A Virtual Reality System for Post Stroke Recovery

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Abstract— A low cost smart system for upper limbs motor function recovery is presented in this paper. Based on Virtual Reality, the proposed system ushers the patient in a virtual scenario where a virtual therapist coordinates the recovery exercises aimed at restoring brain function. An inertial measurement unit, a glove with sensors and an immersive virtual reality headset connect the patient to the virtual environment developed in Unity. The visual feedback correlated with augmented limb movement increase the recovery performance and decrease the training time. The laboratory preliminary tests reveal the users' acceptance and interest and also the prospects for further development.

Keywords— Human-Computer Interaction; rehabilitation; virtual/augmented feedback; stroke, Unity

I. INTRODUCTION

It is well known that in the last decade the stroke became the leading cause of long term disability and the number of affected people increases warrying especially among people less than 60 years [1]. For patients who survive after a stroke it is very important to start the rehabilitation process in order to relearn the lost skills and finally to succeed complete recovery and social reintegration [2]. The neuroplasticity is the natural ability of the brain to form new connections in order to compensate for cortex damage or brain disorder [3]. This property can be activated not only by medical treatment but also by intense and regular supervised exercises under therapist assistance, brain retraining software and websites, interactive metronome, mirror box therapy, and limb devices that assist with movement repetition [4, 5, 6]. Despite the improvements offered by these methods to the rehabilitation process there are still some drawbacks: relatively few exercises, low motivation, monotony, the patient's condition and position, limited perspective and the lack of challenging tasks. A greater patient's involvement, the boredom overcoming or the increase of the exercises time can be achieved by the use of Virtual Reality (VR) and serious games.

VR creates immersive, computer-generated 3D environments and serious games which are non-entertainment software applications may serve to train, memorize, develop skills and all aspects of education beyond fun. VR integration in stroke recovery systems is quite recent and subject to technical progress [7]. The patient interacts with the virtual environment which is customized for particular medical condition. The digital environment and the scenarios can be adjusted with patient's progress and physical abilities improvement, in order to encourage and stimulate the user. The experiments carried out by different research groups revealed the efficiency of VR facilities together with classical therapy in stroke recovery for patients in convalescence. However, some constraints on the visual perception of spatial relationships between VR objects should be highlighted. The virtual objects and the Avatar driven by the patient do not have the same references of the coordinates and this could disturb the reliability and efficiency of the rehabilitation systems.

Between VR and the real world, augmented reality (AR) is closer to the real world and blurs the line between what's real and what's computer-generated by enhancing what we see, hear or feel. AR adds graphics, sounds, and haptic feedback to the natural world as it exists [8]. AR exceeds the inconvenience of VR related to patient movements compliance with digital environment. In VR the users are isolated from the real world but in AR they continue to be in touch with the real world while interacting with virtual objects around them [9, 10]. For example, a patient can see his hand in a AR scene and the information provided can be controlled in this environment. If a patient is unable to walk or move by himself his limbs in his environment, a combination of AR and a robotic device, provides feedback to the patient and this visual sensation of walking is an important component in motor learning [11, 12]. In hospitals, an important approach in assisted stroke rehabilitation is the use of robotic devices, in scenarios that continues the traditional therapy or for evaluation [13]. These devices can be used alone or with VR [14] to increase patient motivation and involvement [15]. But the costs are really high (around US$60,000) and the results do not exceed much the traditional approach.

Thus, a ubiquitous and low cost system for stroke recovery is of real interest. Every patient should afford to buy one and use it at home to continue the recovery program started in hospital. In this paper we present a stroke recovery system for the upper limb. Because AR needs a mechanism or customized devices to combine virtual and real worlds an inertial movement unit (IMU), a glove with sensors and an Oculus Rift headset are used. The AR scenes are developed in Unity and C++ modules accomplish the assets for devices. This system is developed with the support of the TRAVEE Project described in [8]. The TRAVEE System has a modular design that allows the therapist to add/remove monitoring and stimulation/assisting devices in correspondence with rehabilitation exercises.

