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ExCITE Project: A Review of Forty-two Months of Robotic Telepresence Technology Evolution

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Abstract
This paper reports on the EU project ExCITE with specific focus on the technical development of the telepresence platform over a period of 42 months. The aim of the project was to assess the robustness and validity of the mobile robotic telepresence (MRP) system Giraff as a means to support elderly and to foster their social interaction and participation. Embracing the idea of user centered product refinement; the robot was tested over long periods of time in real homes. As such, the system development was driven by a strong involvement of elderly and their caregivers but also by technical challenges associated with deploying the robot in real world contexts. The results of the 42 months long evaluation is a system suitable for use in homes rather than a generic system suitable for e.g., office environments.

1 Introduction

This paper provides a technical description of the results obtained in the EU Ambient Assisted Living Joint Programme Project ExCITE (Enabling SoCial Interaction Through Embodiment). With the aim to develop an affordable product that is effective in promoting healthy aging and social well-being, a series of short-term and long-term evaluations of the mobile robotic telepresence (MRP) system Giraff have been conducted during the project (July 2010-Dec 2013).

Giraff is one of many commercial MRP systems on a rapidly growing field in which a number of new robotic units have reached the market in the past few years. As a result, a variety of terms have been used to refer to the systems and to the users of such systems. In this paper, we adhere to the terminology used in Kristoffersson, Coradeschi, and Loutfi (2013a) namely:

Mobile robotic telepresence (MRP) systems are characterized by a video conferencing system mounted on a mobile robotic base. The primary aim of MRP systems is to provide social

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interaction between humans. The system consists of both the physical robot (including sensors and actuators) and the interface used to pilot the robot.

A pilot user is a person who connects to the robot from remote via an interface (often from a computer or tablet). The pilot who is embodied in the MRP system can move around in the *local environment* in which the robot is located and interact with other persons.

A local user is the user being situated in the same physical location as the robot. Typically, local users can move around freely while interacting with the piot user through the MRP system.

In common for all MRP systems is that they have a non-anthropomorhic design and appearance. Typically, the pilot user can only use a subset of human skills such as pan and tilt combined with audio and video communication.

In this research report, we will focus on the reporting of how both short-term and longitudinal studies have resulted in technical changes to the Giraff, an MRP system intended to be used in homes of elderly people. The Giraff versions deployed in homes of elderly people during the project were 163cm in height and consisted of a mobile robotic base on which a LCD screen, a web camera with a wide angle lens, speakers and a microphone are mounted on a pole. They could be maneuvered remotely via a client interface called “Pilot” installed on a PC. Graphical depictions showing the aesthetic evolution of the Giraff during the course of the project are provided in Figure 1. Figure 2 shows the first version of the *Pilot* being tested in the project. Figure 3 shows the standard view in a *Pilot* to which plug-ins aimed to support the pilot user can be added.

Figure 1. *Aesthetic evolution of the Giraff over the entire project (from left to right): Giraff 1.0, Giraff 2.0, Giraff 3.0, Giraff 3.2 and Giraff 4.0.*

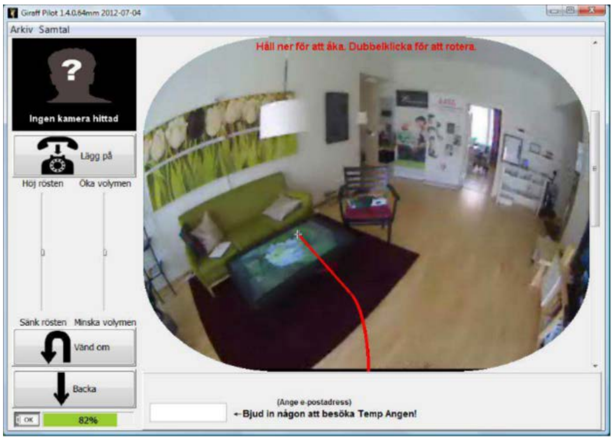

Figure 2. *Software version 1.4 of the Pilot interface*

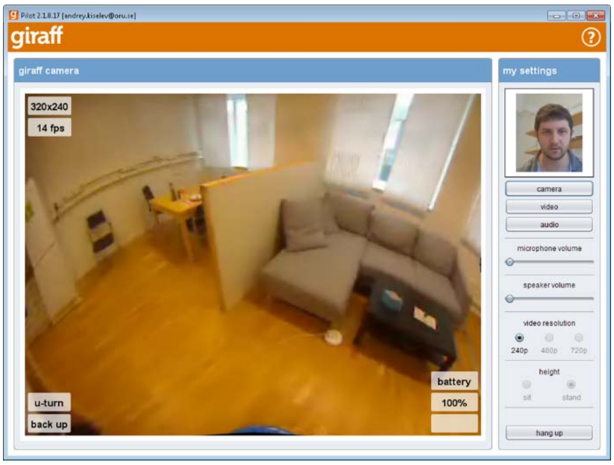

Figure 3. *Software version 2.0 of the Pilot interface*

At the time of experimentation, Giraff was a simple MRP system when compared to other MRP systems. Kristoffersson et al. (2013a) provided an overview of commonly appearing MRP systems in the literature and their intended application area. Giraff is a MRP system that is not equipped with sensors for obstacle detection and tip detection. Beam is another example of a commercial MRP system that is also lacking such sensors. Other functionalities of MRP systems include the ability to adjust the height (QB, Mantarobot Classic, Double and iRobotAva) or to manipulate objects and make expressions. The majority of MRP systems are intended for use in an office setting and other application areas include elderly, healthcare and research. Today, many of the MRP systems incorporate a touch screen and/or can be maneuvered from an iPad/Android tablet. The reader can find more information about the different MRP systems in Kristoffersson et al. (2013a).

Before we continue the discussion on MRP systems, we wish to highlight that an important factor for Giraff Technologies AB, the company developing Giraff, is scalability, i.e., to retain its simplicity and affordability while enhancing the product according to feedback collected from primary users (elderly) and secondary users. The Giraff unit should be available at a price point which leads to attractive business cases for home use when compared to other alternatives of elderly care. While attempts in this field had resulted in MRP systems at price points above €20,000, business case studies had suggested that the price point must be below €5,000. This entails that the manufacturing cost must be pushed down to a low level. Thus, the possibility of adding sensors, and or expensive cameras to the

MRP system is limited by the desire to create an attractive business case for use by elderly people with a limited financial resources.

