Enhancing awareness and personification by virtual reality and multimedia means in post-stroke patients during rehabilitation

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***Abstract*—The use of mechanical/robotic devices and of IT based applications in the post-stroke rehabilitation is one of the main challenges in applied research in health sector. Among the wide spectrum of systems, it seems that the focus is still much on the system itself, as a technological whole, and less on the key actor, that is the patient. In this paper a supporting system for post-stroke rehabilitation, based on a 2D/3D real time interface, is presented. It aims at enhancing the point of view of the patients by showing them the movements they are performing through an avatar and by presenting some qualitative aspects of the exercises that can help the patients to be more aware of, and eventually improve, their performance.**

Keywords—stroke; rehabilitation; patient; virtual reality; interface; communication; coginfocom

I. INTRODUCTION

It is since several years that the applied research is working hard in the field of new methodologies for supporting the stroke patients in their rehabilitation programs. One of the aims of the research is to integrate, or substitute, the classical rehabilitation exercises with the help of technological means that can support patients while they perform the rehabilitation tasks. In this context, two different paths can be outlined: the development of robotic devices for addressing and stimulating the movements done by the patient [1] and the development of real time and interactive games [2] [3] as a key of motivation based on engagement and competition [4].

The robotic devices, and more in general the mechanical devices, allow the patient to perform very constrained movements for a large number of times with a high degree of repeatability by recruiting motor units with high efficiency and precision [5] [6]. Moreover, it is possible to add to robotic devices a wide range of different sensors for tracking various observable quantities that can be further processed [7]. On the other hand, a patient undergone a rehabilitative treatment with such approach, discloses some psychological issues, as boredom and lack of motivation, due to the repetitiveness of tasks over the time [8].

The dedicated interactive games want to offer different features with the purpose of increasing the engagement by proposing activities in order to entertain the patients. This thing is a point because it was proved that a deep involvement of patients in the rehabilitation process makes them recover better and faster [9]. Moreover, these digital systems consider also the problem of cognitive lack by proposing rehabilitation exercises aimed at stimulating the recovering of cognitive ability. Developers put an important focus on the game patients have to play in terms of theme of the game itself, of scoring, of adaptation of difficulty level and so on [10] [11]. Patients have to face such games with often no regard for the quality of the movement and, in some cases, for the ultimate goal of the rehabilitation: relearn to perform daily actions like eating or getting far objects [12].

Solutions in which patients play a game, with the presence of both a physical device and a digital environment, are rare [4] [6] [13]. The few existing examples, where digital environment and robotic devices work together, usually consider latter only as the game controller, just like a keyboard or a joystick. Such approach seems to assume that if the aim of a proposed task is reached, movements are performed correctly or at least according to the intentions. No particular attention seems to be paid on the quality of the movements performed, as direction and/or intensity and the feelings of the patient regarding the overall procedure. Consequently, without the constant support of a human therapist some aspects may not fall in the awareness of the patient, because of their nature or due to the patient impairments. Therefore, patients should be kept informed about what they are doing and how well they are performing in order to make them and robots feeling closer to each other.

We hypothesize that a system capable to provide the patients with a well-studied set of information, weighed on their psychological and physical state, about their performance, could be a good mean to improve the patient awareness and (partially) substitute the human therapist during the rehabilitation with a robotic device. In this paper we present a system (let's call it *REAPP*) in which cognitive enhancements and ways of representations have been analyzed and designed in order achieve these goals. The target users of the system are patients that had a stroke since at least six months (chronic condition), with the upper limb impaired but with a good residual cognitive condition.