II. SISTEM ARHITECTURE

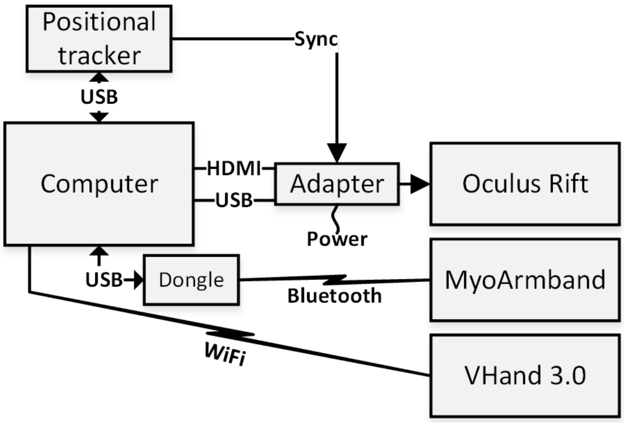

Fig. 1. The System architecture

The hardware components of the stroke recovery system are presented in Fig. 1. The Myo Armband contains an IMU used for relative movement of the upper limb and an electromyography (EMG) module which detects the electrical potential generated by active muscle cells [16]. VHand 3.0 is a glove with sensors that detects hand movement and orientation and also performs accurate finger movements tracking [17]. Both MyoArmband and VHand offer SDKs in C++. The Oculus Rift is a virtual reality headset that allows a natural interaction with generated virtual environment [18]. Due to the integrated position sensor, the head movement induce orientation in 3D space and generate total user's immersion in the virtual environment.

A. The Myo Armband

The Myo Armband has eight segments of expandable casing connected with stretchable material that allows the armband to fit comfortable on user's arm (fig. 2). The medical-grade EMG sensors, placed on the inner faces of the casing elements, measure electrical signals produced by muscle activity. The Myo armband translates these signals into poses and gestures using an onboard ARM Cortex M4 Processor. The armband also has a three-axis gyroscope, a three-axis accelerometer, and a three-axis magnetometer to detect motion in any direction. It can be connected to the computer using Bluetooth 4.0 Low Energy and a Dongle driver. The frequency acquisition from IMU is 50 Hz. The armband provides two types of data: *spatial data* (orientation and movement of the user's arm) and *gestural data* (provides details about what the user is doing with his hands). The SDK of the armband provides two types of spatial data: the orientation represented as a quaternion that can be converted to other representations, like a rotation matrix or Euler angles and a three-dimensional vector acceleration vector of the armband at any given time. The gestural data are provided in form of several preset poses, which represent a particular configuration of the user's hand [16]. Myo provides very good results especially for determining the relative position of the arm, but in the case of absolute position pattern recognition some cumulative errors are noticed. This must be taken into account when pattern recognition algorithms are applied.

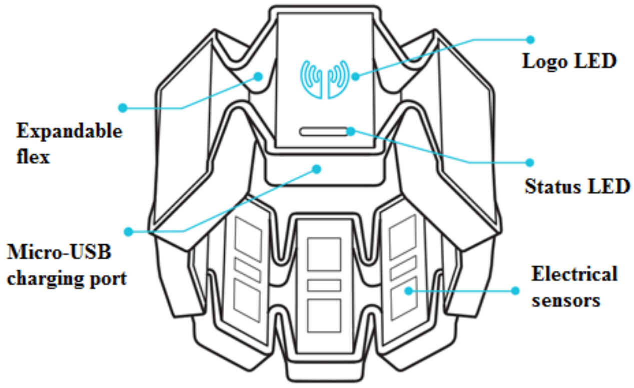

Fig. 2. The Myo Armband

B. The glove with sensors

The Vhand Data Glove (fig. 3) is a low cost device for detecting hand movement (up/down, left/right, back/forward) and orientation (roll, pitch, yaw) due to 3 axes accelerometer, 3 axes gyroscope and 3 axes magnetometer. More important for stroke recovery, the glove has five embedded bend sensors which offer the possibility to accurately measure the fingers' movements [17]. The internal sensor fusion algorithm provides stable and accurate hand position information. The sampling rate is 100Hz. The data glove can communicate with others devices via WiFi or USB cable.