The scalability factor was in sharp contrast with the result of several already concluded research projects in which robots intended for homes of elderly people were developed. These made use of a number of sensors for safe navigation in the development of robots which to some extent can be classified as MRP systems. These include MILO (Salemi, Reis, Saifhashemi, & Nikgohar, 2005) which lacked a screen, the “telerobot system” (Boissy, Corriveau, Michaud, Labonté, & Royer, 2007; Michaud et al., 2010) and TRIC (Tsai, Hsu, Ma, King, & Wu, 2007) which are all much smaller in height than today’s MRP systems. The usability tests in home environments of these MRP systems which never reached the commercialization stage are very limited. To our knowledge, only Michaud et al. (2010) present usability results from a short-term pilot study conducted on a local network. Similarly to the aforementioned MRP systems, Giraff aims to allow elderly to continue living independently for a longer period of time while keeping in touch with family, friends and caregivers. This idea is supported by e.g., Boissy et al. (2007) who conducted focus groups with geriatric caregivers and elderly people in order to examine requirements for robots in home telecare. Most results of the focus groups regard usability issues such as privacy concerns regarding the use of cameras and worries about robots operating in cluttered spaces. Finally, issues of cost and financing the service were brought up. This supports Giraff’s effort to remain affordable and accessible to a wide customer base. Therefore, a Giraff API which allows third party developers to introduce new functionalities on the Pilot side were introduced two years into the ExCITE project. This includes full access to video streams, an ability to draw over the original image, and full access to the robot control API which allows developing own robot controlling methods in the form of plug-ins.

Returning back to MRP systems, many research efforts have been carried out to identify design features relevant for MRP systems, e.g., Desai, Tsui, Yanco, and Uhlik (2011) and Tsui and Yanco (2013). However, given the fact that most MRP systems are developed for office environments, the majority of research efforts has focused on this application domain. The reader can find examples of such efforts in Kristoffersson et al. (2013a). Some notable exceptioins include Tsui, Norton, Brooks, Yanco, and Kontak (2011) who give attention on people with special needs and their use of MRP systems. Tsui et al. (2014) augmented the VGo[6] over the course of three years to support people with cognitive and motor impairments so that they can operate MRP systems. This work contrasts with the work presented here since focus is placed on users with cognitive impairements who act as pilots of the system whereas ExCITE considers elderly users as local users.

Therefore, considering the lack of long-term evaluations of MRP systems in homes of elderly people, the ExCITE project has made a significant effort in order to define evaluation methodologies and gather relevant feedback from the user experience with Giraff in a systematic and reliable way. Two kinds of user-evaluations were used to collect feedback: a short-term evaluation effort in order to identify immediate comments/feedback from users while using the robot; and a long-term evaluation methodology (Cesta, Cortellessa, Orlandini, & Tiberio, 2016) aiming at assessing the physiological and psychological impact of longitudinal use of Giraff in real living environments by administrating questionnaires on a timeline. In total, the MRP system Giraff was deployed for a longer period of time at 21 test sites (homes of elderly primary users) in Italy, Spain and Sweden. Throughout the project,

[6] Read more about VGo at http://www.vgocom.com.

two important and challenging factors influencing how the system was appreciated and used have been communication infrastructure and system stability, none of which were tested by Michaud et al. (2010), Salemi et al. (2005) or Tsai et al. (2007). As the project progressed and newer more stable versions of the robot were developed, more test sites could run smoothly on a long-term basis. The increased stability resulted in a higher satisfaction and more frequent use of the Giraff in the homes.

While this paper reports on the technical development resulting from a longitudinal project, many of the findings emerging from a number of short-term evaluation sessions have helped driving the development of the system from the very beginning of the project to its end. Findings include problems with: supporting natural communication through MRP systems, the Pilot interface, maneuvering the robot safely and shortcomings in the video features. In addition, the longitudinal studies highlighted a number of ways in which the effectiveness and usability of the Giraff needed to be improved to better suit the use in homes of the elderly. This resulted in a number of functionalities added to the Giraff and changes to the robot's hardware. This paper will not repeat what is already published regarding the short-term evaluation sessions[7], rather this paper will describe how the results from both the short and long-term evaluations guided the development of the platform.

The remainder of this paper is organized as follows: Section 2 provides brief information about all short-term evaluations and longitudinal test sites. Section 3 theorizes regarding the need for and how to support natural communication through MRP systems. A summary of the technical problems experienced and implemented actions in ExCITE is provided in Section 4. Finally, a discussion of the findings in this project is provided in Section 5.

2 Short-term Studies and Longitudinal Test Sites within ExCITE

A large number of short-term evaluations collecting feedback from more than 250 people (elderly, health care professionals and alarm operators) were conducted during the project.

The project entailed the instantiation of 21 long-term case studies in three countries and the creation of an evaluation plan, based on interviews and questionnaires to be administered to the older persons (primary users) and to the family members, friends and caregivers (secondary users). While this paper focuses on the technological results of the evaluation, the longitudinal methodology used within the ExCITE project, which mainly focused on changes in various physiological and psychological parameters through the use of questionnaires, is provided in Cesta, Cortellessa, Orlandini, and Tiberio (2012a) and Cesta et al. (2016).

The 21 test sites were selected in order to cover different situations in which a robot such as Giraff can be deployed. Table 1 provides a brief summary of the test sites deployed within the project. These test sites varied in composition and covered seven different use cases, the

[7] Publications of results from short-term evaluations within ExCITE include: Cesta, Cortellessa, Orlandini, and Tiberio, 2012b; González-Jiménez, Galindo, and Ruiz-Sarmiento, 2012; Gonzales-Jimenez, Galindo, and Guiterrez-Castaneda, 2013a; Kiselev, Kristoffersson, and Loutfi, 2014; Kiselev and Loutfi, 2012; Kiselev et al., 2015b; Kiselev, Scherlund, Kristoffersson, Efremova, & Loutfi, 2015c; Kristoffersson, Coradeschi, Loutfi, and Severinson-Eklundh, 2011, 2014; Kristoffersson, Coradeschi, Severinson-Eklundh, and Loutfi, 2013b; Kristoffersson, Severinson-Eklundh, and Loutfi, 2013c; Mosiello, Kiselev, and Loutfi, 2013; and Tiberio, Cesta, Cortellessa, Padua, and Pellegrino, 2012.

most common one being private residences with family members as secondary users. There were also clear cultural differences. For example, the Swedish test sites in which family members chose to be involved had secondary users that were located in other geographical locations. In Italy and Spain, the secondary users involved were predominantly family members living at a close proximity to the primary user. At a couple of the Spanish test sites, also healthcare professionals acted as secondary users. Each primary user had the Giraff at home for a period of 3-12 months during which the secondary users could visit him/her through the robot. Fielding Giraff 2.0-3.2 (see Figure 1) in real world contexts, i.e., ExCITE test sites, we could gather evidence that situations exist in which additional technical advancements can dramatically affect the effectiveness and usability of the Giraff when deployed in the homes of elderly people. These situations were not found when testing the robot in the ten short-term evaluations conducted during the first 24 months of the project.

