Telerehabilitation Model of Physical Therapy using Kinect and Embedded Systems

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Abstract— **In this paper a model which provide the patient with a fast and simplified way of performing home therapy is described. Model is based on virtual reality, movement tracking and sensors' reading. Technically, it is consisted of (1) medically designed Software as a Service platform which provide remote, secure, reliable and always available software platform, (2) interactive virtual reality games that increase patient's motivation and concentration, (3) Microsoft Kinect for motion tracking and (4) embedded systems for tracking physical abilities during gameplay. The paper presents the results of applying this model of therapy to a single post-stroke patient. Therapy was focused on the upper limb and visual difficulty and resulted with improvements in both.**

Keywords – Motor Disorder, Telemedicine, Virtual therapy, Motivation, Post-Stroke

I. INTRODUCTION

According to World Health Organization Report [1], 10 million people survive a stroke worldwide each year, while half of survivors remain disabled. Stroke is one of the leading causes of disability. Paralysis of one side of the body is a frequent consequence, which is treated with physical therapy [2]. Recovery time is individual, but rehabilitation center accommodation time is limited and patients are forced to continue therapy at home. After leaving the hospital, recovery is reduced to occasional visits to rehabilitation center. Exercising at home depends on the patient's self-discipline. Repetition of same exercises leads to saturation and skipping therapy sessions, which usually leads to discontinuity of home physical therapy.

The goal of this paper is to create the system that would improve the success of treatment at home with small investments in equipment. Adding virtual reality to the system creates an interactive environment. Adding purpose to each movement, through interaction with virtual objects, the patient becomes less aware of physiotherapy. After the treatment, although physically exhausted, the patient will feel satisfaction for fulfilling tasks and will be more motivated to exercise again. Virtual physical therapy has the form of games because its several characteristics contribute to a better quality of exercise. In the games there is always the goal that player needs to reach, using the skills or capabilities, and there are rules and restrictions forcing player to perform actions properly.

This paper describes a complete model of virtual physical therapy for upper limb in gaming form, that besides maintaining the continuity of practice constantly records the results of exercises, generates reports and information about the success of therapy and automatically proposes new exercises if the patient shows good results in several consecutive therapy sessions. The model also has the ability to perceive limitations in hand movement and to adapt the exercises to the patient.

II. RELATED VIRTUAL REHABILITATION SOLUTIONS

With the advent of Microsoft Kinect, peripheral device for PC, in 2012, creating an interactive environment has become easier. Kinect can track movements of the whole body and therefore it is often applied in projects of virtual physical therapy. The Spanish group *VirtualWare* developed *VirtualRehab* system, which is consisted of control center as administrator software platform and several games designed for Kinect (http://www. virtualrehab.info). The control center is used by therapists to prepare a plan of exercises, monitor and assess the progress of therapy. Canadian startup *Jintronix* also developed rehabilitation software, based on Kinect that allows therapists to remotely monitor treatment and determine the following exercises based on the activities of the patient (www.jintronix.com).

Lithuanian start-up *Devmotion* goes a step further - they have virtualized entire area around person, which has been playing game. Their therapeutic solution was designed for children, in order to replace the virtual hospital ward (http://devmotion.eu/virtual-rehabilitation-solutions). It is not uncommon to develop specific wearable gadgets, for purpose of virtual therapy or specific measuring. Researchers at Britain's University of Southampton developed three tactile devices [3], which are stimulating finger skin, of patients with poorly-operated hand, in order to regain a sense of handling objects. Wearable, specially tailored gloves are also used in the treatment for hands and fingers. For instance, Swiss startup company *YouRehab* developed wearable interactive glove *YouGrabber,* for hand therapy as well as the *YouKicker* device, for leg therapy and foot movements [4]. Research [5], in which *CyberGlove* and *Rutgers Master II-ND* glove were worn by people with poor fingers mobility after a stroke, showed that the mobility of the thumb increased 50-140% and mobility of fingers increased 10-15%. However, the use of these wearable devices is not adequate for clinical conditions, due to sterilization and size that does not fit all patients, such as for children.

From the all above mentioned, Kinect is the basis of most virtual rehabilitation solutions. The exercises are usually performed through the game. In more serious projects, it is possible to remotely monitor the results of playing and adjust difficulty of the game. However, we

noticed that only few solutions accurately capture the mobility of limbs and improve capability and mobility of muscles. Also, feedback is usually calculated based on time spent playing game and on number of achieved goals, while the accurate measurements of muscle contraction or speed of a limb movements (reflex) is not considered. Projects' advantage are wearable embedded devices, which measure their physical ability and opportunities, while patient plays a game.