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II. System Design

The REAPP extends an already existing setting of robot aided rehabilitation system, located at the Villa Beretta Hospital (Costamasnaga, Lecco, Italy), where the post-stroke patients with impairment at upper limb follow a rehabilitation program [14] [15]. Such setting is composed by an industrial robot (Mitsubishi PA10) with seven degrees of freedom with a force sensor (ATI Industrial Automation Mini45-E Transducer) installed on its end-effector. The patients do the exercises with the robot by holding its end-effector while the robotic arm moves, driven by a specific computer program. The patients can follow the device movements (passive mode) or can actively participate exerting a force on the end-effector (active mode). The driving movements are the "hand to mouth" and the "reaching", which were chosen among the typical rehabilitation exercises since they represent common gestures in daily life and since they involve both the shoulder and the elbow joints [16] [17]. At present, an assistant instructs and corrects the patients during the therapy session, by providing them verbal information. REAPP is an add-on to the above setting and it consists in a software application that provides two different graphical user interfaces (GUI) to be shown on two different screens. One screen, with audio speakers, is placed in front of the patient. The second screen shows a GUI that is used by the therapist. The application receives in real time a stream of data about the actions and the performances of the patient, processes them and provides a digital environment (2D and 3D) where a set of audio and visual elements (widgets), that are meaningful for the patients' understanding, are displayed (Fig. 1 and Fig. 2). The self-evaluation tests and the behavior of the patient during the rehabilitation sessions are stored in a database that can be looked up for further investigations.

The widgets are the way the REAPP focuses the attention on:

- The evaluation of the psycho-physical state of the patient before and after the session (*tell us how you are today*).
- The representation of the patient body (*look at yourself*).
- The identification of wrong postures and strategies (*look at your posture*).
- The transfer of the rehabilitation gestures to the daily life context (*imagine a real life situation*).
- The punctual advices and encouragements given to the patients (*correction and motivation*).

On the patients side, the act of understanding what they are doing can be a good point for making them aware and for correcting or addressing their approach, their intentions and their movements while doing the exercise [18].

Now we describe the key points that, with this new setting, have to be emphasized to the patient.

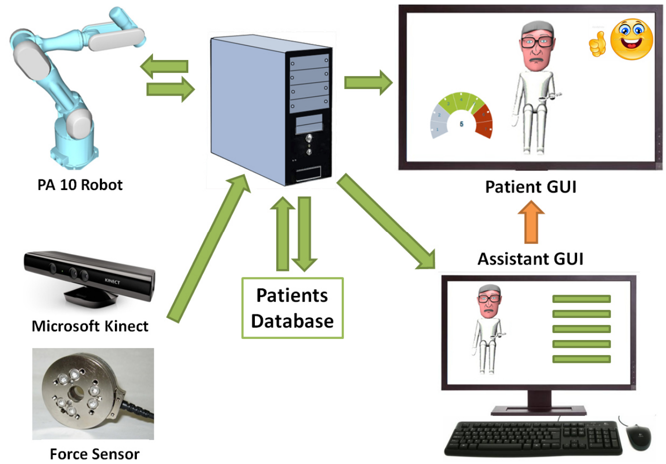

Fig. 1. The main components of the REAPP system application.

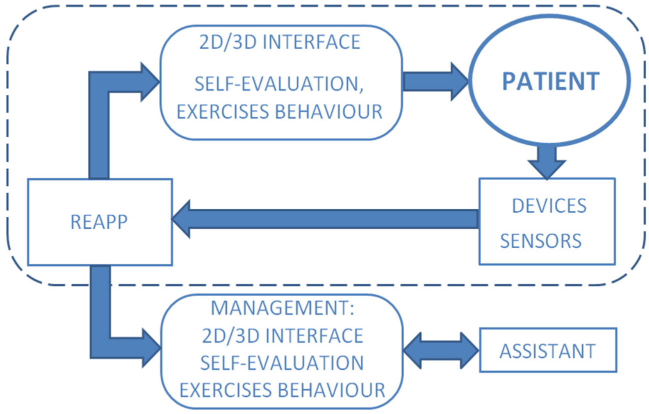

Fig. 2. The logical workflow of the REAPP system application.

