computer Interaction*, 16(2-4): 229–241, 2001.

P. Dourish. *Where the action is: the foundations of embodied interaction*. MIT press, 2004.

S. Elrod, R. Bruce, R. Gold, D. Goldberg, F. Halasz, W. Janssen, D. Lee, K. McCall, E. Pedersen, K. Pier, J. Tang, and B. Welch. Liveboard: A large interactive display supporting group meetings, presentations, and remote collaboration. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '92, pages 599–607, New York, NY, USA, 1992. ACM. ISBN 0-89791-513-5. doi: 10.1145/142750.143052. URL http://doi.acm.org/10.1145/142750.143052.

T. Erickson and W. A. Kellogg. Social translucence: An approach to designing systems that support social processes. *ACM TOCHI*, 2000. ISSN 1073-0516. doi: 10.1145/344949.345004. URL http://doi.acm.org/10.1145/344949.345004.

G. W. Evans, S. J. Lepore, and A. Schroeder. The role of interior design elements in human responses to crowding. *Journal of Personality and Social Psychology*, 70(1):41, 1996.

D. Fiorella, A. Sanna, and F. Lamberti. Multi-touch user interface evaluation for 3d object manipulation on mobile devices. *Journal on Multimodal User Interfaces*, 4(1):3–10, 2010. ISSN 1783-7677. doi: 10.1007/s12193-009-0034-4. URL http://dx.doi.org/10.1007/s12193-009-0034-4.

S. Greenberg and H. Kuzuoka. Using digital but physical surrogates to mediate awareness, communication and privacy in media spaces. *Personal Technologies*, 3(4):182–198, 1999.

S. Greenberg, N. Marquardt, T. Ballendat, R. Diaz-Marino, and M. Wang. Proxemic interactions: The new ubicomp? *interactions*, 18(1):42–50, Jan. 2011. ISSN 1072-5520. doi: 10.1145/1897239.1897250. URL http://doi.acm.org/10.1145/1897239.1897250.

S. Gustafson, P. Baudisch, C. Gutwin, and P. Irani. Wedge: Clutter-free visualization of off-screen locations. In *Proc. of CHI '08*, 2008. ISBN 978-1-60558-011-1. doi: 10.1145/1357054.1357179. URL http://doi.acm.org/10.1145/1357054.1357179.

C. Gutwin and S. Greenberg. A descriptive framework of workspace awareness for real-time groupware. *CSCW*, 2002. ISSN 0925-9724. doi: 10.1023/A:1021271517844. URL http://dx.doi.org/10.1023/A:1021271517844.

M. Hachet, F. Declec, S. Knodel, and P. Guitton. Navidget for easy 3d camera positioning from 2d inputs. In *3D User Interfaces, 2008. 3DUI 2008. IEEE Symposium on*, pages 83–89, March 2008. doi: 10.1109/3DUI.2008.4476596.

E. T. Hall. *The Hidden Dimension*. Doubleday, 1966.

M. Hancock, O. Hilliges, C. Collins, D. Baur, and S. Carpendale. Exploring tangible and direct touch interfaces for manipulating 2d and 3d information on a digital table. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces*, pages 77–84. ACM, 2009.

S. Harrison and P. Dourish. Re-place-ing space: the roles of place and space in collaborative systems. In *Proceedings of the 1996 ACM conference on Computer supported cooperative work*, pages 67–76. ACM, 1996.

L. A. Hayduk. Personal space: The conceptual and measurement implications of structural equation models. *Canadian Journal of Behavioural Science/Revue canadienne des sciences du comportement*, 17(2):140, 1985.

H. Hediger et al. Wild animals in captivity. an outline of the biology of zoological gardens. *Wild animals in captivity. An outline of the biology of zoological gardens.*, 1950.

K. Hinckley. Synchronous gestures for multiple persons and computers. In *Proceedings of the 16th annual ACM symposium on User interface software and technology*, pages 149–158. ACM, 2003.

