Robotics Enabled Augmented Health

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Abstract. Nowadays it is increasingly important, for social and economic reasons, to provide augmented health assistance for people at home. This will mostly benefit some specific user groups, such as elderly, patients recovering from physical injury, or athletes. This chapter describes the application of robotics, under the scope of the Augmented Human Assistance (AHA) project, for assisting people health. Two complementary and interacting approaches are described. The first consists on a mobile robot nurse, that assists patients and elderly on their daily lives, such as for advising on medicine intake, or providing complementary biomedical sensing equipment for health monitoring. The other approach consists of multimodal feedback assistance through augmented reality, haptic sensing and audio, in order to guide and assist people on the execution of exercises at home.

1 Introduction

The world population is aging rapidly. There is an increasing need for health assistance personnel, such as nurses and physiotherapeutic experts, in developed countries. On the other hand, there is a need to improve health care assistance to the population, and especially to elderly people.

The World Health Organization estimates that sedentarism is the 4th main factor in worldwide mortality, and is associated with several diseases, such as breast and colon cancer, obesity, diabetes, and ischemic strokes. For instance, childhood obesity originates other health problems such as hypertension related to left ventricular hypertrophy, atherosclerosis and diastolic dysfunction. It is therefore important to identify children in risk, through continuous health monitoring (e.g. body temperature, blood pressure, electrocardiogram). Concerning elderly, estimates indicate that by 2030, ~4% of the USA population will have experienced a stroke, with related costs expected to rise from $71.55 billion to $183.13 billion between 2012 and 2030.

Hence, sedentarism is not only a social problem, but also economical, threatening the sustainability of current health systems. New technologies are required for enabling treatment at home, reducing pressure for health care personnel at hospitals. Furthermore, automated systems at hospitals will enable significant cost reductions and improved efficiency. Information technology has also been playing an increasing role in the health care area throughout the years, aiding it to be more accurate, faster to respond, and less susceptible to human errors. There is therefore the need not only to develop technological solutions that promote active aging and prevent sedentary behaviors, but also to find new technologies for assisting a growing, aging population.

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In this context, the advances in information, robotic and assistive technologies have the potential to increase quality of life and change health care delivery models, reducing costs, and improving monitorization. The "AHA: Augmented Human Assistance" project is a novel, integrative and cross-disciplinar approach combining innovation and fundamental research in the areas of human computer interaction, robotics, serious games and physiological computing. AHA's goal is to develop a new generation of ICT based solutions that have the potential to transform healthcare by optimizing resource allocation, reducing costs, improving diagnoses and enabling novel therapies, thus increasing quality of life. The project proposes the development and deployment of a novel Robotic Assistance Platform designed to support healthy lifestyle, sustain active aging, and support those with motor deficits.

The AHA project will develop a novel and modular set of ICT based solutions that in isolation or integrated as a Robotic Assistance Platform will address:

- Physical (re)training: Building on the existing expertise on Augmented Reality (AR) and serious games, we propose to develop adaptive AR physical training tools that deliver online feedback on performance to prevent sedentarism, support active aging and provide personalized tools for function re-training in motor impaired patients.
- Increasing self-awareness: Monitoring of user state by means of biosensors, computer vision systems and exercise performance data. User state will be assessed in a transparent manner and data will be visualized through friendly user interfaces, and shared with patients, clinicians and/or relatives.
- Augmented assistance: The above systems will be integrated on a mobile robotic platform with indoor navigation capabilities (in environments such as senior houses and hospitals) that will interact through a virtual coach system to assist patients, provide reminders on tasks, guide patients through exercises, and support them in daily routines.

These technologies may be very useful in other scenarios, such as those of MOnarCH project (Multi-Robot Cognitive Systems Operating in Hospitals). This CE FP7 project is focused on introducing a fleet of social robots that will interact with sick children and collaborate with medical staff on the pediatric ward of a hospital, the Portuguese Oncology Institute of Lisbon (IPOL).

1.1 The Need for Robots

There are several scenarios in which robots and augmented reality are very useful in the two aforementioned environments corresponding to these two abovementioned projects.

- Teaching, for robots to supporting human teachers by projecting augmented reality content on a wall or on objects.
- Patient rehabilitation exercises support, by projecting augmented reality content during physiotherapeutic activities in which the patient receives in real-time visual feedback and corrective postures
- Information providers, such as projection of AR content informing people that a new activity is about to start, or calling then with visual signs, or even moving along with people to places where action is going to take place (e.g. using projected directional arrows), or informing someone to stop performing an

exercise.

- People protection, such as projecting augmented reality content (for instance a stop sign) if a person moves into a forbidden zone or door, or performs a forbidden rehabilitation exercise or movement
- People entertainment: robots can play games with children or elderly people, according to content projected into the floor. In another scenario, a patient rehabilitation can involve game playing (serious games).

Furthermore, robots can perform several supporting activities at home, such as:

- support safe medicine delivery and intake. A robot may carry the medicine, and at the appropriate time, take it to the patient.
- In addition, the robot may also carry on board medical equipment, such as thermometer, arterial pressure measurement device, or electrocardiogram (ECG) equipment, making it available to patients at home.