A. *Tell Us how You Are Today*

In the real practice the therapist frequently talks with the patient for various reasons, included of course the technical aspects proper to the rehabilitation. It is important for the therapist to know and to track the patient's daily conditions, both physical and psychological, to adjust the session goals, to have a picture of the general trend in order to relate the performance of the patients to their subjective perceptions and to try to understand their feelings about the therapy [19] [20]. These aspects are kept in consideration and emphasized in REAPP: the patients are inquired with a self-evaluation test, aimed to investigate their current state with the support of a GUI. This test is divided in two parts, one to be done at the beginning of the session and the other at its end. At the beginning of the session, patients are asked to provide their evaluation of their subjective feeling (mood, strength, precision and quality of sleep during the night preceding the session) [21]. The quality of sleep is thought to be strictly related to the patients' fatigue and, consequently, to their rehabilitation session results [22] [23]. At the end of the session, the patients are asked to provide the evaluation of their subjective feeling of: participation, mood, fatigue, precision in the execution of the tasks [21]. The therapist manages the whole process of self-evaluation with his/her own GUI. The therapist goes through a predefined sequence of questions by submitting to the patient one question at a time. Simultaneously, the patient sees on his/her dedicated screen the visual representation of the specific question and the available answers. The set of answers is represented in the form of Likert scale with a list of explanatory images and icons. This way of asking questions was chosen to make them as clearer as possible, even for subjects with mild cognitive impairments [6]. Patients orally communicate the answers to the therapist, who selects the corresponding item on his/her GUI. All the choices of the patients are stored in their personal file and will be recoverable at any time, for further investigations.

B. Look at Yourself

During the execution of the tasks the patients should have the opportunity to look at themselves, so that they can gain awareness on the overall body, especially in case of damaged sensory pathways. For this functionality, the patients were chosen to look at their representation consisting in a 3D avatar moving in a virtual environment while their body is tracked by a Microsoft Kinect device. The avatar is rendered real time in the patient's GUI and it mimes the patient movements during the therapy session, without any perceptible delay. This choice was preferred to other solutions, such as using a traditional camera or a mirror effect, for two main reasons. The former is that the dedicated GUI allows the therapist to set the point of view on the 3D scene by flying around the moving the avatar, in order to focus the attention of the patient on a certain particular, seen from a special point of view. The latter reason is that forcing the patients to really look at themselves, like in something similar to a mirror, may induce distraction or also unease deriving from the continuous perception of an altered physical look due to the stroke [24]. Moreover, we hypothesized that having an allocentric point of view may have, for the patients, some beneficial effects in terms of mirror motor neurons activation, too [25]. These neurons activate not only when an individual performs an action but also when he/she observes someone else doing that same action [26]. In the rehabilitation context, their stimulation is believed to promote cortical plasticity and, consequently, motor re-learning and motor memory. Studies had provided evidence for this hypotheses, demonstrating that action observation coupled with simultaneous action performance enhance the learning of skilled movements more than motor training alone, both in healthy subjects [27] and in stroke patients undergoing upper limb rehabilitation [28].

The avatar face is customizable. Patients, at their very first session, with the aid of the therapist, design the avatar face as symbolic representation of the self, by choosing among different features as: hair, skin and eyes color, hair style and presence of beard, mustache, glasses (Fig. 3). This is made to increase the patients' embodiment and their capabilities to relate to their avatar [21], as also suggested for example in [18]. The body of the avatar, instead, will not be customizable but its basic features can be modulated according to male and female patients.

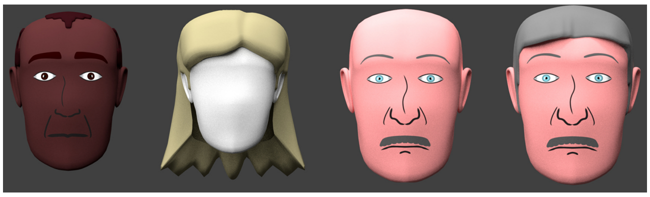

Fig. 3. Some examples of customized avatar faces.