By combining qualitative data from the real world experience with immediate comments/feedback collected through questionnaires and observations made during the short-term evaluations, we could derive a number of technical problems with the Giraff prototype. A majority of them were derived from a thorough analysis of the feedback collected during the first two years of the project (July 2010-June 2012). These served as guidelines on how to further enhance the Giraff during the remaining 18 months of the project. Others were derived towards the end of the project when testing implemented solutions. Our classification of the derived problems were grouped according to the following categories: pilot interface, video features, autonomous navigation, additional Giraff functionalities and robot hardware. This classification was inspired by previous research work, e.g., Desai et al. (2011) and Tsui et al. (2011). Section 4 provides further information regarding the derived problems.

Table 1. *A longitudinal test site summary*

Name	**Type of home**	**Secondary users**	**Number of test sites**
Italy(1a), Italy(1b), Italy(1c), Italy(1d), Italy(3), Italy(4), Spain(1), Spain(3),	Private residence	Family	8
Italy(5), Sweden(1a), Sweden(5), Sweden(6)	Private residence	Health care	4
Spain(2), Spain(4), Sweden(4)	Private residence	Health care, family	3
Sweden(1b), Sweden(3)	Rehabilitation center	Health care	2
Sweden(2a), Sweden(2b)	Elderly residential home	Researcher	2
Italy(2)	Health care organization	Health care	1
Sweden(7)	Private residences	Health care, friends	1

3 Supporting Natural Communication through MRP Systems

While all MRP systems offer an opportunity for people who are physically located remotely from each other to communicate in a “natural” way, a common concern amongst health care professionals is that the technology can be used to replace people according to Kristoffersson et al. (2011) who conducted a study with students and teachers in audiology, nursing and occupational therapy. The study indicates that the attitude towards the technology is dependent on the tools that the health care professionals normally use to communicate with their patients. The audiologist, for which communicating via video is not new, were positive towards MRP systems whereas nurses, who commonly touch their patients while communicating with them, were less positive. For this reason, it is important that the communication enabled by the MRP system is socially accepted (Beer & Takayama, 2011).

Several short-term evaluations conducted within ExCITE indicate that the quality of interaction could be improved in order to make the communication more socially accepted. Kristoffersson et al. (2013c) found that the perceived presence among people operating the Giraff robot was correlated to the perceived ease of use and to the spatial formations between the robot and the local user (an actor). The pilot users who found the pilot interface being used for manuevering the robot difficult had more problems positioning the robot in spatial formations being appropriate for human-human interaction (Kendon, 1990). Those positioning the robot in a spatial formation being inappropriate for human-human interaction also felt less socially and spatially present. Interested in how this would affect the experience among elderly people, Kristoffersson et al. (2014) conducted a study in which elderly people interacted with a pilot user who positioned the robot either in the appropriate spatial formation or in inappropriate spatial formations while guiding the elderly around a smart home. Using a retrospective interview technique in which the elderly were shown their own interaction with the pilot user, the elderly confirmed that it is important that the pilot user can maneuver the robot sufficiently well in order to form the appropriate spatial formations. In particular, the elderly emphasized the importance of being able to see the person and to have eye-contact (Kristoffersson et al., 2014). In an additional study, Kristoffersson et al. (2013b) found that sociometric data, a quantitative measure of social relationships (Moreno, 1953), correlates to presence and how well people can maneuver the robot. Acknowledging that the design of a pilot interface is critical for creating conditions supporting natural interaction and presence, Mosiello et al. (2013) developed two plug-ins which augmented the reality when using the Pilot interface 2.0. The two plug-ins were more intuitive to use as assessed through observations and a questionnaire. The user evaluations also indicate that aspects related to presence, such as the spatial perception and mental workload, were improved by adding an augmented reality to the Pilot interface.

Findings by Kiselev et al. (2014) suggest that limiting the horizontal field of view by flipping the robot’s camera around 90° may increase the quality of interaction since it decreased the angle between the optical axis as a line from the robot’s camera and the line between the local user and the camera. I.e., the opportunity for eye-contact increased as an effect of flipping the robot’s camera. Positioning the robot appropriately is also crucial for improving the auditory experience for both primary users and pilot users since the speakers and the microphone are located on the front side of the Giraff’s screen. Finally, it is also believed that the increased vertical view angle can improve the driving experience by eliminating the need for tilting the screen while driving, and talking, a task which can be mentally demanding.

The pilot users of the Giraff will connect to elderly people, who regardless of living an active healthy life or having a deteriorating health may spend a lot of their time without being in close proximity of the robot’s docking station. For this reason, the pilot user has to localize the position of the primary user prior to interaction can occur. One way of doing so is through sound. An inexpensive solution for this was developed and tested by Kiselev et al. (2015c). The results show that two microphones is sufficient for sound source localization which may be crucial in emergency situations.

Finally, Labonte et al. (2006) have shown that the design of the pilot interface can limit the efficiency and safety during teleoperation of a robot. Findings by Kiselev and Loutfi (2012) suggest that this may also have a negative impact on the perceived mental workload among pilot users of MRP systems. Similarly, the study by Mosiello et al. (2013) shows that the ability to follow paths and passing through narrow passages such as doorways is affected by the interface design. There were also other differences between the pilot interfaces, e.g., the positioning of buttons for steering the robot. The results indicate that user preferences vary and that “buttons” for maneuvering the robot should be located within the driving area. For example, the participants found it easier to back up the robot when the button was positioned within the driving area. This finding is supported also by Cesta et al. (2012b).

> **Recommendation 1.** MRP system for use in homes of elderly people should help the pilot user in positioning the MRP system face-to-face with the elderly during communication.
> **Recommendation 2.** MRP system should be tested by all prospective target groups in order to ensure that the mental workload when using the pilot interface is low.
> **Recommendation 3.** Position all the buttons needed for maneuvering the MRP system within the driving area of the Pilot interface.

4 Problems Experienced and Implemented Actions

4.1 Pilot Interface

The user feedback collected by Cesta et al. (2012b), Mosiello et al. (2013) and during training session 1[8] provide evidence to the fact that the pilot user focuses on the driving area while maneuvering the robot. For example, experiments have shown that pilot users have had difficulties finding the means for adjusting the volume being located to the left of the driving area while communicating through the Giraff. Obviously, the ability to hear each other at appropriate volume is crucial for natural communication.