1.2 Remote Health Assistance

Ageing population has an enormous economic and social impact in a various areas, especially healthcare systems. Elderly people are more vulnerable to physical or mental impairments, disabilities and chronic illnesses. Falls and problems with muscle bone can also limit the daily routines. Hence, such problems increase the potential need for assistance of elderly people.

Patient health monitoring was traditionally done through periodical visits to the doctor in order to undergo on-site tests for blood pressure, pulse, temperature, or sugar level. The alternative is stationary monitoring, upon internship at a health care provider. Currently, patients have the possibility to take home sensors attached on a belt, usually for a specific time period, to collect biosignal data for that period. However, the patient still has to move to the health care provider to get the sensor, and afterwards, he/she has to return to remove the sensor and deliver the data. Nowadays, we are reaching seamless health monitoring by placing a mobile sensor on the patient, executing biosignal collection, and transmitting data through a wireless access technology interface to a storage facility for further medical analysis [1].

On the other hand, medical assistance personnel play a very important role on patient recovery. In physical therapy, for instance, the therapist helps patients fighting their pain and recovering from injury. His role is fundamental on therapy planning. In addition, he not only demonstrates the correct execution procedure for the exercises, but he also makes sure afterwards the exercises are executed correctly. With this goal in mind, the therapist can intercede during the session and adapt the exercise schedule according to the patient's feedback [2]. However, the patient might perform incorrect movements at home, without the therapist presence, to avoid pain [3]. Hence, there is a need to provide assistive solutions that do monitor remotely the patients' execution of exercises, but also support, motivate and advise the patient to correctly perform the exercises. The former is accomplished through biosensors, augmented reality and haptic technology, that should monitor continuously the patient, transmitting wirelessly information concerning its health state and providing feedback. An interacting mobile robot should provide the patient motivation and guidance.

1.3 Chapter Structure

This chapter will start by presenting a review of previous relevant literature for augmented health assistance. Afterwards, section 3 overviews the Augmented Human Assistance project, namely its structure and challenges. Section 4 addresses the design of robot assistants targeting the AHA project user groups, which will act as nurses for elderly people and patients in recovery of physical injury. It will be also shown that robotics and augmented reality can provide further functionalities for providing visual or haptic feedback to users, as described on section 5. Finally, section 6 will draw the main conclusions, together with directions for future work.

2 Background Review

Various studies show evidence physically active elderly having lower rates of chronic conditions such as cardiovascular diseases, diabetes, cancer, hypertension and obesity [4]. There is the need, therefore, to develop solutions that promote healthy habits and prevent sedentarism. Since chronic patients experience loss of autonomy and low self-esteem, it is also important to provide assistance to patients with age related chronic conditions. With these goals in mind, hereafter we overview previous research works and discuss the most relevant strategies.

2.1 Service Robotics

Research interest in service robotics for active aging and health care has grown in the last few decades with potential applications on healthy people, elderly, children or patients. Robotic devices in elderly care [5][6], rehabilitation [7], autism diagnosis and therapy [8] and weight loss applications [9] have been empirically demonstrated to be effective. Hence, robotics raised great expectations on the use of robots as personal assistants. On such robot is the Nursebot platform, able to interact residents, remind or accompany them of an appointment, as well as provide information of interest to that person [10].

Intouch Health deployed their robot in a Neurology Intensive Care Unit. A study suggested improvement in critical care nursing team satisfaction [11]. The robot Paro in Japan (a robot resembling a baby seal, with expressive eyes) was reportedly able to improve the mood of elderly people, and simultaneously reduced stress not only to patients but also to their caregivers [12]. This has been demonstrated more recently to treat some cases of depression suffered by the survivors of the devastating earthquake and tsunami in the northeast coast of Japan in March of 2011.

Several solutions employing devices exist to support self-administration of medicine and manage personal medicine administration [13]. The Kompai robot has been tested for elderly assistance using a diary application for monitoring the medication and give information about daily events [11]. The autom robot is a weight-loss social robot [9] that asks questions concerning what a person ate, or how it exercised. It also provides personalized, helpful suggestions and feedback using facial expressions and a simple touchscreen interface. In Europe, the EMOTE (Robotic Tutors for Empathy based Learning) research project explores the usage of social robots for teaching children, using the NAO robot. This project has shown that the robot appearance, as well as its motion, and functionality, plays a very important role on engaging the attention of the learner [14]. Other authors incorporated the strict functional constraints imposed by complex environments (such as hospitals) and specific groups of users, into the robot design process [15].

2.2 Biomedical Signal Analysis and Human State Estimation

Biomedical signal analysis is nowadays of greatest importance for data interpretation in medicine and biology, providing vital information about the condition and affective/emotional states of subjects. In patients with neuromuscular diseases, a constant monitoring of the patient's condition is necessary [16]. Heart rate variability, respiration, muscular and electrodermal activity signals are extremely important, since they indicate when a muscular crisis is occurring.

Tracking devices are important to infer the human state, such as the posture and motion of the human body during an activity (such as playing a sport or a therapeutic exercise). Usually, several tracking points are used to represent human body joints (with respect to both both position and velocity). Cameras have been used to detect and estimate the pose of human subjects [17] and body parts [18], detect faces [19] and their expressions [20] and, at a close range, detect eye movement and gaze direction [19]. Hidden Markov Models have been successfully used in gait recognition [21].