D. Holman, R. Vertegaal, M. Altosaar, N. Troje, and D. Johns. Paper windows: Interaction techniques for digital paper. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '05, pages 591–599, New York, NY, USA, 2005. ACM. ISBN 1-58113-998-5. doi: 10.1145/1054972.1055054. URL http://doi.acm.org/10.1145/1054972.1055054.

N. P. Holmes and C. Spence. The body schema and multisensory representation (s) of peripersonal space. *Cognitive processing*, 5(2):94–105, 2004.

S. Hoober. How do users really hold mobile devices?, February 2013. Online: http://www.uxmatters.com/mt/archives/2013/02/how-do-users-really-hold-mobile-devices.php, accessed 28-August-2014.

H. Ishii and M. Kobayashi. Clearboard: A seamless medium for shared drawing and conversation with eye contact. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 525–532. ACM, 1992.

J. Jankowski, T. Hulin, and M. Hachet. A study of street-level navigation techniques in 3d digital cities on mobile touch devices. In *3D User Interfaces (3DUI), 2014 IEEE Symposium on*, pages 35–38, March 2014. doi: 10.1109/3DUI.2014.6798838.

R. Johansen. *Groupware: Computer support for business teams*. The Free Press, 1988.

W. Ju, B. A. Lee, and S. R. Klemmer. Range: exploring implicit interaction through electronic whiteboard design. In *Proceedings of the 2008 ACM conference on Computer supported cooperative work*, pages 17–26. ACM, 2008.

Kalman, Rudolph, and Emil. A New Approach to Linear Filtering and Prediction Problems. *Transactions of the ASME–Journal of Basic Engineering*, 82(Series D):35–45, 1960.

D. Katz. Animals and men: studies in comparative psychology. 1937.

A. Kendon. *Conducting interaction: Patterns of behavior in focused encounters*, volume 7. CUP Archive, 1990.

A. Kendon. Spacing and orientation in co-present interaction. In *Development of Multimodal Interfaces: Active Listening and Synchrony*, pages 1–15. Springer, 2010.

S. Knoedel and M. Hachet. Multi-touch rst in 2d and 3d spaces: Studying the impact of directness on user performance. In *3D User Interfaces (3DUI), 2011 IEEE Symposium on*, pages 75–78. IEEE, 2011.

G. Kortuem, C. Kray, and H. Gellersen. Sensing and visualizing spatial relations of mobile devices. In *Proceedings of the 18th annual ACM symposium on User interface software and technology*, pages 93–102. ACM, 2005.

R. Kraut, C. Egido, and J. Galegher. Patterns of contact and communication in scientific research collaboration. In *Proceedings of the 1988 ACM conference on Computer-supported cooperative work*, pages 1–12. ACM, 1988.

A. Kunz, T. Nescher, and M. Kuchler. Collaboard: a novel interactive electronic whiteboard for remote collaboration with people on content. In *Cyberworlds (CW), 2010 International Conference on*, pages 430–437. IEEE, 2010.

E. Làdavas, G. Di Pellegrino, A. Farnè, and G. Zeloni. Neuropsychological evidence of an integrated visuotactile representation of peripersonal space in humans. *Journal of Cognitive Neuroscience*, 10 (5):581–589, 1998.

L. Liu, X. Wu, L. Wu, and T. Guo. Static human gesture grading based on kinect. In *Image and Signal Processing (CISP), 2012 5th International Congress on*, pages 1390–1393, Oct 2012. doi: 10.1109/CISP.2012.6469917.

P. Luff and C. Heath. Mobility in collaboration. In *Proceedings of the 1998 ACM conference on Computer supported cooperative work*, pages 305–314. ACM, 1998.

D. Marchal, C. Moerman, G. Casiez, and N. Roussel. Designing intuitive multi-touch 3d navigation techniques. In P. Kotzé, G. Marsden, G. Lindgaard, J. Wesson, and M. Winckler, editors, *Human-Computer Interaction – INTERACT 2013*, volume 8117 of *Lecture Notes in Computer Science*, pages 19–36. Springer Berlin Heidelberg, 2013. ISBN 978-3-642-40482-5. doi: 10.1007/978-3-642-40483-2_2. URL http://dx.doi.org/10.1007/978-3-642-40483-2_2.