We believe that statistic data recording of each therapy, remote access by patient and therapist and remote control of therapy sessions by therapist, will contribute to better home therapy and continuity in exercises. Also, the patient could be aware of information doctor oversees and also follow games' results, which could contribute with confidence in telerehabilitation model.

III. TECHNICAL REQUIREMENTS OF THE MODEL

As a substitute for standard therapy, virtual therapy must ensure all benefits of standard therapy. The primary goal of virtual therapy is that patient performs the full day therapy. The secondary goal is to collect data during exercise, in order to measure progress, as well as to establish a relation between the type of exercise and mental, physical and verbal recovery. With these goals, a software-hardware model has been made (see Fig. 1), which is consisted of:

- *Kinect* motion tracking device,
- *Embedded system* for measuring physical parameters,
- *Software as a Service (SaaS)* cloud platform for performing therapy and processing, storing and analyzing data, collected during therapy sessions,
- *Interactive virtual reality games* that increase patient's motivation and concentration.

A. Motion Tracking

Kinect launched the expansion of various creative projects which use 3D camera. This device consists of RGB camera 640x480px resolution, infrared (IR) camera and IR projector. RGB camera is a standard color camera. IR projector emits infrared rays in space which bounce off objects and return back to IR camera. That's how the distance between Kinect and objects is measured. This feature is useful in the creation of therapy, if patient is required to put his hand in front or behind his body. All three components: RGB camera, IR camera and IR projector allow the creation of 3D images. Open source library, Simple-OpenNI, allows Windows, Linux and OSX users to connect with the Kinect device and thus opens the door to a wide range of artistic and medical projects. Kinect can distinguish parts of the body and determine the position and orientation of the body. In addition to objects, Kinect can detect sound. This feature is not sufficiently exploited, although Kinect can very accurately determine the source of sound.

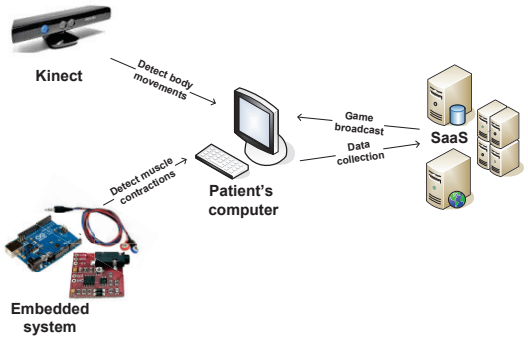


Figure 1. Telerehabilitation model of physical therapy

In our model, the function of Kinect is to determine the patient's mobility and limitations, before starting with virtual home therapy. By testing the patient on certain movements (e.g. height to which he can raise affected hand or move it to the right, left or how much he can bend it and how fast makes a move), a set of parameters is obtained, upon which the patient get a recommended list of games. During testing, body position is also very important, because patient will tilt to the right, if he finds too hard to lift left arm. Therefore, based on these initial measurements, a set of best suited games is automatically determined.

B. Embedded System forMeasuring Physical Parameters

Embedded system is a computer system of special purpose which executes predefined tasks. Embedded system is part of this model for two reasons: to diagnose the physical abilities of the patient based on measurements and to use values recorded from embedded devices, as input parameters in virtual games.

Embedded systems applied to this model are microcontroller Arduino Uno and muscle sensor with three electrodes. We can detect electrical potential EMG, using muscle sensor by placing electrodes in three positions: in the middle of the muscle, at the end of the muscle and on bony part near the muscle. Before placing electrodes it is necessary get skin prepared: remove hairs and clean it with alcohol. These steps are mandatory in order to provide better grip of electrodes and reduce the electrical resistance of the skin. Proper placement of EMG electrodes is very important for accurate measurement of muscle contraction. Unfortunately, if the muscle has more body fat, EMG signal will be weaker and difficult to record.

The value read from the muscular sensor will be used in rehabilitation games of this model. If the patient is required to alternately contracts and relaxes the muscle, it will represent an effort for him, but if he's doing the same unconsciously while playing game, the effect will be the same and results will be better. Based on the above, the use of muscle sensor in rehabilitation games should lead to improvements in patient's muscle structure.