One approach consists of using anthropometric proportions of human limbs and the characteristics of gait, to achieve view-independent markerless gait analysis [22]. Microsoft's Kinect is a markerless tracking device with an acceptable accuracy in comparison with other motion tracking alternatives [23][24]. It provides full skeleton tracking at low price. It is also easily portable, especially when compared to other solutions requiring special equipment (e.g. markers) on the human body. A large number of applications based on such sensors are addressing some of the difficulties in unsupervised rehabilitation [25][26]. For instance, Gama et al. [27] proposed a Kinect based rehabilitation system that tracks user position. The user sees himself on the screen with overlaying targets representing the desired position. Real-time feedback using visual messages is provided in case of incorrect postures.

2.3 Rehabilitation Systems

Various rehabilitation systems have been proposed to improve patient recovery. Many focus on specific injuries, e.g., stroke [25], or limbs rehabilitation [28][29]. Such systems may have an important impact on patient's rehabilitation on an ambulatory scenario (e.g. at home). Enabling the patient to comfortably exercise at home improves his motivation [25].

A patient's rehabilitation is affected by exercise repetition, expert feedback, and patient's motivation [30]. The repetitive nature of rehabilitation exercises can quickly become boring for a patient [28][31], therefore, there is a need of turning these exercises into something less tedious. Indeed, successful patient recovery depends on adherence to the scheduled planning [32].

Repetitive exercises should be divided into several sub-goals, so the patient achieves incremental success through each repetition. This improves motivation compared to the approach where success is only achieved after finishing the whole task [30]. Feedback can be given in two different ways, during the execution (concurrent feedback) and at the end of exercise execution (terminal feedback) [2]. Concurrent feedback is given in real-time for offering guidance or corrections in exercise execution. It allows the patient to have Knowledge of Performance (KP). Terminal feedback gives patients only Knowledge of Results (KR), since the patient receives feedback after fully executing the task [33][30]. Sigrist [2] suggests a temporal evolution along the recovery phases. It proposes to gradually reduce KP, giving more emphasis to KR, to stimulate patient's autonomy.

2.4 Motor Training on Rehabilitation

The term *exergaming* is used for gaming approaches that motivate players to engage in physical activity. Previous research [34] showed evidence that commercial tools can produce physical, social, and cognitive benefits [35].

Unfortunately, these current tools are not suited to elderly or motor (re)training. Motor rehabilitation, or motor re-learning, is an extensive and demanding process for a patient, requiring discipline. Moving injured body parts may produce discomfort or even significant pain [36]. Physical therapy sessions may be performed several times both at a clinical and at home, or on either one of them. Later on, the patient might have to continue therapy exercises at home [37] to avoid suffering a setback on rehabilitation [25] (or to decrease recovery time). This requires patients to learn the appropriate recovery exercises. Furthermore, these exercises should be executed correctly, to prevent an aggravation of the injury [3].

Repetition of specific movements is important for rehabilitation, whether at a clinic or at home [30]. However, this is one of the main causes of deteriorated rehabilitation at home, since patients tend to get bored and lose focus, due to the repetitive nature of the task [36]. A mobile robot nurse should play a very important role here in order to replace the therapist presence to guide and motivate the patient.

2.5 Augmented Reality

Augmented Reality (AR) is considered a promising technology in the rehabilitation field. Several studies presented evidence for the benefits of employing Augmented Reality (AR) techniques for supporting functional motor recovery [38], enabling effective motor training [39]. AR based approaches potentiate the combination of interesting features such as training customization, extended multimodal feedback, quantifiable therapy measures, extra motivation, among others [40].

Interactive AR applications have been proposed for different applications. Shader Lamps [41] is a seminal work on AR. Its purpose was to augment an existing blank model with computer-generated graphics to make the model exhibit realistic lighting, shadow and even animation effects, thus providing it with characteristics previously inexistent. Dynamic Shader Lamps [42] allows users to interactively change the generated graphics, and to digitally paint onto objects with a stylus.

There are various spatial augmented reality (SAR) projects with different applications. iLamp [43] supports SAR by casting the pre-distorted image of virtual objects from the projector, which can capture the 3D environment based on structured patterns. An interactive SAR system is described in [44] with multiple depth cameras and a projector. The system detects the information of the surrounding environment along with the users motion through depth cameras, and displays images on the surface objects in a planar, real world table for the user to interact with. Pixelflex [45] adopted an array of multiple projectors to make a huge screen space. Automatically self-configured projectors are able to create a huge projection area.

A projection-based information display system was proposed in [46], which displays virtual images in a room with a series of sensors. The robot tracks the user viewpoint with the sensors, and then the robot can generate anamorphic (i.e., projection format in which a distorted image is stretched by an anamorphic projection lens to recreate the original aspect on the viewing screen), properly distorted images for users on flat- surfaces. WARP [47] allows designers to preview materials and finished products by projecting them onto rapid prototype models. The system uses a standard graphical interface, with a keyboard and mouse used for user interface. The projection is not restricted to a fixed area; all feedback is projected onto the tools. Surface Drawing [48] allows a user to sculpt 3D shapes using their hands. Spray modeling [49] uses a mock-up of a physical airbrush to allow the user to sculpt 3D models by spraying matter into a base mesh. The system enhances physical tools by projecting status information onto them allowing the overload of a single tool with several functions.

