User-centered Implementation of Rehabilitation Exercising on an Assistive Robotic Platform

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Abstract.
The paper focuses on the method and steps implementing a suite of rehabilitation exercises on an assistive robotic platform. The suite is based on extensive user needs identification procedures and consultation with medical and rehabilitation experts. For the design of the human-robot interaction (HRI) component of the platform, the user centered approach was adopted, which in this case employed a range of multimodal interaction facilities including a free user-robot dialogue, visual and speech signals.

Keywords: Human-Robot Interaction; Multimodal HRI design; User-centered design; Assistive HRI; User group recruitment methodology; Rehabilitation strategy

1 Introduction

A direct consequence of the rapid change in demographic data associated with the aging of populations in modern developed societies is the increase of the population percentage that faces different degrees of mobility and cognitive problems apart from those caused by chronic related diseases and/or accidents [1,2]. Under this perspective, the need to improve the quality of daily living by supporting mobility and vitality and to enhance independent living of individuals with motor limitations [3] has inspired technological solutions towards developing intelligent active mobility assistance robots for indoor environments, which should provide user-centered, context-adaptive and natural support [4-6].

The role of personal care robots is multiple, covering physical, sensorial and cognitive assistance, health and behavior monitoring, and companionship. The necessity for robotic assistants that could help with elderly mobility and rehabilitation is clear. Almost twenty years have passed since the first robotic rollators [7-12], as well as sensorial and cognitive assistance devices for the elderly [13] emerged. However, most intelligent assistive platform designs aim to solve only specific problems, while considerable research effort has focused on analysing anthropometric data from various sensors for assessing human state and, eventually, control a robotic platform.

The i-Walk project aims at developing and testing a new pioneering robotic system that will provide a range of mobility and cognitive support functions for the targeted population groups. To do so, it builds upon the experience gained from research in the framework of the previously accomplished MOBOT[1] project [14], targeting the development of a flexible platform of robotic technologies adapted on a rollator walker, which will provide active assistance, incorporating the ability to acquire knowledge and adapt to the environment, personalized to each individual user, in order to support mobility and enhance health and vitality. To achieve this goal, several methodologies are currently being developed, which are foreseen to be synergistically utilized. These include:

- Processing of multi-sensory and physiological signals and identification of actions for the monitoring, analysis and prediction of human gait and other actions of the user.
- Behavioral and user-adaptive robot control and autonomous robot navigation for the dynamic approach of the user and the interactive co-occurrence combined also with voice guidance
- Human-robot communication, including speech synthesis and recognition technologies and a virtual assistant (avatar) to enhance the naturalness of communication.

The i-Walk project is researching the enhancement of these technologies and their application to meet major social needs. One of the project's major characteristics is the synergy of the technological achievements with medical services that concern rehabilitation, aiming at interacting with target audiences (i.e. patients) to design and integrate systems based on the needs of potential users.

Overall, the i-Walk project aims to support elderly people and patients with mobility and/or cognitive inabilities, by achieving:

- More effective patient mobilization in the clinical environment of a rehabilitation centre, reducing the burden on clinical staff and increasing the efficiency of rehabilitation programs, and
- Continuous support at home through technologies monitoring patients' progress, but also their mobilization through interfaces of cognitive and physical support, increasing their degree of independence and improving their quality of life.

[1] http://www.mobot-project.eu/

Fig. 1. The i-Walk concept components

Here, we focus on the user-centered characteristics of the platform, which serve rehabilitation purposes. Emphasis is placed on the design and implementation of the human-robot interaction component, which derives from extensive research on defining end-user needs.

2 Definition of user group and system specifications

The investigation of user needs followed standard procedures which were developed in two stages. During the first stage, user needs were collected by means of organizing workshops with potential users and rehabilitation experts, which involved interviews as well as questionnaires.

At the second stage, the target group was defined as entailing people with a functional impairment in movement due to a neurological condition (e.g. Parkinson's Disease or Multiple Sclerosis) and/or elderly people and/or people with cognitive impairment. The state of cognitive and motor ability of the users were the two main inclusion criteria to the project target group.

The data collection took place at Diaplasis Rehabilitation Center in Kalamata, Greece, where participants were patients attending rehabilitation sessions either as in-patients or as out patients.

After the evaluation of the medical files by clinical experts, 21 patients were selected, based on their medical history, to participate in the required tests and provide feedback during the design and implementation stages, evaluate the system’s components and, finally, use the robotic walking device experimentally. All participants were informed about the research stages and their voluntary participation by the clinical experts. Subsequently, their cognitive status was imprinted and they were subjected to functional tests to evaluate their mobility, mainly in terms of balance and gait. Patients who met the inclusion criteria (Table 1) conducted tests with the robotic i-Walk platform according to scheduled appointments. The process began with the written consent of the participants and the provision of specific information about the i-Walk research program for the collection and processing of personal data.