N. Marquardt, R. Diaz-Marino, S. Boring, and S. Greenberg. The proximity toolkit: Prototyping proxemic interactions in ubiquitous computing ecologies. In *Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology*, UIST '11, pages 315–326, New York, NY, USA, 2011a. ACM. ISBN 978-1-4503-0716-1. doi: 10.1145/2047196.2047238. URL http://doi.acm.org/10.1145/2047196.2047238.

N. Marquardt, J. Kiemer, D. Ledo, S. Boring, and S. Greenberg. Designing user-, hand-, and handpart-aware tabletop interactions with the touchid toolkit. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces*, ITS '11, pages 21–30, New York, NY, USA, 2011b. ACM. ISBN 978-1-4503-0871-7. doi: 10.1145/2076354.2076358. URL http://doi.acm.org/10.1145/2076354.2076358.

N. Marquardt, T. Ballendat, S. Boring, S. Greenberg, and K. Hinckley. Gradual engagement between digital devices as a function of proximity: From awareness to progressive reveal to information transfer. *Proc. ACM ITS*, pages 31–40, 2012a.

N. Marquardt, K. Hinckley, and S. Greenberg. Cross-device interaction via micro-mobility and f-formations. In *Proc. of UIST '12*, 2012b. ISBN 978-1-4503-1580-7. doi: 10.1145/2380116.2380121. URL http://doi.acm.org/10.1145/2380116.2380121.

A. Martinet, G. Casiez, and L. Grisoni. Integrality and separability of multitouch interaction techniques in 3d manipulation tasks. *Visualization and Computer Graphics, IEEE Transactions on*, 18(3):369–380, 2012.

W. W. Mayol, A. J. Davison, B. J. Tordoff, and D. W. Murray. Applying active vision and slam to wearables. In *Robotics Research*, pages 325–334. Springer, 2005.

T. Meyer and D. Schmidt. Idwristbands: Ir-based user identification on multi-touch surfaces. In *ACM International Conference on Interactive Tabletops and Surfaces*, ITS '10, pages 277–278, New York, NY, USA, 2010. ACM. ISBN 978-1-4503-0399-6. doi: 10.1145/1936652.1936714. URL http://doi.acm.org/10.1145/1936652.1936714.

C. Moerman, D. Marchal, and L. Grisoni. Drag'n go: Simple and fast navigation in virtual environment. In *3D User Interfaces (3DUI), 2012 IEEE Symposium on*, pages 15–18, March 2012. doi: 10.1109/3DUI.2012.6184178.

O. Morikawa and T. Maesako. Hypermirror: toward pleasant-to-use video mediated communication system. In *Proceedings of the 1998 ACM conference on Computer supported cooperative work*, pages 149–158. ACM, 1998.

L. Neyfakh. My day as a robot, May 2014. Online: http://www.bostonglobe.com/ideas/2014/05/10/day-robot/6UAMgmUFnOmZhoMS8vyOGK/story.html, accessed 14-June-2014.

D. Nguyen and J. Canny. Multiview: spatially faithful group video conferencing. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 799–808. ACM, 2005.

H. L. Petri, R. G. Huggins, C. J. Mills, and L. S. Barry. Variables influencing the shape of personal space. *Personality and Social Psychology Bulletin*, 1974.

A. M. Piper, E. O'Brien, M. R. Morris, and T. Winograd. Sides: a cooperative tabletop computer game for social skills development. In *Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work*, CSCW '06, pages 1–10, New York, NY, USA, 2006. ACM. ISBN 1-59593-249-6. doi: 10.1145/1180875.1180877. URL http://doi.acm.org/10.1145/1180875.1180877.