LightGuide [50] proposed projection mapping onto the user, using his body as a projection screen. Different type of real-time visual cues are projected onto the user's hand to guide him for performing 3D movements. This way, the user is less susceptible to be distracted by external factors.

3 The Augmented Human Assistance Project

This section described the Augmented Human Assistance project. It is presented the project structure of partners, its focus areas, as well as the main challenges and expected impact.

3.1 Project Partners

A consortium of key partners, addressing a large scope of technology fields, forms the AHA project. IST-ID is the project coordinator. The Computer and Robot Vision Lab (Vislab) research group at IST/Institute of Systems and Robotics addresses research on Robotics, Computer Vision, and Cognitive Systems. The Carnegie Mellon University (CMU) team is part of the Quality of Life Technology Centre, at the Robotics Institute, working on Artificial Intelligence and Human Computer Interaction. The M-ITI NeuroRehabLab at University of Madeira addresses Serious Games, Interactive Technology, and Rehabilitation. Two groups are specialized on biosignals data acquisition and processing. The team at FCT/UNL works on Signal Processing, Machine Learning, and Electrophysiology. And PLUX Biosignals, a company that creates innovative solutions for Sports, Healthcare and Research, by integrating biosignals processing and miniaturized wireless sensor devices. YDreamsRobotics is another company specialized in robotics, mechatronics and the internet of things, which is addressing Augmented Reality, Robotics Design, and Haptic Feedback, for building a therapeutic robot and for providing patient feedback through actuation. Finally, the Interdisciplinary Centre for the Study of Human Performance (CIPER) at Faculdade de Motricidade Humana (FMH) is specialized in the main areas addressed by the project, namely Sports Science, Therapeutic exercises, and Human Function and Performance.

The project targets three main environments (clinical, sports, and home assistance), as described in the next subsection. Supporting external partners collaborate by providing solution requirements, on-going feedback, as well as facilities for empirical evaluation, as described in Table 1.

Table 1. External partners and their focus areas on the project.

Area	External partners
Rehabilitation	*HealthSouth of Sewickley* *Clinical Physiology Translational Unit, IMM*
Sports	*Associação da Madeira de Desporto Para Todos* *Via Activa Animação Turistica*
Elderly	*Comfort Keepers*
Public Administration	*Camara Municipal da Ponta do Sol*

3.2 Project Focus Areas

The AHA project addresses three main target groups, as shown in Fig. 1. The Elderly People group, addressed both on a clinical setting as well as at home. The goal is to enable simultaneously sustainable care and active aging. New technologies are proposed, such as medicine and medical equipment delivery by a mobile robot, and remote assistance on therapeutic exercises using multimodal feedback and augmented reality. Remote assistance on therapeutic exercises is also proposed for a second target group, those with motor deficits. Serious games, emotional and haptic feedback, are among the technologies proposed to support patients on their recovery. Finally, the project addresses sports for supporting a healthy lifestyle. It aims to improve athletes' performance, and to facilitate their learning, training and performance evaluation using new technologies.

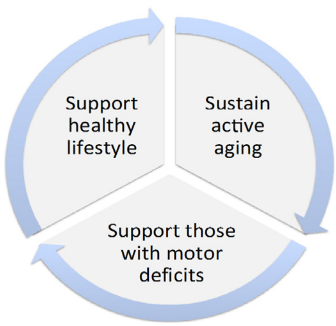


Fig. 1. User groups targeted by AHA: patients, athletes, and elderly people.

The three main target environments, namely clinical, sports facility, and home assistance at a senior house, have different characteristics.

The **clinical environment** is more accessible but it is often a more complex environment. A virtual coach module is proposed to interact with the patient, guiding him throughout the exercises and providing positive and corrective feedback.

Sports facility is characterized by large indoor open spaces where robot navigation is facilitated. The Robotic Assistance Platform will be able to identify an adequate surface for the projection of the Augmented Reality Training Games, and provide its users with the gaming training experience. Users will be able to challenge remote users to a competitive game, while playing the training games.

At a **senior house**, the Robotic Assistance Platform will visit some of the residents at specific times. The robot reminds the elder about the pills he needs to take, and also asks him to take heart rate measurements with the on board sensors of the robot. Furthermore, it will help the elder through his/ her gaming exercises, and it will provide a feedback summary on performance, making this information also remotely available to their clinicians.

3.3 Innovations and Impact

The AHA project proposes the development of novel robotics assistive platforms for health exercise program management. Several functionalities will be provided, such as user engagement, execution monitoring, and supporting therapists in patients' rehabilitation tasks. These functionalities will be developed considering the target user groups, with the aim to promote a healthy lifestyle, a sustainable active aging of the population, and supporting those with motor deficits. This should be accomplished using several interdisciplinary technologies, and combining these in innovative ways. For instance, it is proposed advanced "*exergaming*" and *assistive technologies* based on human-computer interaction, robotics, serious games, multimodal sensing, physiological computing, among other fields. The goal is to employ technology to help to prevent sedentarism related diseases, to facilitate therapy of chronic conditions related to aging and rehabilitation of motor deficits. Therefore, the project will tackle users with special needs, focusing on elderly and patients with motor deficits, as well as on athletes. It will provide customization and personalized tools for increasing motivation and engagement, using augmented reality, online feedback, gamification, social networking, and interactive interfaces. It is also proposed a better measurement and monitoring of user condition through multi-modal sensing (biosensors, computer vision) and multi-modal feedback (haptic devices, sound feedback, augmented reality). Augmented assistance will be provided by a nurse mobile robotic platform, together with virtual coaching, for guiding patients in their exercises and daily routines. The project also proposes to support clinicians through personalized user profiles and advanced display of information.