User Specifications were based on user input on 18 YES/NO questions and free discussion, which targeted the definition of functional and interaction characteristics of a robotic rollator that users anticipated to be necessarily incorporated in such a device. As expected, basic features of a walking support device of the rollator type

were prevalent among user priorities. However, a surprising finding was that features such as the availability of rehabilitation exercises have proven to be of similar importance according to user preferences.
User specifications were completed through consultation sessions with expert groups, where similar procedures (free discussion and questionnaires) completed the picture of the features users felt were necessary to incorporate in system functional and interaction design.

Table 1: Inclusion Criteria to data collection and platform evaluation user group

INCLUSION CRITERIA
Mini Mental State Examination-MMSE ≥ 17
4M Gait Speed Test, u < 0.6 m/s
Five-time chair sit-to-stand test (5-STS), t >16.7 sec.

Furthermore, this work also resulted in the definition of the use case scenarios, which form the testbed for the platform functionality and interaction characteristics. The adopted scenarios involve:

- *Walking with a rollator*. This scenario covers basic rehabilitation needs of supporting patients with ambulation problems.
- *Rehabilitation Exercises*. The users are instructed to perform a suite of rehabilitation exercises in seated and standing position including hand raises, torso turns, sit-to-stand transfers, etc.
- *Use of the elevator*. This scenario targets the support of patients' independent living.
- *Transfer to bathroom*. This scenario covers needs of patients with mobility problems in basic activities of daily life.

The user group which provided the initial input on the i-Walk HRI design, consisted of 13 adults (6 female and 7 male subjects) from 50 to 86 years of age, also including one adult of 25 years old. All subjects experienced comparable functional impairments deriving from different pathologies such as Parkinson's disease, multiple sclerosis, stroke, hip fracture and rheumatologic disorders. All subjects have been users of walking aids such as walker, cane, quad cane and rollator [15,16]. The screening process followed to extract the participants group made use of several evaluation scales including the MMSE scale for mental status evaluation, the BERG [17] and TUG scales for balance, dynamic balance and mobility evaluation, as well as the TINETTI POMA scale for gait and balance evaluation. It also made use of two tests: (i) the Chair-Stand Test, which evaluates lower limb and corps strength [18], and (ii) the Gait-Speed Test [19], also used for evaluating mobility. This complex screening method, on the one hand, allowed for mapping the targeted user population and, on the other hand, enabled collection of data well fitted within this population spectrum.

Fig. 2. The i-Walk passive rollator used for initial testing of HRI design

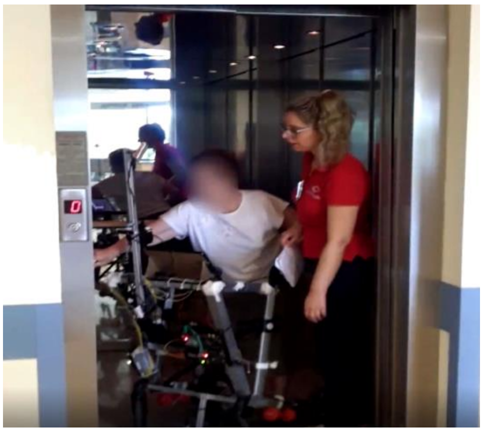

Fig. 3. Trials of the preliminary edition of the i-walk aiming at user needs definition

3 Design and implementation of the rehabilitation exercising suites

The i-Walk platform has been designed to fill a range of user needs, by combining multisensory streams to perform a multitask understanding of human behavior, including speech intention recognition, generalized human activity recognition, and mobility analysis. The multimodal interaction framework of i-Walk [20] aims to provide natural communication but also essential feedback to the user and the medical expert regarding the progress of an applied rehabilitation program, in a way close to that of a personal carer.

Furthermore, the i-Walk communication ecosystem incorporates a set of multimodal interaction options, which intent to raise user trust and engagement, as a result of the user-centered approach followed in designing the user-platform interaction environment.

3.1 HRI design based on user needs

Since the platform is designed to perform as a rehabilitation aid to patients with motion problems, focus has been placed on two major functionalities incorporated in the platform interaction design. That is, (i) the walking assistant, and (ii) the rehabilitation exercises instructor. The design of both these modules has been driven by user needs, as identified and prioritized via the procedures described in section 2.

When designing the rehabilitation exercises module, a number of parameters had to be taken into account, which led to exercise grouping and the building of the multimodal interaction dialogue system accompanying their presentation.

Fig. 4. Execution of rehabilitation program, aided by audio-visual instructions

Furthermore, after consultation with the team of experts, issues relating to the appearance and performance of the virtual instructor, as well as its placement in the most appropriate virtual environment, should also be dealt with, since these have been elements significant for the perception of the message sent to the user. Under this perspective, avatars of manga or transformer type have been excluded. Similarly, virtual environments incorporating various sound or visual effects and/or decorative elements have been considered inappropriate.