Implemented actions. The Giraff Pilot interface was redesigned, Pilot 2.0 (see Figure 3). The right frame incorporates everything concerning the driver’s own video conferencing equipment. Here, the pilot user can adjust the speaker and microphone volume but also see his own local image, select camera and audio output/input during a call. The possibility to select camera and audio output/input was hidden in a menu in prior versions of the Giraff Pilot and the changes could not be done during a call. The right frame has been experimentally validated as being a significant improvement compared to the previous Giraff Pilot. All commands related to maneuvering the robot are located within the driving area as suggested in recommendation 3.

In addition, findings by Cesta et al. (2012b), González-Jiménez et al. (2012) and Kiselev and Loutfi (2012) show that the possibility of having more control over the robot’s behaviors and to use different control interfaces such as keyboard, joystick, etc. seems to be more convenient for some secondary users (especially those who have experience with computer games). Relating back to Mosiello et al.’s (2013) finding that augmenting the reality of the driving area improves the interface intuitiveness in comparison to the line aiming method

[8] Training session 1 was conducted with 38 Swedish alarm service operators in preparation for the deployment of Sweden(5) who can touch a button to get in touch with the alarm services via a speaker phone. However, network problems at the test site lowered the trust of the robot and hindered its use by alarm operators.

used in the Giraff pilot, introducing alternative ways for controlling the Giraff robot could be another means for lowering the mental workload and therefore also increase the pilot user's perception of presence within the remote environment.

> **Recommendation 4.** Support different control interfaces in order to motivate different categories of people to use the MRP system

Moreover, it has been clearly observed in user evaluations that the way in which the Giraff robot's tilt mechanism was implemented was not intuitive. The use of the mouse to control both the robot's movement and screen tilt was introducing some control interferences. In fact, unwanted tilt movement commands and/or forward motion commands have been issued by novice pilot users of the Giraff robot in training session 1. This finding reinforces recommendation 2.

4.2 Video Features

A number of needed improvements related to the video features of the Giraff robot have been recognized as crucial in the short-term and long-term evaluations. The video quality has not completely satisfied the needs of neither the primary nor the secondary users. In several short-term evaluation sessions, e.g., Cesta et al. (2012b) and Kiselev and Loutfi (2012), we found that pilot users had problems with visual inspections such as recognizing the state of objects and reading text if not written using a large font and high contrast colors. Additionally, some secondary users with a high technological profile have perceived the camera image quality to hamper their awareness of obstacles while steering the robot and their perception of detail while docking the robot to the docking station (González-Jiménez et al., 2012). Figure 4 provides examples from real test sites which are generally crowded by furniture while having poor lighting conditions. The subfigure at top shows that secondary users found it difficult to distinguish details such as the meal on a plate. The bottom two subfigures illustrate typical low lighting conditions at the test sites and the secondary users' concern with the ability to perceive the mental state of the primary users. Being able to assess the mental state of primary users but also e.g., changes in the elderly person's skin color are two examples of typical needs among health care professionals using MRP systems. While these needs could be met in good lighting conditions and open spaces, such as office environments, the Giraff was tested in real homes in which the furniture at times guided the way in which the pilot users could position the robot while interacting with the primary users and while maneuvering the robot towards the docking station. Thus, furniture influenced the way in which the Giraff was positioned with respect to the few light sources available. This in turn affected the video resolution negatively.

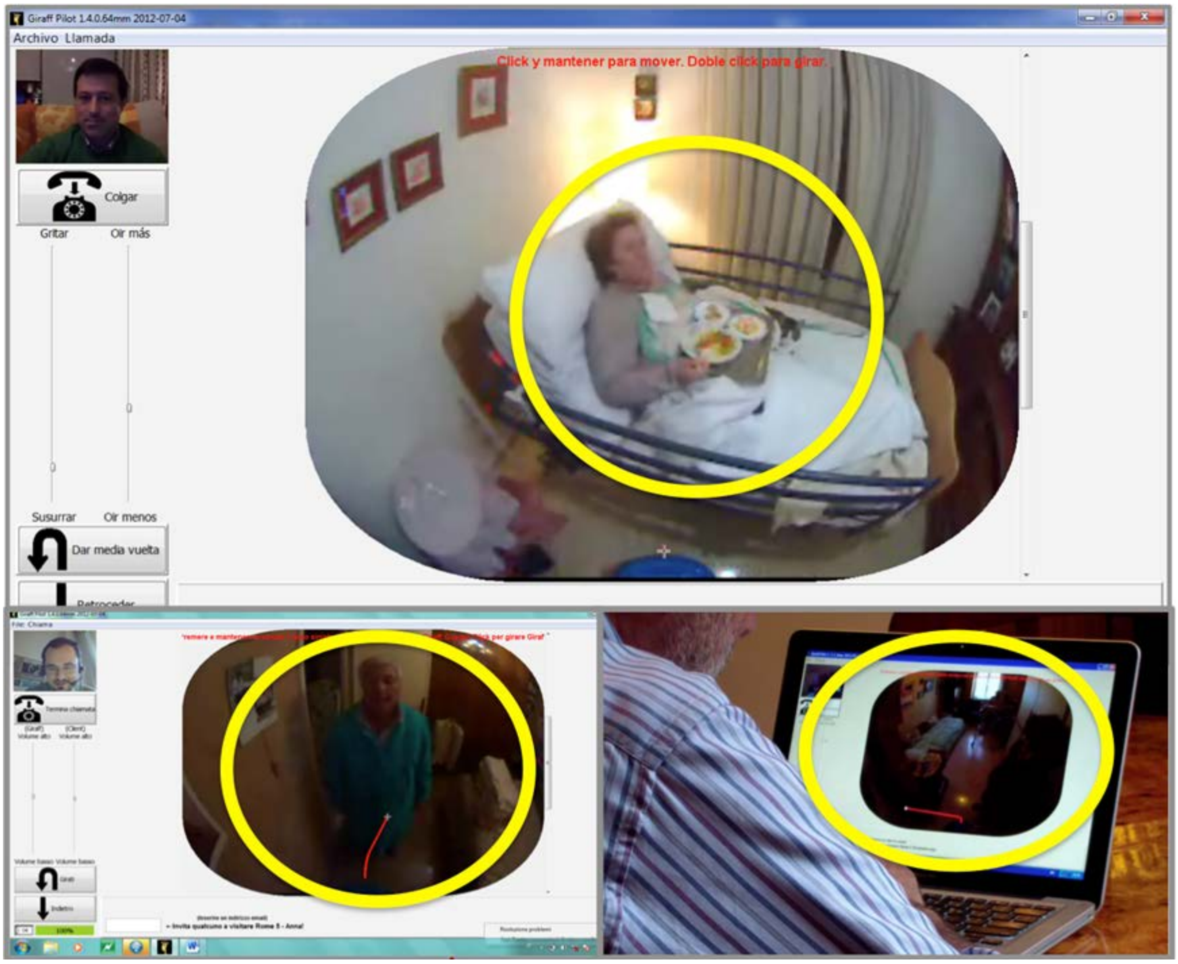

Figure 4. *Example of scarce video quality using Giraff 3.1 in low light conditions.*