The project outcomes aim to impact significantly different entities:

- **Society:** Reduce effects of sedentarism related diseases and aging conditions.
- **Elderly:** Increase physical fitness, independence, autonomy, self-esteem.
- **Patients:** Can exercise independently at home, adherence to schedule.
- **Clinicians:** Follow patient progress remotely, customize therapies.

- **Science & Technology:** New algorithms and systems for eHealth technologies.
- **Education:** Formation of highly skilled human resources in close cooperation with technology integrators and end-users.
- **Companies:** Close to market technologies; large exploitation opportunities.

3.4 WorkPlan

AHA project work plan is shown in Fig. 2. It represents the platforms, the modules to be integrated on them, as well as the interactions among modules.

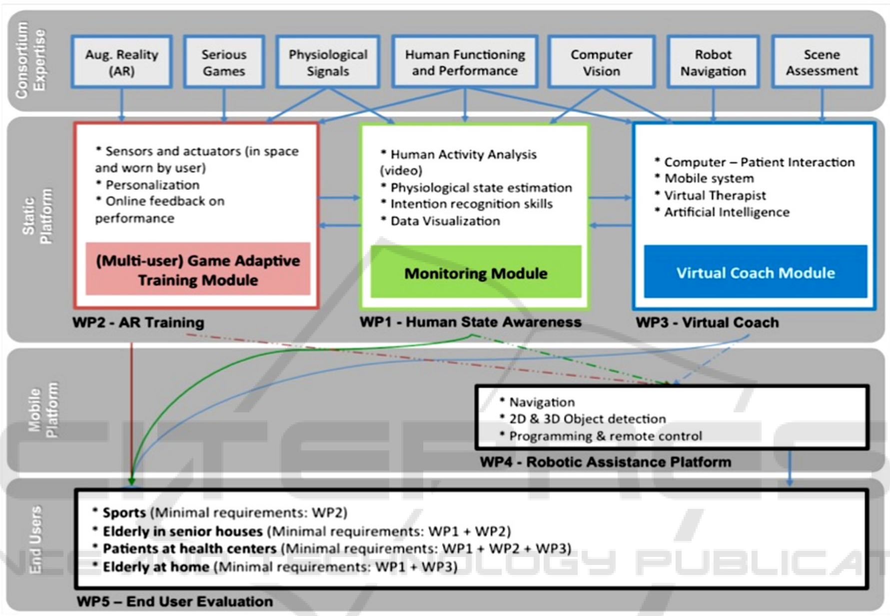


Fig. 2. Project workplan according to the different workpackages.

Human State Estimation (WP1) employs state of the art wearable technology and training, for the integration of vision based activity monitoring and emotion detection modules into a core technological and scientific component of the Robotic Assistant Platform - the human monitoring module. Augmented Reality Training (WP2) integrates AR technology that will serve as the basis for the development of a set of novel serious games for physical training. Integration of Virtual Coaches (WP3) on a physical context is aimed for the improvement of the quality of life of those with special needs. It includes (see fig. 3) user interaction aspects of the system, as well as interactions of the virtual coach and the human monitoring modules. Robotic Assistance Platform (WP4) consists of the sensing and software robot architecture. It includes integration of the monitoring, AR training, and virtual coach modules into the final Robotic Assistive Platform. User evaluation (WP5) will consist of the solution's experimental validation with real data on a clinical context.

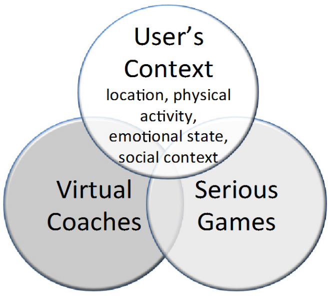


Fig. 3. Integration of interdisciplinary technologies on the AHA project.

4 Robot Design for Human Augmented Assistance

Recently, there is a trend for bringing robots into operations among people, helping people. Elderly people, athletes and patients constitute challenging groups for robot interaction. Addressing athletes' needs is challenging due to their energy and high performance requirements. Elderly people and patients pose strong safety concerns. These challenges need to be tackled on the design process. This is essential for the robots to be able to operate safely, while interacting socially with people.