F. H. Previc. The neuropsychology of 3-d space. *Psychological bulletin*, 124(2):123, 1998.

G. H. Price and J. M. Dabbs Jr. Sex, setting, and personal space: Changes as children grow older. 1974.

R. Ramakers, D. Vanacken, K. Luyten, K. Coninx, and J. Schöning. Carpus: a non-intrusive user identification technique for interactive surfaces. In *Proceedings of the 25th annual ACM symposium on User interface software and technology*, UIST '12, pages 35–44, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1580-7. doi: 10.1145/2380116.2380123. URL http://doi.acm.org/10.1145/2380116.2380123.

R. Raskar, G. Welch, M. Cutts, A. Lake, L. Stesin, and H. Fuchs. The office of the future: A unified approach to image-based modeling and spatially immersive displays. In *Proc. of SIGGRAPH '98*, 1998. ISBN 0-89791-999-8. doi: 10.1145/280814.280861. URL http://doi.acm.org/10.1145/280814.280861.

B. Reeves and C. Nass. *The Media Equation: How People Treat Computers, Television, and New Media Like Real People and Places*. Cambridge University Press, 1996.

J. L. Reisman, P. L. Davidson, and J. Y. Han. A screen-space formulation for 2d and 3d direct manipulation. In *Proceedings of the 22nd annual ACM symposium on User interface software and technology*, pages 69–78. ACM, 2009.

M. Rofouei, A. Wilson, A. Brush, and S. Tansley. Your phone or mine?: fusing body, touch and device sensing for multi-user device-display interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, pages 1915–1918, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1015-4. doi: 10.1145/2207676.2208332. URL http://doi.acm.org/10.1145/2207676.2208332.

V. Roth, P. Schmidt, and B. Güldenring. The ir ring: authenticating users' touches on a multi-touch display. In *Proceedings of the 23nd annual ACM symposium on User interface software and tech-*

nology, UIST '10, pages 259–262, New York, NY, USA, 2010. ACM. ISBN 978-1-4503-0271-5. doi: 10.1145/1866029.1866071. URL `http://doi.acm.org/10.1145/1866029.1866071`.

N. Roussel, H. Evans, and H. Hansen. Proximity as an interface for video communication. *MultiMedia, IEEE*, 11(3):12–16, 2004.

M. Satyanarayanan. Challenges in implementing a context-aware system. *IEEE pervasive computing*, 1(3):2–2, 2002.

B. Schilit, N. Adams, R. Gold, M. Tso, and R. Want. The parctab mobile computing system. In *Workstation Operating Systems, 1993. Proceedings., Fourth Workshop on*, pages 34–39, Oct 1993. doi: 10.1109/WWOS.1993.348175.

B. Schilit, N. Adams, and R. Want. Context-aware computing applications. In *Mobile Computing Systems and Applications, 1994. WMCSA 1994. First Workshop on*, pages 85–90. IEEE, 1994.

D. Schmidt, M. K. Chong, and H. Gellersen. Idlenses: dynamic personal areas on shared surfaces. In *ACM International Conference on Interactive Tabletops and Surfaces*, ITS '10, pages 131–134, New York, NY, USA, 2010. ACM. ISBN 978-1-4503-0399-6. doi: 10.1145/1936652.1936678. URL `http://doi.acm.org/10.1145/1936652.1936678`.

J. S. Shell, T. Selker, and R. Vertegaal. Interacting with groups of computers. *Communications of the ACM*, 46(3):40–46, 2003.

R. Sommer. Studies in personal space. *Sociometry*, pages 247–260, 1959.

R. Sommer. Personal space in a digital age. *Handbook of environmental psychology*, pages 647–660, 2002.

A. Tang, C. Neustaedter, and S. Greenberg. Videoarms: embodiments for mixed presence groupware. In *People and Computers XX—Engage*, pages 85–102. Springer, 2007.

P. Tanner and V. Shah. Improving remote collaboration through side-by-side telepresence. In *CHI'10 Extended Abstracts on Human Factors in Computing Systems*, pages 3493–3498. ACM, 2010.