However, increasing the video resolution is not the only video feature that needed to be improved. Cesta et al. (2012b) have shown that a video zoom feature is needed in order to allow for the observation of details within the remote environments, e.g., the plate in Figure 4 and for assessing the elderly person's health. Secondary users involved in long-term test sites have requested the same feature.

Finally, as already described, the typical environment in which the Giraff is installed has poor lightning conditions. The nurses participating in e.g., Cesta et al.'s (2012b) expressed the need for night vision capabilities. Access to such a feature would improve their ability to conduct night surveillance activities both at hospital and in homecare activities. Figure 4 shows how the lack of night vision capability negatively affects the pilot user's ability to control the robot. It can be assumed that the mental workload for the pilot user would decrease if night vision was added. The importance of good lighting conditions have been manifested at a number of test sites, e.g., Sweden(1a) and Sweden(5) who desired alarm operators to visit them using the Giraff in the case of quite alarms, but also at Spain(3) where the pilot user connected to a dark home with the result of being unable to operate the robot. Sweden(5) had similar conditions, the docking station was situated in a room in which the light was usually off.

> **Recommendation 5.** MRP system for use in homes of elderly people should have a camera which allows for distinguishing details such as colors of pills and skin color.

Recommendation 6. MRP system for use in homes of elderly people should support controlling the robot in low light conditions.

Implemented actions. While it should be noted that all the collection of feedback regarding video features was done while Giraff offered a resolution of 320p, the maximum resolution of the Giraff has been gradually increased throughout the project. Even though the resolution was increased to 480p already in Giraff 3.1, the feedback collected showed that also this camera was insufficient for usage in home environments. Therefore, a careful selection of a new camera satisfying all the above needs was made for the release of Giraff 4.0. The new high performance camera and matching lens can provide HD720 resolution in the call at up to 30FPS depending on connection quality, i.e., the resolution can be automatically adjusted to upkeep the highest frame rate possible. This increases the Giraff's robustness since the network conditions within the same home can vary significantly. The camera has also allowed for the implementation of digital zoom and for operating the Giraff in low light conditions and even at night. The Pilot interface has been equipped with controls to zoom-in and –out with magnification up to 8X. In order to achieve a higher visual dynamic range and better performance in low light conditions, new controls allowing the pilot user to switch the camera into monochromatic mode were added to the right frame (see Figure 5). Another advantage with the implemented solution is that no additional light source, which may be perceived as disturbing for the primary user, is required. Figure 5 shows how the pilot user's perception of the remote environment is improved by switching to the monochromatic mode. Hence, the illumination from the robot's screen is enough for comfortable operation. The addition of night vision allows alarm operators to connect to the robot and navigate the robot even at dark hours. This way, a quick assessment of the state of the elderly person can be done even prior to home care services can arrive.

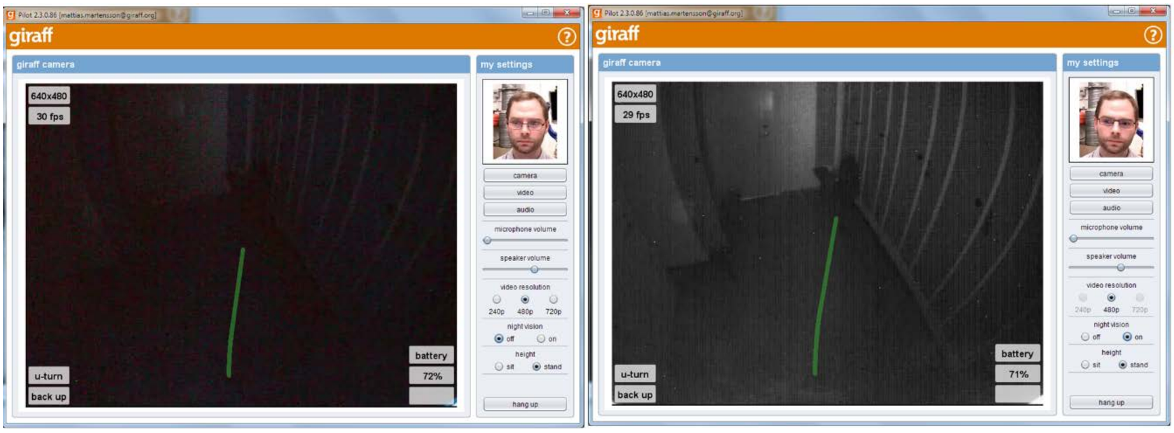

Figure 5. *Two pictures of the same scene with night vision OFF (left) and night vision ON (right).*

4.3 Autonomous Navigation

It is worth observing that the MRP system Giraff is relatively simple (as most of the currently available MRP systems are). Striving for scalability while retaining its simplicity and affordability, the Giraff robots used in our evaluations have been fully operated by the remote pilot users and thus not been endowed with any autonomous behaviors. However, a number of short-term evaluations and test sites[9] provide evidence that situations exist in which adding autonomous behaviors to the robotic platform and/or the Pilot interface would enhance the effectiveness (and also the safety) of Giraff. Considering the fact that quantitative measures of social relationships and perceived presence are related to the ability to maneuver the robot (Kristoffersson et al., 2013b) and that difficulties in maneuvering the robot has a negative impact on the mental workload (Kiselev & Loutfi, 2012), development of autonomous features can also increase the quality of the interaction.