Gonçalves and Arsenio [15] proposed a formal design process for building socially interacting robots within a group of children with special needs in a hospital environment. The design takes into consideration the input of the project partners. This is incorporated on the robot specifications during the development process. Robots design needs to account with several security factors. Under the scope of the AHA project, we have been applying this process to the design of mobile robots targeting new user groups. This "nurse" mobile robot, although posing similar challenges as the ones described by Gonçalves and Arsenio [15], also adds new requirements. Elderly people, athletes and patients poses specific requirements that often differ from those for children in hospitals. Concerning security factors and human-robot interaction features (see Fig. 4):

- Sick children often carry medical equipment carried, like wheeled structure to carry serum bags. This still applies to some groups of elderly people. It may also apply in less extent to patients on recovery from physical injury.
- No sharp surfaces that may cause injury to children. Although a less stringent requirement for elderly people and patients, it is still an important issue.
- Avoid geometries that may invite children to step up the vehicle or insert fingers on holes. This is not relevant for the group of users under consideration.
- Emotional expressions and engagement behaviors. A nurse robot targeting adults should pose a professional stance, compared to a more character like concept for children.
- Avoid inspiring fear and disgust: should instead induce comfort and trust, which applies for all user groups (except in specific niches, such as military)
- An appealing aesthetics to children often has a different meaning than for an adult.

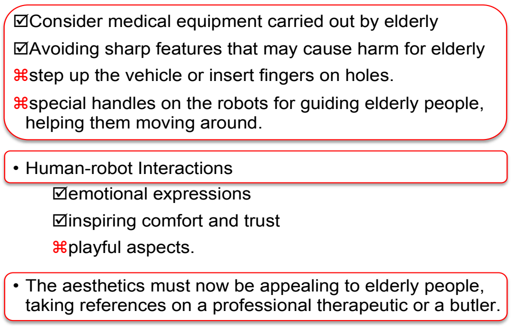


Fig. 4. Comparative analysis of security factors and human-robot interaction features, for robots to interact with children versus elderly people.

4.1 Shell Development Process

The shell development process is divided into several stages, and here briefly resumed. It started by an analysis of the environment and the way elderly people, athletes and patients should interact with the robots. At this stage we also performed research related to existing robots, and "soft" and "clean" materials prone to be used at clinical, hospital and sport facilities. With this information we concluded that rounded shapes, soft materials, and neutral, light colors should be used, together with active colors (red) on very small information symbols.

Different options were analyzed taking into account aesthetic properties, emotional feelings provoked by the robot, its the actual expression, feasibility constraints and functionality inherent to the robot, so that it could perform the envisioned tasks.

Afterwards, the material developed so far became the basis for the CAD model development. The CAD model and photo-real imagery was also developed taking into account the different production methods available, the assembly procedure, the maintenance operations, the cost involved, and of course the aesthetics and functional requirements defined at the early stages.

4.2 Operational Environment Analysis

The shell development process started by performing an analysis of the environments where the robots will operate, including the deployment space, targeted groups of people, and tasks to be executed by the robot, in order to define a set of features taking references on other existing and relevant systems.

The features to apply include rounded shapes and soft touch feeling materials, due to the danger of fall by elderly people or patients recovering from physical injury. This issue is also present in sport facilities due to high energy placed into activities. The robots were given a dynamic stance, although this requirement has much more relevance on sport facilities than on the senior houses or hospital/clinical environments.

The features to avoid include mechanical type shapes, which are more aggressive, and not appealing for the target user groups. Exposed components, salient from the robot body, are potentially dangerous and should be avoided as well. Robots outfit should inspire users for interacting with them.

4.3 Ergonomics and Human Factors

Lets now consider the ergonomics and user factors, since problems can arise from bad positioning and dimensioning of the robot components.

According to Fig. 5, we opted for: i) a non-threatening overall stance; ii) no arms; iii) touch screen for better conveying user feedback, as well as to provide a simpler user interface for elderly people.

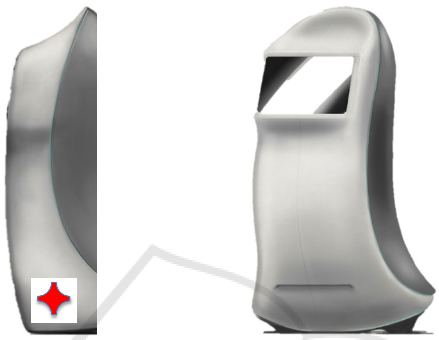


Fig. 5. Mobile robot platform – the nurse.

Similarly to the Monarch robots (see Fig. 6), these should have a modern and cool appearance. And since they operate in a hospital setting, there is a preference for lighter colors (such as white color, common in hospitals), since it is easier to identify dirty surfaces on robot and to clean them. Contrary to the Monarch robots, there is no multifunctional face on the nurse robots.

Fig. 6. Mobile robot platform for children at hospitals, developed under the Monarch project [15]. In contrast to the professional look and feel for the nurse robot, the monarch robots are character-like, but not resembling any particular known artificial character.

5 Assistance Robotics for Augmented Health

Novel approaches have taken Augmented Reality (AR) beyond traditional body-worn or hand-held displays, pushing such capabilities into mobile robots [51]. Spatial Augmented Reality (SAR) uses digital projectors to render virtual objects onto 3D objects located in the robot's navigation environment. When mounting digital projectors on robots, this collaboration paves the way for unique Human-Robot Interactions (HRI) that otherwise would not be possible. This is especially useful for supporting patients performing recovery exercises, or for providing additional information to elderly people (e.g. time for medicine intake).