Fig. 3. VHand 3.0 DataGlove

The VHand Manager Software can be used to calibrate and to test the data glove features, sensitivity and functionality. The assessment of the acquired data revealed a good detection of every joint position, links between joints, fingertips or phalanges movements [19]. This is crucial for a reliable control of an avatar in the virtual environment.

C. Oculus Rift and positional tracker

The Oculus Rift used for system development is the DK2 version and it is considered to be the most advanced head mounted display (HMD) currently marketed. Whereas head tracking refers only to the rotation of your head (pitch, yaw and roll), positional tracking registers the exact position of the headset in space by recognizing forward/backward, up/down and left/right movements [18]. The positional tracking is customary in VR application because its usage allows the removal of the errors associated with absolute head position.

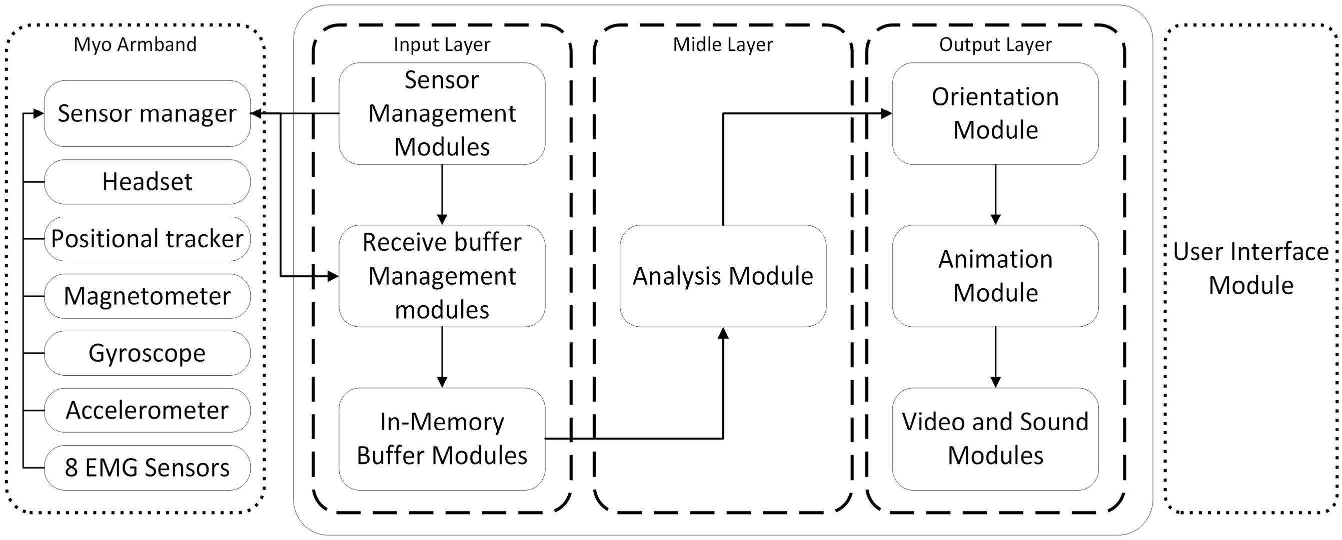

Fig. 4. Software modules

III. SOFTWARE IMPLEMENTATION

The VR environment is developed in Unity that is a powerful platform for building applications with 3D interfaces [20]. Written in C#, Unity is widely used in the last years as a cross-platform game engine. However, Unity is increasingly used as a development platform for integrating spatially aware wearable devices in 3D scenes. Many assets are available for different devices. Myo SDK comes with a plug-in for Unity but VHand DataGlove do not have such a facility. A versatile scenario for performing rehabilitation exercises for patients with neuromotor disabilities is developed. This scenario consists of a virtual therapist that coordinates the exercises and a patient who must execute them. The application provides visual feedback for the patient and additional information regarding the accuracy of the performed exercises. In fig. 4 the modules of the software application are presented. The software architecture is based on a three tier paradigm which helps to decouple the input, processing and output stages of the system.