One of the main worries among pilot users involved in a number of short-term evaluation sessions (e.g., Cesta et al., 2012b; González-Jiménez et al., 2012) is related to safer navigation. In particular, some difficulties were encountered when Giraff had to be maneuvered through extremely narrow spaces or in areas with many obstacles, both of which are common in typical homes of elderly people. Therefore, adding some autonomy for helping the pilot user while driving is critical as it could alleviate the mental workload for the pilot user while navigating the Giraff. González-Jiménez et al. (2012) found that even pilot users with a high technological profile were particularly worried about the safety issue during navigation and that they considered the obstacle avoidance capability as a key functionality of the robot. Finally, also the primary users have identified the need for obstacle detection. Although these features are already very common in robotics (e.g., Durrant-Whyte & Bailey, 2006; Lefebvre, Lamiraux, Pradalier, & Fraichard, 2004; Thrun, 2002), some MRP systems lack them. In fact, there are a number of reasons for not making MRP systems fully autonomous. Two of them are related to system cost and performance. Laser scanners can cost more than the robot itself and in conjunction with processing algorithms, they can significantly reduce the battery life of the robot. Other reasons are related to the overall system safety. For example, it is yet unclear how to ensure that autonomous robots can safely operate in real homes of elderly.

Another aspect of autonomous navigation is related to mapping. The alarm service company responding to alarms via the Giraff at Sweden(1a) had never visited the test site. Therefore, they drew their own map of the test site and positioned it above the alarm operator’s computer to ensure safe navigation. Findings by González-Jiménez et al.’s (2012) support the need of increasing the pilot user’s situation awareness by enriching the Pilot interface with a map indicating the position of the robot within the remote environment.

Finally, a task considered critical from a usability point of view is the docking procedure[10]. The docking task, which was further complicated also because of the low video resolution and poor lightning conditions already described in Section 4.2, was perceived as frustrating and time consuming. Figure 6 illustrates the difficulty of identifying the docking station in lighting conditions being typical for the test sites and homes in general. Sometimes it lead to situations in which the main part of the call was dedicated to docking. Hence, the use of Giraff as means for communication was discouraged. The access to a docking station for MRP systems deployed in homes of elderly people is crucial. Because of the fact that the elderly cannot be expected to dock the robot in case the pilot user fails, the robot should always be able to reach the docking station regardless of lighting and wireless conditions.

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[9] E.g., Cesta et al. (2012b), González-Jiménez et al. (2012), Kiselev and Loutfi (2012), Kristoffersson et al. (2013b, 2013c), training session 1, Italy(1d), Spain(1), Sweden(1a) and Sweden7.

[10] E.g., Cesta et al. (2012b), González-Jiménez et al. (2012), Kiselev and Loutfi (2012), training session 1, Italy(1d), Spain(1), Sweden(1a) and Sweden(7).

Recommendation 7. Developers of MRP system for use in homes of elderly people should strive to provide obstacle detection, a map indicating the position of the robot and to ease the docking procedure.

Figure 6. *Evidence of difficulties in identifying the docking station.*

4.3.1 Implementation of Autonomous Behaviors and Maps

Two separate initiatives have been taken in order to address the usability problems related to the worry about safe navigation through narrow passages with many obstacles and the perceived lack of a map indicating the robot's position. In the first initiative, the Giraff was equipped with abilities for autonomous navigation, but the robot is only allowed to navigate between known checkpoints in an environment. Additionally, the components of the system were carefully selected in order to maintain an overall low system cost and to allow for a certain level of modularity so that the Giraff robot can be produced with or without this functionality in the future.

Two plug-ins have been developed for the Giraff Pilot interface (see Figure 7 and 8). The plug-in shown in Figure 7 incorporates the functionalities developed using a 2D laser range scanner to allow autonomous navigation, concretely the first plug-in:

- Visualizes a geometric-schematic map of the elderly person's home where the pose (position and orientation) of the robot is continuously shown. The remote pilot user can remotely construct such a map as well as add distinctive labels to identify different rooms or areas, e.g., "kitchen". These labels help the driver to be aware of the robot's location within the environment. They can also be used as destinations for the reactive navigation algorithm.
- Allows the pilot user to navigate inside the robot's environment using a map and labels and to see the current position of the robot in the environment. The pilot user can see the current position of the robot even when driving in manual mode rather than using the autonomous navigation mode.
- Includes additional commands to drive the robot using linear and angular velocities consigns. Similarly to the commands in videogames, some users have identified this new navigational mode as an intuitive way for driving the robot (see also recommendation 4).

Additional information regarding the implemented solution is found in Gonzalez-Jimenez, Galindo, Melendez-Fernandez, and Ruiz-Sarmiento (2013b).

Figure 7. *Autonomous navigation, plug-in 1.*

In a second iteration, the safety was improved by the addition of a reactive navigator which takes into account the shape of the robot and obstacles in 3D. The second plug-in shown in Figure 8 has a look and feel which is more similar to the traditional Giraff Pilot. The plug-in allows the user to drive manually and/or drive autonomously using either the labels on the map or the labels in the dropdown menu. Similarly to findings by Cesta et al. (2012b), Gonzaléz-Jimenez et al. (2012), Kiselev and Loutfi (2012) and Mosiello et al. (2013), the initial evaluations show that the user preferences vary. Some drives the robot only manually, some use only the autonomous features while others combine manual and autonomous driving. The implementation and evaluation of the second plug-in are further detailed in Kiselev et al. (2015b).

Figure 8. *Autonomous navigation, plug-in 2.*

The second initiative is vision-based and makes use of no sensors other than the robot's camera. Kiselev, Kristoffersson, and Loutfi (2015a) present an image-based system for drivable area discovery and collision avoidance which implements cooperative control in a parallell mode, i.e., the system modifies the user input in order to automatically avoid obstacles, if there are any, within the drivable area. Walls and furniture cut the drivable area using a straight line. For other obstacles, where no straight line can be detected, the robot automatically reduces the speed while the pilot user attempts to pass the obstacle. The plug-in implemented incorporates a visualization of the drivable area. Figure 9 shows how information indicating the space needed to manuever the robot is provided.

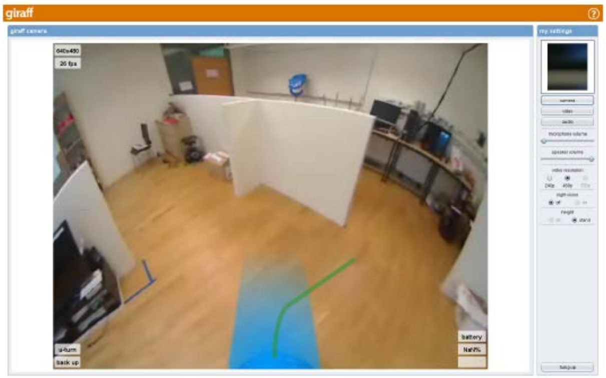

Figure 9. *Visualization of the drivable area using a robot wide corridor.*

The implementation is supported by the evaluations conducted by Mosiello at al. (2013). Kiselev et al.'s (2015a) solution which adds no cost to the MRP system has proved to work in lab environments but there are still several issues to handle prior to such a system can be deployed in home environments. The implemented solution cannot cope with light blobs, i.e., overexposed segments. For this reason, the robot is not allowed to cross overexposed areas, which may be free of obstacles. Another problem may occur for example when there is a carpet with a color being different than the floor color. Although the system interprets that both the floor and the carpet is drivable, the margin between them is a straight line, i.e., an obstacle is detected.