Y. Tao, H. Hu, and H. Zhou. Integration of vision and inertial sensors for 3d arm motion tracking in home-based rehabilitation. *Int. J. Rob. Res.*, 26(6):607–624, June 2007. ISSN 0278-3649. doi: 10.1177/0278364907079278. URL `http://dx.doi.org/10.1177/0278364907079278`.

T. Teixeira, D. Jung, and A. Savvides. Tasking networked cctv cameras and mobile phones to identify and localize multiple people. In *Proceedings of the 12th ACM international conference on Ubiquitous computing*, Ubicomp '10, pages 213–222, New York, NY, USA, 2010. ACM. ISBN 978-1-60558-843-8. doi: 10.1145/1864349.1864367. URL `http://doi.acm.org/10.1145/1864349.1864367`.

B. Ullmer, H. Ishii, and D. Glas. mediablocks: physical containers, transports, and controls for online media. In *Proceedings of the 25th annual conference on Computer graphics and interactive techniques*, pages 379–386. ACM, 1998.

S. Vaishnavi, J. Calhoun, and A. Chatterjee. Crossmodal and sensorimotor integration in tactile awareness. *Neurology*, 53(7):1596–1596, 1999.

A. Van Dam. Post-wimp user interfaces. *Communications of the ACM*, 40(2):63–67, 1997.

R. Vertegaal, I. Weevers, C. Sohn, and C. Cheung. Gaze-2: conveying eye contact in group video conferencing using eye-controlled camera direction. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 521–528. ACM, 2003.

D. Vogel and R. Balakrishnan. Interactive public ambient displays: transitioning from implicit to explicit, public to personal, interaction with multiple users. In *Proceedings of the 17th annual ACM symposium on User interface software and technology*, pages 137–146. ACM, 2004.

R. Want, A. Hopper, V. Falcao, and J. Gibbons. The active badge location system. *ACM Transactions on Information Systems (TOIS)*, 10(1):91–102, 1992.

M. Weiser. The computer for the 21st century. *Scientific american*, 265(3):94–104, 1991.

M. Weiser and J. S. Brown. Designing calm technology, 1995. *Xerox PARC*, 2009.

R. Wolff, D. J. Roberts, A. Steed, and O. Otto. A review of telecollaboration technologies with respect to closely coupled collaboration. *International Journal of Computer Applications in Technology*, 29(1): 11–26, 2007.

L. Yu, P. Svetachov, P. Isenberg, M. H. Everts, and T. Isenberg. Fi3d: Direct-touch interaction for the exploration of 3d scientific visualization spaces. *Visualization and Computer Graphics, IEEE Transactions on*, 16(6):1613–1622, 2010.

Appendix A

Preliminary Evaluation

A.1 Questionnaire

Questionnaire

The following personal data serve to better study the Remote Proxemics' technique and will be used exclusively for the purpose of this research.

Anonymous Identification: ________

I - User Profile

1. What is your age?
   1. Less than 10 years ☐
   2. Between 10 and 14 years ☐
   3. Between 15 and 17 years ☐
   4. Between 18 and 34 years ☐
   5. Between 35 and 55 years ☐
   6. More than 55 years ☐

1. Gender:
   1. Male ☐
   2. Female ☐

1. What are your qualifications?
   1. 9th grade or less ☐
   2. High School or equivalent ☐
   3. University course ☐

II - Usability Experience

Rate from 1 (strongly disagree) to 6 (strongly agree) the following statements.