The input layer receives the data provided by the sensors network, adapts the system and triggers the actions of the avatars based on the chosen exercises. The use of memory buffers is very important in order to avoid data loss and to allow multitasking for communication and saving data files. The middle layer is represented by the Analysis Module that receives raw data from sensors, analyzes and processes them according to the exercises that patient should perform. The Analysis Module works in sync with In-Memory Buffer Modules having the aim to prevent data loss which is an important issue in wireless communication. The application stores the data in working memory and displays a meaningful error if the connection with Myo Armband or Oculus Rift is not available.

The Output Layer is responsible to manage the visual facilities of the application and contains the animation modules for the therapist and for the patient. According to the active scene, the virtual therapist indicates to the patient the type of exercise and how this must be executed. This guidance is done by the use of suggestive animation. The sound generation module is based on the Microsoft Speech Platform. The exercise starts after the patient is accommodated with all the technical details.

Once the data from Myo Armband and DataGlove are processed in concordance with the chosen exercise, the patient's avatar mimics the real patient's movements.

VHand SDK do not have support for C#, as Unity requires. The related software modules are written in C++ and the code can be easily invoked in C# by the use of two special classes: *libmyo* and *libVHand*. Using these classes, the needed functions for Myo and VHand identification are imported and the events including IMU data are captured. The purpose of this Wrapper is to provide access in Unity to the data issued by Myo Armband and VHand to mimic movements in 3D space for patient's upper limb and hand.

The software developed for rehabilitation by the use of the virtual reality has to accomplish the requirements of the recovery exercises regarding the flexion and the extension for the upper limb and the hand.

Upper limb recovery program consists of two stages, each of them with two different scenarios. The first stage follows immediately after the stroke when the patient is unable to control his affected limb. The second stage begins when the patient regains a certain control of his limb and wants to continue the exercises for the best possible recovery.

The first stage is associated with the mirror box therapy [21]. According to this practical protocol the patient must put his weakened limb in the mirror box and moves his strong limb. The mirror box gives the illusion that the movement is performed by the limb affected by the stroke. This is done through activation of mirror neurons in the premotor cortex of the brain based on visual feedback. In essence, the mirror tricks the mind and the weak hand into working better [22].