4.3.2 Implementation of Means Facilitating the Docking Procedure

A plug-in making use of a cardboard target attached to the top of the docking station has been developed. The plug-in provides a simple interaction with the pilot user by searching for the best target candidate in the image and by highlighting the target with a box. The pilot user selects the target by double clicking on the box (see Figure 10).

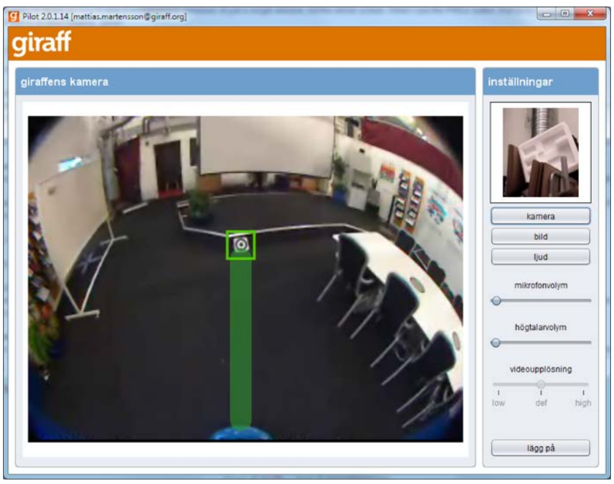

Figure 10. *Auto-docking operation. The box marks the locked target.*

This action locks/confirms the target. Once a target has been confirmed, the pilot user presses and holds the left mouse button to carry out the automatic docking of the Giraff robot. This solution is cheap compared to for example the one developed for the CompanionAble (the result of a research project developing a more expensive robot offering different services such as fall detection, reminders, and video telephone to people with a cognitive decline) which required an extra web camera (Gross et al., 2011).

4.4 Additional Giraff System Functionalities

Almost entirely because of fielding the MRP system Giraff in real world contexts, i.e., longitudinal test sites, we found a number of ways in which the effectiveness and usability of Giraff needed to be improved to better suit the use in homes of elderly.

An illustrating example is Sweden(1a) who used a Giraff 2.0 (See Figure 1). Already when deploying the robot, it was clear that several access levels to the Giraff were needed. Sweden(1a) wanted to allow alarm operators entering the home via Giraff without her consent while being able to accept (or reject) the Giraff visits initiated by others. Additionally, she wanted to be able to initiate calls to her brother via the Giraff. None of these features were available in the Giraff deployed. In addition, she spent most of the time in a wheelchair or in bed. Therefore, it was important to find a solution which allowed her to accept/reject calls without having to touch the robot.

> **Recommendation 8.** MRP system for use in homes of elderly people should mimic a phone, i.e., the elderly should be able to accept/reject and initiate calls.
> **Recommendation 9.** Several access levels are needed for MRP systems for use in homes of elderly people.

Implemented actions. To satisfy the needs of Sweden(1a) but also the majority of the remaining test sites, a database (Sentry) was developed and introduced in conjunction with the release of Pilot software version 1.2. A new remote control (see Figure 11) was introduced with Giraff 3.1.

Figure 11. *The remote control for answer/decline and volume up and down*

The remote control allows the primary user to accept or decline calls by pushing the green or the red button. In addition, there are two buttons which allows the primary user to adjust the volume. The primary user can initiate a call to a predefined user by pushing the green button. A drawback with this solution is that it entails that the predefined user is sitting in front of a PC, a situation which cannot be guaranteed. Our experiences show that elderly may wish to use the callout functionality in emergency situation (Cesta et al, 2012b; Sweden(7)). Therefore, Sentry has been further developed so that the administrator of a specific Giraff can add an email address or a phone number to which a notification should be sent if a primary user tries to do a callout and noone answers on the pilot side. A similar functionality has been implemented in order to send a notification if the robot goes offline.

Our experience from the longitudinal evaluation is that the remote control has been found easy to use by the primary users. Also other MRP systems, e.g., the VGo has a 21-button handheld remote. Seeyle et al. (2012), who conducted a 2-day trial with elderly people using VGo, found that such a remote can be confusing to use.

Another illustrating example can be provided by feedback from Italy(1d) and Italy(3). For them, the possibility to initiate calls to just one single predefined callout user was insufficient and a clear limitation of the Giraff. In fact, having no assistance from a caregiver (e.g., a relative or an alarm operator), the primary user may want to select someone else using a personal list of contacts. Similarly to the phone, the elderly may wish to use the robot to connect with different people in different situations, e.g., a doctor if not feeling well, the police if someone that the elderly person does not know tries to enter the home or a friend for social communication. So, besides the fact that the robot keeps company, the need to have some additional useful and more practical functionalities clearly emerged. It is also plausible to think that enhancing the system with the possibility to call other persons could contribute to maintain the elderly people's "active ageing". This issue has not been resolved during the course of the ExCITE project. However, this functionality has been implemented for the Giraff robots used within the currently ongoing Victoryahome[11] project.

> **Recommendation 10.** A contact list is desired by elderly people using MRP systems in their homes.

Finally, even though most areas in modern society have a good infrastructure with respect to internet, problems with the network connection have occurred at some of the longitudinal test sites. Reasons include concrete pillars at Sweden(1b), a rehab center, and large areas needed to be covered at Sweden(2), an elderly residential home. As a consequence, the pilot users experienced a high latency in the sound compared to the image and also with respect to the response to the commands issued. Empirical testing in Italy shows that the minimum Internet requirements for a reliable connection to a Giraff robot is 1.5 Mbps up and down with a latency of less than 300 ms between the pilot user and the robot. However, additional evaluations regarding the best Internet settings for the Giraff but also for the secondary users connecting to the Giraff using a Pilot software are needed. Studying the reference network requirements provided by competitors to the MRP system Giraff, the requirements are comparable. The Beam[12] from Suitable Technologies requires minimum 1 Mbps upload and download (3 Mbps for best experience). VGo Communications[13] claims that VGo can operate from about 200 kbps to 850 kbps up and down but recommends a minimum speed of 1.5 Mbps for best performance.