3.2 Virtual instructor implementation

The principal technologies that have been utilized for the implementation of the virtual instructor are motion capture and real-time rendering. We have followed a motion capture pipeline process that is similar to the ones that we meet for the implementation of animated characters in video games and films. It is important to mention that the rendered output is done in Unreal game engine that in combination with a high-end graphics card and CPU allows renderings of Full High Definition (1080p) and high frequency of frames per second to be completed in minutes instead of hours that usually happen in 3D softwares. The series of processes that contribute to the pre-mentioned implementation are mentioned below and are schematically depicted in Figure 5:

Fig. 5. Pipeline of processes resulting to the virtual instructor performance

Original Content: With the guidance of rehabilitation experts, we captured in video the actual exercises that need to be presented to the patient. These have been used as reference for the motion capture session.

Motion capture: We setup a markerless optical motion capture system consisting of two Kinect V2 devices, each of which was connected to a computer in a local network, where the first one acted as a “master” and the second one as a “slave” computer. A rehabilitation expert reproduced the exercises having as reference the pre-recorded videos mentioned in the previous step. Both Kinect V2 devices captured the movement of the subject and the slave computer provided the master computer with motion data. The combination of these two camera outputs was fused to a virtual skeleton that was constructed accordingly. The two Kinect V2 devices were set up against each other in order to capture data about the entire body of the subject and avoid data errors or offsets due to occlusion of body parts. This is the point where a virtual skeleton animation was constructed, while its motion data was still uncleaned; this means that there would be possible offsets in the animated movement, for instance, an arm would visually clash with the main body.

Retargeting: We chose a rigged and skinned 3D model representing a user-friendly virtual instructor and we attached the movement onto it so as to execute the animation. In order to do this, we ensured that the 3D model mesh corresponded to the needs of our use scenarios. In addition, since the mesh itself is not movable, it was mandatory to attach a rig into it. A rig represents a hierarchy of virtual bones that correspond to the standard body-type of a human. Thus, the skinning method is the procedure of attaching the 3D mesh into the rig. The weights of the skins are configured to each body part, and they correspond to how much the body part can bend. Finally, it is important to clarify that the bone hierarchy of the 3D model's rig is the same or similar with the virtual skeleton of the animation in order to have a successful retargeting.

Cleanup: This is the stage where the virtual skeleton is imported into a 3D software in order to edit the motion data that is problematic. A control rig is created in order to have access to the Inverse Kinematics/Forward Kinematics (IK/FK) of the virtual skeleton, and thus to edit its movement data more efficiently through positional and rotational curves. An fbx format, the most compatible one for inter-platform utilization, is exported.

Fig. 6. Virtual instructor implementation following user specifications; avatar viewing options enable disambiguation of the movements to be im

Environment in Game Engine: The animated 3D avatar is imported to the Game Engine, where a virtual scene is constructed that is consistent to the usability scenario. In our case, we developed a well-lit, minimal room that allows the user to focus exclusively to the virtual character and, at the same time, feel that they are in an exercise room. For each exercise, the camera is focused and moves accordingly to the dedicated area of the body that is exercised.

Rendering: The fact that this scene is implemented in a game engine indicates that it runs as a real-time application and, following specific actions, it executes the corresponding animation of exercise at that moment. However, for the time being, we decided to have pre-rendered animations reproduced according to the needs of the patients. Since the visualization can be reproduced in real time, in high quality and in fps format, rendering to a video format can be completed within minutes instead of hours for an output of FHD or 2K quality and 60 fps or 120 fps.itated by end users.

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4 Conclusion

Cognitive and robotic architectures may be able to provide advanced interactive capabilities with humans and influence the usability and functionality of a resulting system, thus, contributing to its quality of services. Such systems may not only integrate multiple advanced cognitive abilities, but also employ methods that are extendible to various other robotic and non-robotic applications required in assisting humans with mobility limitations [21]. Since systems aiming to address the requirement of high user trust [22] and acceptance seem to fail in respect to user engagement, user-centered system design incorporating “natural”, “intelligent” ways of human-machine communication is becoming obligatory.

The current goal is to bring HRI modeling further by: (i) fully exploiting information derived from patients’ everyday routines as regards the range of both physical and mental functionalities available and tasks to be accomplished, and (ii) augmenting the device’s communication capabilities, based on the actual linguistic and embodied interaction patterns used by the targeted user group in real use environments.

Beyond any short- and mid-term goals, the long term goal should be set towards increasing user engagement with a given assistive device for a longer period, which is also the perspective underlying the i-Walk services design. In this line, extensive evaluation with end users has been planned for all components of the i-Walk platform. Subjective and objective user evaluation results will be reported as soon as related data analysis is available.

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