C. Look at Your Posture

Functional improvements in upper limb kinematics post stroke are due to two different mechanisms: recovery and compensation [29]. Even though the latter might be an useful and efficient mechanism to accomplish daily activities as independently as possible, studies demonstrated that relying excessively on compensatory strategies may lead to disrupted synergies, joint contractures and, in some cases, limit patients' functional outcomes, as mentioned in [30] [31].

The robot used in this study was explicitly programmed with the aim to address the movements of the patients and to make them, during the exercise, perform the tasks, as they would have done before the stroke. Therefore, during the therapy session, compensatory movements and wrong postures should be corrected or, at least, limited. The 3D avatar has a key role in doing this, because it shows the patients' movements in real time, by giving them the possibility to know their body segments position, even in case of lack of proprioception. The application gives also the therapist the possibility to set, depending on the residual capabilities of the patient, specific constraints on each joint. In this way, when a movement is not performed properly and exceeds the imposed constrain, the patient is informed by visual and auditory (i.e. earcons [32]) signals indicating on the avatar which joints are out of the optimal trajectory.

Previous studies [29] [33], preliminary observations and evidences of patients undergoing robot therapy helped to define which poor postures or compensatory strategies are common in post-stroke subjects. For the reaching task, it was shown that patients tend to help themselves for reaching farther with trunk rotation or forward bending. Excessive shoulder abduction was also noticed in some patients at the beginning of the reaching movement. For the hand-to-mouth task, shoulder hiking was found to be commonly used to compensate for limited elbow flexion. Head bending was also observed as a common strategy to get the mouth closer to the robot end effector. Occurrence of a poor posture involving the lateral bending of trunk was also noticed during both tasks. All these wrong behaviors can be assessed using the Kinect data, which allows computing body-segments positions and configurations. Such configurations are then compared to the constraints the therapist defined for each patient and, if a constraint is eventually exceeded, an error is signaled to the patient as described above.

D. Imagine a Real Life Situation

Previous studies showed [34] [35] that, even if the patients accomplish the rehabilitation tasks in a good way during the therapy sessions, they are not able to repeat the same movements in real life situations. This happens especially for patients with cognitive deficits, because they are not able to relate the movement they perform in clinic to the common activities of daily living (ADL). To facilitate the transfer of the rehabilitation movement to the daily context, the 3D avatar holds a virtual object of the real life in the hand of the limb corresponding to the real impaired one. Therefore, patients have the opportunity to experience some real objects manipulation through their avatar during the exercise. In this way, the gestures already performed during the rehabilitation sessions can be related more easily to common gestures in different environments and daily life contexts [35]. The selection of the virtual object to be hold does not affect the difficulty level of the exercise. It rather acts as part of the pre-exercise self-evaluation test and as an evaluation on how much "difficulty" the patient feels able to face.

For the reaching gestures performed in real life situations, the difficulty increases as the weight of the object does. Thus, the patients are asked about their subjective perception of strength and, based on their answer, a "light" or a "heavy" virtual object is rendered in the avatar's hand. Examples of objects with increasing weight that are displayed during the reaching task are a nut, an apple or a melon. The choice of the patient is not made directly among these three real objects, but among three "metaphors" each one representing a category of objects with different weight. In this way, the type of displayed objects is varied from session to session enabling the patient to relate the performed movement to more different ADL [35] [36].

For the hand-to-mouth gesture, instead, the increase in difficulty is dependent on how much the movement has to be precise and accurate. Since the hand-to-mouth movement easily relates to the activities of eating and drinking, the three different levels are represented, for instance, with a fork with short-cut pasta on it, a fork with spaghetti twirled on its tines and a soup spoonful. The patient's selection is made among three metaphors representing the three different levels in this case either.