It should also be noted that most test sites were not connected to the Internet via fiber or cable prior to being test sites. This is a very common situation among elderly people in Italy and Spain. It should also be noted that a growing number of people, including elderly, has mobile Internet. In fact, both the VGo and Beam support 4G LTE which adds more flexibility.

4.5 Robot Hardware

The deployment of Giraffs in a real life context and for a long period of time have highlighted a number of problems related to the utility of the robot. The current design of the docking station forces the installation of the Giraff in a position such that the robot screen is facing a wall. This meets a direct request from elderly people, i.e., assures them that they are

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[11] Read more about Victoryahome at http://www.victoryahome.eu.
[12] Read more about Beam at http://www.suitabletech.com/beam/ .
[13] Read more about VGo at http://www.vgocom.com/faq .

not being observed. The design choice comes with a major drawback in that the primary users cannot see who is trying to call them. While also Lee and Takayama (2011) have outlined the need for an identification system for MRP systems targeting office environment, the lack of this information strongly affected the perceived usability of Giraff at Italy(1d) and Italy(3).

> **Recommendation 11.** The MRP systems camera should face the wall when no pilot user is connected to the robot.
> **Recommendation 12.** MRP systems should provide an identification system showing who is trying to call the robot.

Implemented actions. The hardware surrounding the Giraff's screen was modified in order to allow for flipping the screen 180 degrees when someone calls so that the primary user can easily see the caller-ID. All Giraffs from 3.4 and onwards have tilt able screens. See Figure 1 for a comparison with older Giraffs.

The design of the Giraff robot, up to hardware version 3.4, entails a human-height aspect in order to resemble the presence of a real human. Some elderly involved in the project spend most of their time sitting (e.g., in a wheel chair) or have other mobility problems. Several primary users, particularly Italy(1a) have found the Giraff's height uncomfortable when sitting and asked for adjustable height in order to enhance the visual contact between primary and secondary users and thereby also making the communication more natural.

> **Recommendation 13.** The height of MRP systems should be adjustable.

Implemented actions. A complete redesign of the mechanics inside the Giraff robot was made to fit the requested height adjustment feature. This allows the person driving the Giraff to adjust the height of the screen (his/her face) and to "sit down" by a table. The feature is available from Giraff 4.0, see Figure 12.

Figure 12. *The Giraff 4.0 can "sit down" (140cm) and "stand" (165cm)*

5 Discussion and Conclusions

This paper has reported on the technical development of the mobile robotic telepresence (MRP) system Giraff during the course of the 42 months EU Ambient Assisted Living Joint Programme Project ExCITE (Enabling SoCial Interaction Through Embodiment). The aim of the project was to define evaluation methodologies and determine factors which led to the product refinement of the Giraff platform. Ultimately, the goal of the Giraff platform is to provide a telepresence system which is specifically suited for the use in homes of elderly people while retaining the simplicity, affordability and scalability.

The technical development is the result of a series of short-term studies collecting feedback from more than 250 people (elderly, health care professionals and alarm operators) and the long-term deployment of Giraffs at 21 test sites in Italy, Spain and Sweden. The test sites were selected in order to cover a total of seven different use cases, the most common one being private residences of elderly people with family members as secondary users.

The feedback collected in the short-term and longitudinal studies is complementary. The longitudinal studies have resulted in qualitative data from real world experience of using the Giraff. The short-term studies have resulted in immediate feedback in the form of comments but also allowed for observing the use of Giraff (e.g., spatial relationships), the collection of quantitative data regarding the ease-of-use and perception of presence and sociometry (social relationships). Kristoffersson et al. (2013b, 2013c) have found that there are correlations between these measures.

Comparing our results with the work conducted by others, in general, it was found that the requirements for a MRP system in the elderly care application domain drive the overall system design (hardware, software, administration, etc.) in a dramatically different direction than a “generic” system that might be used in general business applications.

In particular, privacy needs to be ensured. This has led to the development of a database in which rights to see whether a particular robot is online, the right to call it, or the right to enter without an answer in an emergency situation can be set. Additionally, given the fact that the primary users of the MRP system may be computer novices with a deteriorating health, the system needs a higher degree of reliability than MRP systems deployed in office environments. Even the execution of simple tasks such as checking if the MRP system is charged cannot be expected from the elderly people. A higher usability of the system from the secondary users’ perspective is also needed to ensure that the system is actually regularly used.

Operating a MRP system located in a home requires a higher attention than operating a similar device in an office environment for a number of reasons. Firstly, the home layout generally contains more narrow passages and smaller rooms in combination with more furniture in proportion to the space available. Secondly, the internet connection within a home is generally less reliable than the internet connection in an office. While the latter may be equipped with solutions offering a stable Wi-Fi or 4G connection within the entire office, the network conditions in a home are affected by the added amount of (thick) walls but also by the network infrastructure surrounding each home. ADSL, rather than fiber or 4G, is often the only possible solution for these apartments. Finally, the lighting conditions in home environments are poorer. While office environments make use of a combination of natural daylight and appropriate ambient light sources to help the personnel focus on work tasks (Begemann, van den Beld, & Tenner, 1997), the light sources in homes are used to create a more relaxing environment. Additionally, the access to natural light varies significantly between and within each home environment due to the narrow passages, thick walls and corresponding deep window sills. Located elsewhere, the secondary users piloting the MRP systems must be ascertained that they can drive safely and be able to put the robot back into the docking station. The location of the docking station is often the only free wall space available in the home, thus other furniture may influence the path that the robot needs to take while docking the robot to the docking station but also negatively affect the lighting conditions around the docking station.

Our experience from the ExCITE project is that development of technology over a significant period of time is not always a straightforward process. In the case of ExCITE, none of the primary or secondary users had been exposed to a MRP system before. For this reason, it was difficult for them to outline their requirements on the technology prior to experiencing the use of Giraff over a longer period of time i.e., their requirements changed due to habituation and familiarization with the technology. Hence, system requirements may be unclear in the beginning and they can change over time as a result of an increased understanding of what the technology enables. The requirements can at times be contradictory and can become outdated because of overall technology development and users' familiarization. Finding such contradictions and understanding the role of users' familiarization with a product cannot be done without the conduction of longitudinal studies in real contexts – which has been the overarching aim of ExCITE. After the 42 months, the evolution of the Giraff platform has stabilized and future work is now concentrated on integrating the Giraff system with other complex systems such as a sensor network.

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