II.1 - The meeting and its participants

		1	2	3	4	5	6
1	It was easy to see who is present at the meeting.	☐	☐	☐	☐	☐	☐
2	It was easy to see where each participant is.	☐	☐	☐	☐	☐	☐
3	It was easy to see how I become moderator.	☐	☐	☐	☐	☐	☐
4	It was easy to see who is the current moderator.	☐	☐	☐	☐	☐	☐
5	It was easy to see who is in my social bubble.	☐	☐	☐	☐	☐	☐
6	It was easy to join the social bubble of another local participant.	☐	☐	☐	☐	☐	☐
7	It was easy to join the social bubble of another remote participant.	☐	☐	☐	☐	☐	☐
8	The task of making a sketch with a local participant was simple to perform.	☐	☐	☐	☐	☐	☐
9	The task of making a sketch with a remote participant was simple to perform.	☐	☐	☐	☐	☐	☐

A.2 User's Profiles

User	Age	Gender	Qualifications
1	5	2	3
2	4	2	3
3	4	1	3
4	4	1	3
5	4	1	3
6	4	1	3
7	4	1	3
8	4	1	3
9	4	1	3
10	4	1	3
11	6	1	3

Table A.1: Test user's profile (the values shown in the table correspond to sub-paragraphs in the questionnaire).

A.3 Answers from the Questionnaire

	Question								
Users	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	5	5	6	6	6	5	5	5	5
2	6	6	6	6	6	5	5	6	6
3	6	5	6	6	6	6	5	5	5
4	6	6	6	6	5	6	6	6	6
5	5	5	6	6	6	5	5	6	5
6	6	5	6	6	5	6	5	6	5
7	5	5	6	5	6	6	6	6	6
8	6	6	6	4	6	6	6	6	6
9	5	5	6	6	6	6	5	5	5
10	3	3	5	5	3	5	5	3	3
11	5	2	6	6	6	6	6	6	6

Table A.2: Questionnaire's responses (Likert scale of 6 values)

Appendix B

Solution Evaluation

B.1 Questionnaire

Questionnaire

The following personal data serve to better study the Remote Proxemics' technique and will be used exclusively for the purpose of this research.

Anonymous Identification: ________

I - User Profile

1. What is your age?
    1. Less than 10 years ☐
    2. Between 10 and 14 years ☐
    3. Between 15 and 17 years ☐
    4. Between 18 and 34 years ☐
    5. Between 35 and 55 years ☐
    6. More than 55 years ☐
1. Gender:
    1. Male ☐
    2. Female ☐
1. What are your qualifications?
    1. 9th grade or less ☐
    2. High School or equivalent ☐
    3. University course ☐
1. Do you have a smartphone and/or tablet?
    1. Yes ☐
    2. No ☐
1. How often do you use your smartphone and/or tablet?
    1. Never ☐
    2. Few times a month ☐
    3. Few times a week ☐
    4. Once a day ☐
    5. More than once daily ☐

II - Usability Experience

Rate from 1 (strongly disagree) to 6 (strongly agree) the following statements.

II.1 - The meeting and its participants

		1	2	3	4	5	6
1	It was easy to see **who** is present at the meeting.	☐	☐	☐	☐	☐	☐
2	The **wall display** helped to realize **who** is present at the meeting.	☐	☐	☐	☐	☐	☐
3	The **floor** helped to realize **who** is present at the meeting.	☐	☐	☐	☐	☐	☐
4	It was easy to see **where** each participant is.	☐	☐	☐	☐	☐	☐
5	The **wall display** helped to realize **where** each participant is in the meeting.	☐	☐	☐	☐	☐	☐
6	The **floor** helped realize **where** each participant is.	☐	☐	☐	☐	☐	☐

II.2 - Interactions with the Wall Display

		1	2	3	4	5	6
7	It was easy to see how I can control what is shown on the **wall display**.	☐	☐	☐	☐	☐	☐
8	It was easy to see **who** is controlling the wall display.	☐	☐	☐	☐	☐	☐
9	The **wall display** helped to realize **who** is controlling it.	☐	☐	☐	☐	☐	☐
10	The **floor** helped to realize **who** is controlling wall display.	☐	☐	☐	☐	☐	☐