5.1 Augmented Reality for Robotic Assistants

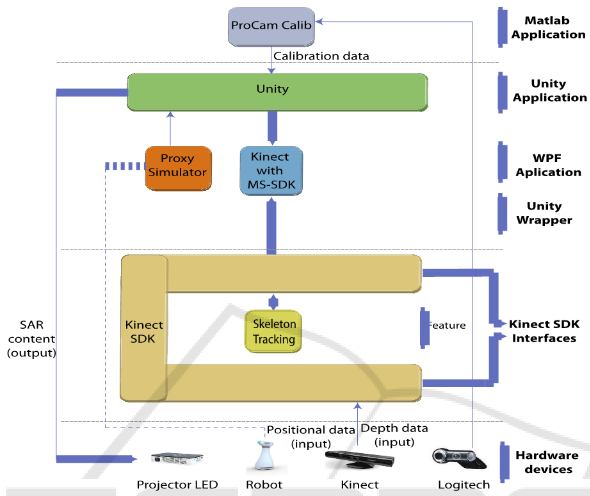


Fig. 7. Architecture of the proposed solution. The line in dash represents the connection to the mobile robot localization system.

The architecture for SAR enabled robots is represented in Fig. 7. It is comprised of six main categories:

- The hardware includes a projector, a camera, and a Kinect depth camera for human-robot interactions;
- The Kinect SDK interface, which allows direct access to Kinects RGB and depth sensors. One of Kinects' key features we used was skeleton tracking;
- Unity wrapper, which enables the use of Kinect SDK internal functions within Unity;
- A Windows Presentation Foundation application (WPF) was developed in order to simulate positional information retrieved from a robot localization system;
- Unity, the game engine on top of which the main applications were developed;
- The camera-projector calibration application, which makes use of ProCamCalib, developed on Matlab.

A collection of modules (given by a series of scripts in Unity) were designed to perform specific tasks:

- Homography matrix update: updates the matrix associated with each projection scene and apply that transformation in OpenGL's vertex pipeline;
- Tracking: Controlling each projection surface position in the virtual scene;
- Intrinsic Setting: Alters Unity's default projection matrix so that the values obtained from the projection calibration process can be properly applied;

- Update Unity's camera position: based on localization (position/pose) information provided by an exterior application (on the robot or elsewhere);
- Save and load: of projection surface positional data from an XML file;
- Human-Robot Virtual Interface (HRVI): Updates the game logic of an interactive AR game based on input received from Kinect's skeleton tracking information.

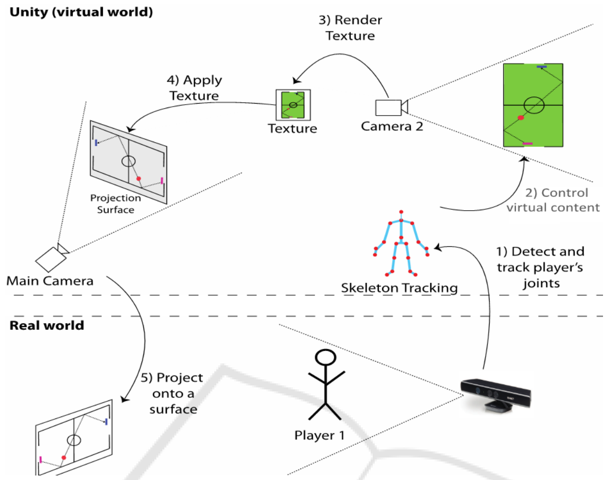


Fig. 8. Human interactions. One or two humans are tracked simultaneously using Kinect's skeleton tracking (step 1). The corresponding joint, for each player, controls the respective virtual object (step 2). Camera 2 renders the texture containing the view of the camera (step 3) that is then applied to one of the projection surfaces and updated in runtime (step 4). The final step can now take place: project onto one real world surface (step 5).

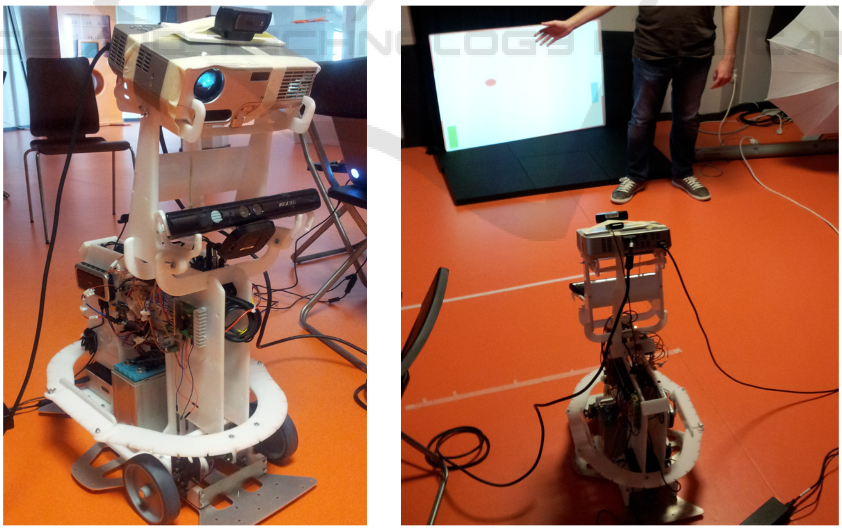


Fig. 9. Augmented reality on Wheels – Content is projected onto multiple surfaces in order to help user perform actions, or to play games with users (such as the Air Hockey game, as shown in the right image).