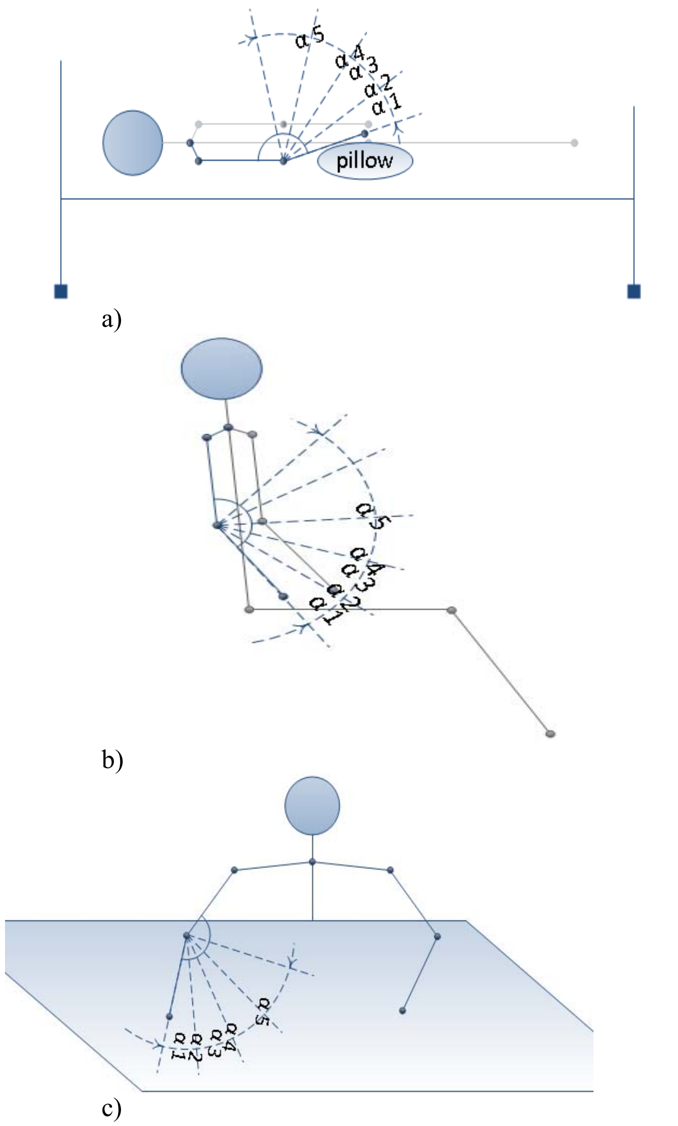

Fig. 5. Typical exercises for different patient's portures

All mirror neurons present congruence between visual actions at which they respond and motor responses which they encode. In order to obtain the same effect, the sensors (armband and the glove) are attached to the strong limb and specific exercises are performed.

In VR environment the patient sees his both limbs. Based on data sent by the movement sensors, both limbs of the patient's avatar are identically moved and the patient has the illusion of controlling his weakened limb. Patient's brain is tricked and mirror neurons are activated.

In the second stage, when the muscle activity can be visually noticed, the sensors are placed on the impaired upper limb. The patient can see only the movements of the limb subjected to recovery. These movements are augmented and amplified in order to train the brain by tricking it. As the affected limb muscle activity is improved, the movement amplification is reduced and the difficulty of the exercises is gradually increased as the flexion angle gets higher (fig. 5).

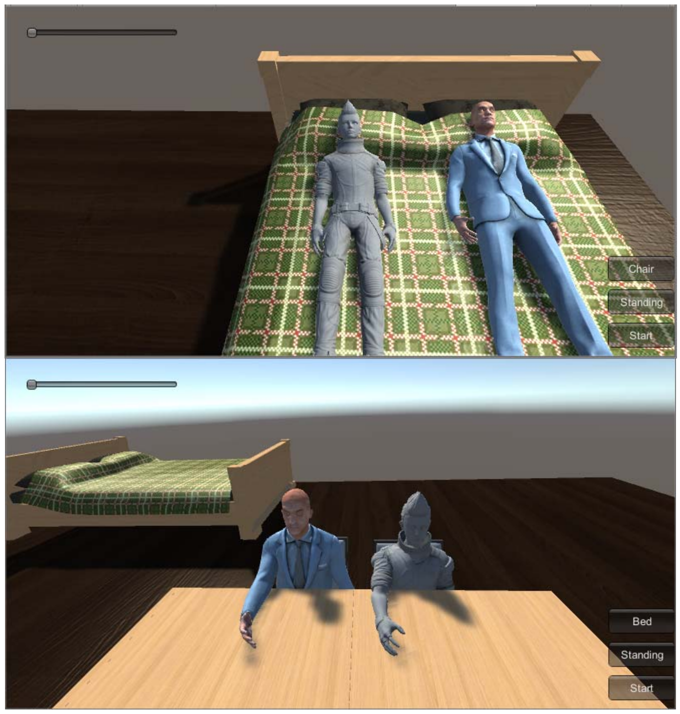

Fig. 6. Snapshot from the running application

The exercises are guided and evaluated by the virtual therapist and the patient is encouraged, congratulated for every movement made.