II.3 - Interaction with other participants

		1	2	3	4	5	6
12	It was easy to start an **interaction** with a **local** participant.	☐	☐	☐	☐	☐	☐
13	It was easy to start an **interaction** with a **remote** participant.	☐	☐	☐	☐	☐	☐
14	It was easy to see that I'm interacting with other people.	☐	☐	☐	☐	☐	☐
15	The **wall display** helped to realize that I'm interacting with other people.	☐	☐	☐	☐	☐	☐
16	The **floor** helped to realize that I'm interacting with other people.	☐	☐	☐	☐	☐	☐
17	The **handheld device** helped to realize that I'm interacting with other people.	☐	☐	☐	☐	☐	☐
18	It was easy to realize with **whom** i'm interacting with.	☐	☐	☐	☐	☐	☐
19	The **wall display** helped to realize with **whom** i'm interacting with.	☐	☐	☐	☐	☐	☐
20	The **floor** helped to realize with **whom** i'm interacting with.	☐	☐	☐	☐	☐	☐
21	The **handheld device** helped to realize with **whom** i'm interacting with.	☐	☐	☐	☐	☐	☐
22	It was easy to see that I'm in the **intimate space** of another **local** participant.	☐	☐	☐	☐	☐	☐
23	It was easy to see that I'm in the **intimate space** of another **remote** participant.	☐	☐	☐	☐	☐	☐
24	The **wall display** helped realize that I'm in the **intimate space** of a remote participant.	☐	☐	☐	☐	☐	☐
25	The **floor** helped realize that I'm in the **intimate space** of a remote participant.	☐	☐	☐	☐	☐	☐
26	The **handheld device** helped realize that I'm in the **intimate space** of a remote participant.	☐	☐	☐	☐	☐	☐

B.2 User's Profiles

User	Age	Gender	Qualifications	Handheld Device Usage	Handheld Device Frequency
1	5	1	3	1	5
2	4	2	3	1	5
3	4	1	3	1	5
4	4	1	3	1	5
5	4	1	3	1	5
6	4	1	3	1	5
7	4	1	3	1	5
8	4	1	3	1	5
9	4	1	3	1	5
10	4	1	3	1	5
11	4	1	3	1	5
12	4	1	3	2	1

Table B.1: Test user's profile (the values shown in the table correspond to sub-paragraphs in the questionnaire).

B.3 Answers from the Questionnaire

	Question									
Users	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	6	6	4	6	6	6	6	6	6	5
2	6	6	6	6	5	6	6	6	6	1
3	6	5	5	6	5	6	4	6	6	5
4	6	5	6	5	5	6	5	6	5	4
5	6	5	6	6	5	6	6	5	6	4
6	5	5	4	5	5	5	4	5	6	2
7	6	5	6	6	3	6	4	6	5	2
8	6	5	5	6	4	6	6	6	6	3
9	6	5	6	6	5	5	6	6	6	6
10	5	5	4	4	4	4	6	6	6	5
11	6	6	6	4	5	5	5	5	6	1
12	6	6	6	4	5	6	6	6	6	5

	Question														
Users	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1	6	5	3	3	3	6	3	5	3	3	5	5	3	3	5
2	6	6	6	1	6	4	6	1	6	5	6	6	1	6	6
3	6	6	6	4	6	6	5	5	5	4	6	6	4	6	6
4	6	6	5	4	6	6	6	5	6	5	6	6	3	6	6
5	6	6	6	4	6	6	6	2	6	5	6	6	2	6	6
6	5	5	6	6	5	3	4	4	5	3	5	5	3	4	6
7	6	6	6	4	6	5	6	3	6	4	6	6	2	5	6
8	6	5	6	4	6	6	6	4	6	1	6	6	1	6	6
9	6	6	6	5	5	6	6	5	6	4	6	6	5	6	5
10	6	6	6	3	6	6	6	5	6	1	6	6	2	5	6
11	6	5	5	1	6	3	5	1	6	3	6	6	1	6	4
12	6	4	6	6	6	6	6	3	6	3	6	6	3	6	6

Table B.2: Questionnaire's responses (Likert scale of 6 values).