E. Correction and Motivation

During the exercise, the patients need to be corrected and motivated, as it would happen in a traditional rehabilitation session with a human therapist [19] [20]. About the movement correction, as already mentioned in paragraph *Look at your Posture*, a visual symbol and an earcon-like [32] sound are used to inform the patients that a joint has gone out of the range the therapist defined. This kind of feedback is immediate and little invasive [10] and it is aimed to recall the patients attention to the movement they are performing [36] [37]. On the other hand, if the patients reiterate the same error more than three times they probably need a more precise indication about the error they are making. For this type of communication, as well for motivating the patients when they are doing well, the character of a virtual assistant was selected [21].

From communication point of view it is important that a contact is established between "audience" (the patients) and "stage" (the GUI): the virtual assistant should communicate not just the content but also the emotional frame related to it. This is motivated by the fact that the character (virtual assistant) should have "life" and be believable in order to make the user (patient) listen to it instead of just hearing speech and reading text from the system in a passive manner [38] [39] [40]. By focusing on these requirements, the virtual assistant has been designed as an animated smiley face provided with hands. The smiley has eyes and mouth, that are the expressive and eloquent human communication means, but it does not evoke, for example, a European, African, Asiatic, young, old, man, woman, brown aired and any specific human instantiation. This choice does not

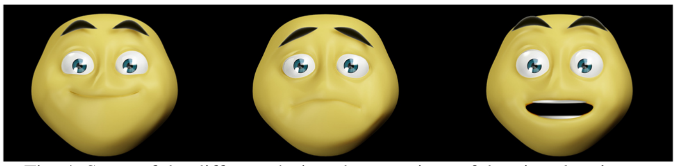

Fig. 4. Some of the different designed expressions of the virtual assistant.

limit the belief of the patient because the human mind has the capability of abstracting (making the semantics independent from a specific formal instance representation). Therefore, almost everything can be interpreted as an alive interlocutor: some famous examples are *HAL 9000*, the sentient computer in *2001: A Space Odyssey, R2-D2* from *Star Wars, WALL•E* from the homonymous movie. The symbolical representation was preferred to a human-like figure also because it does not introduce the complexity of a set-up phase for selecting human tracts that appear pleasant to everyone. The virtual assistant of REAPP is a 3D model that has been properly prepared with a set of predefined facial animations (Fig. 4), involving eyebrows, eyes, mouth, cheeks, with the aim of attracting the patients attention, communicating immediately its mood and, consequently, if its coming on stage is related to correction or encouragement. The implementation of a predefined set of animations gave also the possibility to make the virtual assistant talk with a proper tone of voice, by giving the right emphasis to the content.

The smiley is not always displayed in the patient GUI but it appears either when the patient is performing well or is reiterating an error. In the first case, after a successful repetition of the rehabilitation movement, the virtual assistant appears to encourage the patients and to invite them to participate more actively (if they are not doing it yet). Positive expressions and encouraging hand gestures (e.g.: OK-gesture or thumbs-up gesture) accompany this kind of messages. In the second case, instead, the smiley appears to correct the patients wrong movement or the poor posture. Examples of the coded proposition are: "Do not hike your elbow" or "Do not bend forward". In this case, the smiley presents a neutral expression, since the virtual assistant figure should not be neither demoralizing nor create anxiety. Another important aspect of the smiley is its timing: each appearance of the smiley is followed by an adequate period of time in which it is kept silent. In this way, it does not become an intrusive figure that can annoy or upset the patient.