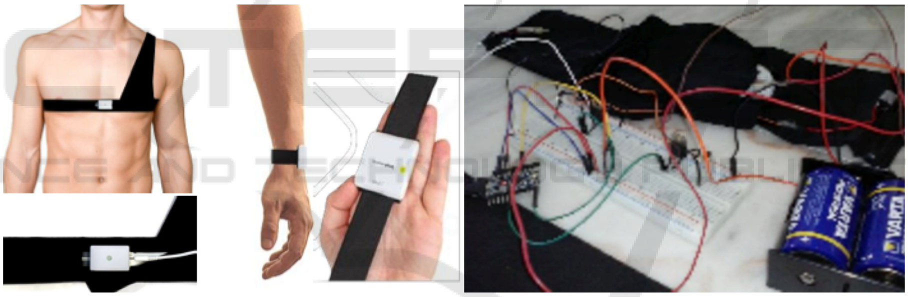
The goal is to project augmented reality content according to objects physics, or other entities. As such, we introduce the human interactions feedback in order to adapt the augmented reality content, and to achieve virtual-real objects integrated behavior, as represented in Fig. 8.

Hence, the application integrates augmented reality information, with projection distortion compensation, and human gestures recognition to enable interactions between people and undistorted augmented reality content. Virtual content is projected onto the real world where humans interact with such content through movements (see Fig. 9), as detected by Microsoft Kinect's skeleton tracking feature.

5.2 Haptic Feedback

The AHA project is also investigating the usage of robotic elements, behind the nurse mobile robot. Besides biosignal sensors on the human body (see Fig. 10a), actuators are being investigated to provide real-time feedback concerning movements to be executes, or corrections to imperfections on the execution of the exercises. Such actuators include an elastic sleeve (see Fig. 10b), enabled with a sensor to measure joint rotation and an array of motors to provide haptic feedback.

Currently two sensors have been tested: a Flex Sensor (see Fig. 11), a flexible strip that senses rotation, as well inertial sensor based on gyroscope and accelerometer. Other devices are planned to be tested, such as mobile phone gadgets (like Pebble), that are able to generate controlled vibrations.



a) b)

Fig. 10. a)Biosignal sensing devices, to acquire data concerning biological variables on the human body; b)Elastic sleeve prototype with a SensorFlex and two vibration motors for haptic feedback.

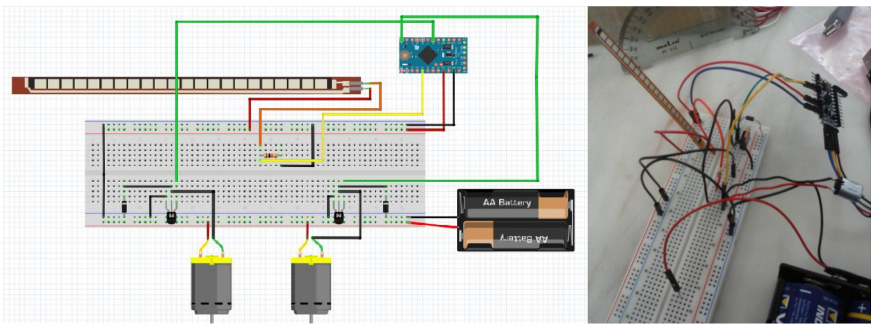


Fig. 11. Prototype schematics and testing, using a Flex sensor and two motors.

6 Conclusions and Discussion

This chapter presented some of the robotics technologies being developed for Augmented Health Assistance, under the scope of the AHA project.

It has been shown that one of the problems with remote rehabilitation is the correct execution of recovery exercises by the patient. Furthermore, due to the repetitive nature of such movements, there is consequently a motivation problem for keeping the patient engaged with the exercise program. The first issue can be addressed by the usage of augmented reality and haptic feedback for providing corrective feedback to the patient. The later issue can be addressed employing nurse robots. These replace the role of the human therapeutic on providing advice and motivation. The nurse robot also plays a very important role on supporting elderly people on their daily activities. For instance, these robots can take medicine to elderly at intake times, or make available medical equipment.

The AHA project proposed to develop new algorithms, and virtual as well as robotic systems for eHealth technologies. It expects to have a significant impact on the health and sport sectors, by employing interdisciplinary technologies at the service of elderly, athletes and patients with physical injury (both at home or on a clinical/hospital environment). Innovative approaches will bring benefits to society, by reducing negative effects of sedentarism, such as related diseases and aging conditions. It proposes as well to improve the quality of life of elderly people. Besides developing a mobile robot acting as a companion nurse to elderly (reducing the problem of elderly isolation and loneliness), it also aims to increase elderly physical fitness, independence from human nurses and family, and consequently improving their autonomy and self-esteem.

Concerning patients in recovery of physical injuries, the AHA project proposes to improve these patients quality of life. This is acomplished by enabling them to perform independently exercises at home, while receiving corrective feedback and motivational incentive to adhere to scheduled exercises.

The project promotes however to keep clinicians in the loop (even remotely) to follow patient progress. The clinician is also able to customize patients therapies, as well as to provide of-line, or real-time, corrections to therapies or exercise execution.

The combination of a large set of interdisciplinary technologies is expected to enable a new level of health assistance to different user groups, improving their quality of life and reducing government economic burden.

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