According to patient's condition (he is laid in bed or he may sit down or even stand up) there are two scenes in which the patient is immersed. For the first one, the patient's avatar is placed in bad beside that of the therapist's one and the camera is fixed on ceiling (fig. 5.a). In the second scene, when patient is sitting up (fig. 5b) or is seated at the table (fig. 5c – exercise without gravity), the camera is fixed on his head. Thus, the patient can see his body in normal perspective and therapist's avatar is in front of him.

Besides the audio congratulations messages for patient's encouragement or setup information, an additional music module was designed to make the application more attractive and successful. In the last years, music therapy was used in conjunction with traditional medical treatment after a stroke [23]. For example, MusicGlove (Flint Rehabilitation Devices) is a rehabilitation tool designed to help individuals to regain lost hand function after a stroke. It leads to significantly greater improvement in hand function and motivates safe and high-intensity movements [24]. Neurologic music therapy (NMT) and therapeutic instrumental playing (TIMP) offer standardized treatment protocols for arm recovery [23]. The actual version of music module is developed in Unity and FMOD Studio but needs future development and higher integration.

The technical performances of the proposed system were extensively tested in terms of hardware and software performance. Regarding the devices used in our system, one important fact must be noted: it is very important to calibrate the Data Glove before each session in order to obtain consistent data. The test techniques and updated versions of the application have contributed to ensure the stability, accuracy, repeatability of the acquired data. The software fulfilled the load, volume and stress testing. The analyses of the data generated by the application revealed a very good concordance between the real position of the limb and the calculated position. Data loss have not been reported.

IV. CONCLUSIONS

Myo Gesture Control Armband and VHand 3.0 DataGlove are low cost devices with good sensitivity to capture accurate signals related with fingers, hand and arm movements. The SDKs provided by vendors offer the possibility to integrate them both in different entertainment applications but also in serious games and stroke recovery systems. Oculus Rift is the central component for VR environment integration.

The system we have proposed aims to be cheaper, captivating for any user regardless of the age, easy to use, computationally powerful, and accurate. It can be easily set up and calibrated and is customizable for individual users. Obviously, the base idea is not new but our approach has a better control of the limb and hand movement by fusing the signals provided by Myo Armband and DataGlove. For example, the system proposed by Pawel Budziszewski [25] uses a motion tracking (Razer Hydra) integrated in the VE and the system used in project PRESENCCIA [26] only the 5DT data glove is used for hand movement detection.

We are currently conducting pilot case studies to assess ease of use and efficacy from the patient's side and rehabilitation process. Preliminary tests suggest users' acceptance of the technology and a real potential for beneficial effects. Some previous studies revealed that usually it is not easy to use a HMD for a long time but the Oculus Rift we had used was considered to be comfortable enough for more than half an hour. This is encouragement, because usually a session of recovery exercises does not exceed 20 – 30 minutes. The system fulfills all the technical test and it is reliable to be used in medical rehabilitation.

The project is in progress and in the next work package the assessment of its efficiency and usability in medical clinics or at home will be coordinated by the Romanian National Institute of Rehabilitation, Physical Medicine and Balneoclimatology. The individuals after stroke with intact cognition and sitting balance are selected for the study. Because it is very important for the study to begin the recovery as soon as possible after stroke new subjects will join the testing cohort to enlarge the sample size. The patients do not receive any other intensive rehabilitation and they should perform gradually the sets of exercises for a maximum of 30 minutes, 3 or 4 times a day, for at least 10 weeks. This type of recovery scheme is used in similar studies [27]. After 5 weeks and at the end of the period, well-known outcome measures will be performed: Motor Activity Log, Wolf Motor Function Test, Nine-Hole Peg Test and Chedoke Arm and Hand Activity Inventory [28]. A software module collects for each user the frequency and duration of use and indexes regarding patient's performance in comparison with avatar. Finally, the individual files will be merged and statistically analyzed.

ACKNOWLEDGMENT

This work is supported by the Romanian National Authority for Scientific Research (UEFISCDI), Project 1/2014 Virtual Therapist with Augmented Feedback for Neuromotor Recovery (TRAVEE).

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