Fig. 2 shows a successful connection of muscle sensor with Arduino Uno microcontroller. The sensor is supplied by two 9V batteries, because Arduino can provide a current of 40mA from digital pins, which is not enough. Arduino is connected to a computer using serial connection, but it is preferred to replace it with wireless connection. That is the way the patient would not be limited in space. Monitor displays muscle sensors measurements as we follow the contraction of the biceps. When the muscle is relaxed, third slider (blue) shows the

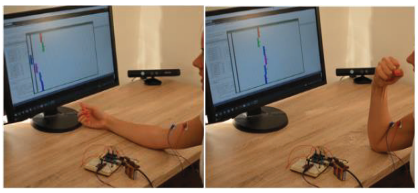


Figure 2. Example of reading data from the sensor muscle with electrodes connected to the microcontroller Arduino Uno. Relaxed biceps place blue slider to 0V (left), Contracted biceps place blue slider to 450V (right)

voltage 0V. When the biceps contracts, blue slider shows the voltage greater than zero. The voltage value depends on physical condition of the patient.

C. SaaS Cloud Rehabilitation Platform

"Cloud computing" refers to the use of the program and the storage space on a remote, scalable, virtual servers, which are considered safe and can be accessed at any time, from any location and any device. Users do not depend on the operating system; they are not required to install programs on personal computers, because programs are available via Internet. This virtual rehabilitation model contains a cloud distributed system, due to simplicity of communication between all users, including therapists, specialists, patients and their family. This SaaS rehabilitation platform consists of:

- *Web portal* for performing rehabilitation games and data access,
- *Data storage* for saving the results of sessions and storing individual patient's settings,
- *Web server* as a connection between data storage and web portal.

Data collected by Kinect and embedded system, during rehabilitation session, will be sent to the cloud SaaS platform. Web server will process received data, and keep every important piece of information in data storage. The problem may arise if user has slow Internet connection. Storing data at remote location (SaaS platform) can slow down game broadcast. The solution is to create local database on user's computer, which will be synchronized periodically with cloud storage.

Through web portal, patient or his family member must connect Kinect and embedded devices with SaaS web portal. Therapists can log into the same web portal and have the ability to view virtual record of patient, create treatment consisted of several games, modify games and communicate with patient.

Web portal contains the following modules:

- *Virtual record.* Each patient who uses SaaS rehabilitation platform will have a virtual record, which will keep information about every performed game including game settings, the goal to be achieved, time of completion, number of successfully and unsuccessfully completed tasks and muscle sensor measurements (muscle strength, reflex). Both, patient and therapist will be able to access all those data, at any time, from any device via Internet.
- *Automatic and manual game modification*. In addition to the manual modification by the therapist, game can be self-modifying. After testing the capabilities and limitations of patient's movements, game is automatically modified. For example, if patient needs to reach items above his head, but the patient is only able to raise his hand to the chin level, rehabilitation game is automatically adjusted to get items, which appear up to the chin of the patient. The therapist may recommend any rehabilitation game, if he determines that patient neglected certain types of exercises.
- *Online communication with therapist.* In addition to playing rehabilitation games, the model provides communication between patient and therapist via text messages, videos or online call.
- *Voice commands for patients with limited hand movements.* Taking into account that Kinect responds to voice commands, the patient can control rehabilitation session with his voice.

IV. Rehabilitation Games

The goal of the game in rehabilitation model is to decrease or eliminate the disability of the patient who survived a stroke, after which his psycho-physical abilities are reduced. Table 1 lists different types of difficulties and a set of movements that patient should practice through games. According to research [6] in United Kingdom, there are 77% post-stroke patients with upper limb disabilities and 72% of patients with lower limb disabilities, 60% of survivors have vision problems while 50% suffer slurred speech. These data indicate what type of rehabilitation games should be represented.

In addition to the games that promote physical and psychological condition of the patient, rehabilitation model includes games that measure progress in rehabilitation. The first group of games is performed every

TABLE I.
Difficulties and Movements Performed in Traditional Physical Therapy

Difficulty and % of affected people	Examples of motions rehabilitation games
Upper limb /arm weakness 77% [a]	Fetch the object in front of body, beside or above head, rowing, biceps contraction, swinging hands diagonally
Lower limb /leg weakness 72% [a]	Moving arm and leg to retrieve or avoid obstacles, bending at the knee, slight squats, lunge right-left, front-back
Visual problems 60% [a]	Tracking objects in particular color, drawing with eye movements, remove objects from the screen by looking at them
Slurred speech 50% [a], Reading difficulty	Reading text that is slowly slipping on the screen, reading the words that come out randomly on the screen
Trunk and postural control	Tilting to the right and left arm/elbow from a sitting position, rotation to the left or right from the sitting/standing position
Balance and reflexes	Exercises for static and dynamic balance, reaction to short-term events, getting up from a chair, lifting objects from the floor

[a] Based on Stroke association research "State of the Nation", United Kingdom, published in January 2015

day, while the second group is performed once a month or less frequently. This rehabilitation model is currently implemented in two games of the first group: "Tennis", intended for the treatment of arm weakness and game "Move items" for visual problems.