III. The Role of the Therapist

With the use of the proposed system, the therapist plays a role of a kind of guardian of the overall session. He/she gives the self-evaluation tests before and after the exercises by eventually helping a little the patient in the selection of the answers. The therapist can modulate the behavior of the system on the type of patient and his/her overall daily conditions. This is a relevant factor to be taken into account: the patient can "float" between different performance capabilities and this should be taken into account since it influences the actual performance. The therapist is the right figure than can realize it and mediate with this aspect since he/she knows who the patients are and which are their essential dispositions, also with the aid of the self-evaluations done before and after the exercises. The therapist is able, with his/her GUI, to modify the default state of the parameters of the runtime of the rehabilitation application in order to adjust the way the cognitive enhancements elements are given, also during the run of the exercises. Such parameters adjustments are operated on the threshold of activation and on the enabled/disabled state of the widgets. With the default settings, when the patient does some movements in a certain way, the smiley appears and plays its part. With the adjustments, for example, certain lines of the smiley are omitted even if they should be done (if the patients are in a not so good day) or, at the opposite, such lines are done more strictly (if the patient shows a good trend).

IV. Cognitive Infocommunication Aspects

The system for supporting the patients during the rehabilitation session here presented can be considered in the context of the Cognitive Infocommunication (*CogInfoCom*) theory [41] [42]. There are two entities connected in a communication process: the patient and the system. Due to their intrinsic nature, they have different cognitive capabilities and cannot communicate in the same mode, thus the mode of communication is inter-cognitive, according to the theory definitions in [41]. The type of the communication established between the patient and the system is a quite complex one. The patients just play their tasks and a set of sensing devices receives a measurement of such performance and the software application processes such data. On the other side, the patients receive communications about their performance through digital audio-visual channels (Fig. 5). With this situation, the involved *sensors* (in the CogInfoCom nomenclature) are different and the type of communication is sensor-bridging, as described in [41]. The patients receives information about the behavior of the performance with 3D avatar real time rendering and with the intervention of the smiley. The patients receive the sensory information sensed of the artificial system in an adapted way not directly corresponding to the original one, and thus this is a representation-bridging communication in the model of [41]. Two main communication sub-channels can be identified in the proposed system: patient-3D avatar and patient-smiley, that is composed by patient-smiley's audio and by patient-smiley's visual representation. Let's focus on the patient-smiley. In the previous paragraph *Correction and Motivation* the smiley is described with its own functionalities of catalyzing point of contact with the patient. The smiley plays the role of a kind of affective computing function [43] [44] [42] with a one-way communication. In fact, the aim of the smiley is not just to provide comments and indications that coldly and shortly notify something specific, but it is also to provide the patients an emotive interpretation emphasis that is another communication means. The artificial system provides, in the communication patient-smiley, also an emotive characterization of the contents. Such characterization strengthens and enhances the contents of communication and is clearly perceived by the human user by gathering the facial expressions and the tone of the voice.

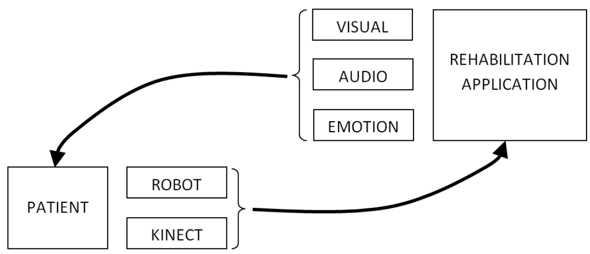

Fig. 5. The loop of communications between patient and rehabilitation system.

V. Remarks and Future Directions

In this ongoing research one of the focus points strives for providing patients a really emotive context rather than a game. This aim is of course somewhat complex; the research, the daily experience and evidence indicate that the way of emotive engagement is not well defined, as many attempts of aimed digital environments show. Several experiences of therapists and patients have been collected and discussed for designing the components of the system described in this paper. From May 2015, a clinical trial will be conducted at Villa Beretta Hospital on real post-stroke patients. From the trial results it will be possible to understand if a sort of emotive bond can really be established between the patients, their virtual self and the virtual assistant. Another thread, not explicitly mentioned in this article, is to bring the REAPP system at home, that is the main aim of the Riprendo@Home Project that funds this research.

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