The game “Tennis” develops motor skills of stroke affected hand, especially the elbow and shoulder. Virtual tennis rackets are distributed on the screen. A tennis ball is moving toward one racket. The player should raise his hand to the height of the racket, at the time when ball comes to racket and clench the fist to catch the ball. The number of rackets is variable, from 2 for initial level of exercise to 9 for more advanced level. The game uses Kinect and embedded system described in chapter three. Kinect detects movements of the hand and the moment when the hand touches the racket. Embedded system can be placed on the biceps or forearm of affected arm. Embedded device is used only if the patient is able to contract the muscles of the hands. At the beginning of the game, patient is required to raise a hand and clench the fist, based on which the game automatically sets rackets at the proper height and determines whether it is possible to use the embedded system.

This virtual game with two rackets, left and right, was played by patient with very low mobility of the left hand. After initial measurements, left racket is set to the maximum height suitable for patient. Embedded device was not used because the patient was unable to clench the fist. The number of thrown balls per game was 60. The patient used his right hand to touch the racket containing ball on the right side of the screen and left hand to hit racket with ball on the left side of the screen. The results of playing are shown in Fig. 3, where it is noticeable that the number of errors decreases during 2 months of playing. The game can become more difficult if we speed up the balls or increase number of rackets.

The game “Move items” helps patients with reading problems caused by reduced field of vision. Patients with reduced field of vision in the left eye are not able to focus beginning of the line and they start reading from the mid-line. In order to improve the focus on the left or right visual field, a game called "Move items" is developed, where the user takes objects from one corner of the screen to another, see Fig. 4. Patients with reduced left field of vision will have a problem to focus objects on the left side of the screen, and they will need more time to transfer all balls from left to right side, rather than vice versa. Objects are moved by hand. Patient should use healthy hand.

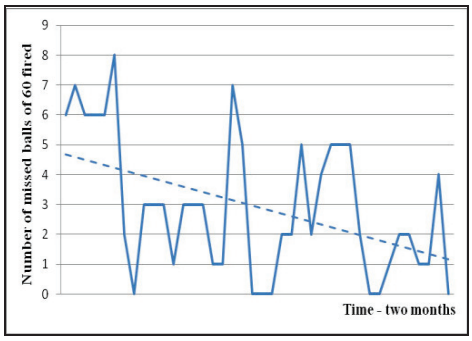
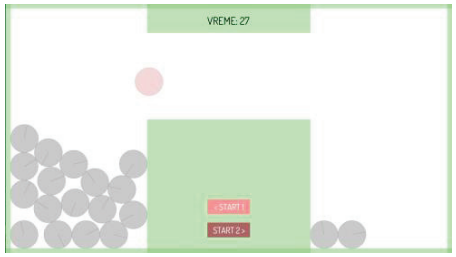


Figure 3: Progress in playing rehabilitation game “Tennis” by post-stroke patient with left arm weakness



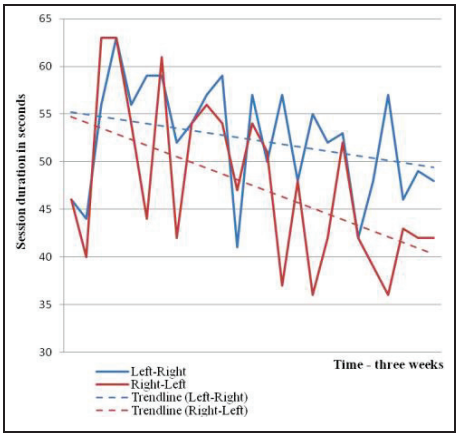


Figure 4: "Move items" game and progress in playing by patient with a reduced left field of vision. Red line - progress in focusing right side, blue line - progress in focusing the left side

Motion detection can be done by Kinect or touch screen. The game can be expanded with embedded sensor described in the third chapter, where fist clench can be used to lower the height of the barrier between left and right side, see Fig. 4, upper image.

Patient with reduced left field of vision played game “Move items” using right hand, in a three week period, once per day and the results are shown in the graph in Fig 4. Y axis shows the time spent on switching 20 balls from right to left (red line) and from left to right (blue line). The graph shows that transferring balls from left to right side lasts longer, which confirms that the patient slowly focuses beginning of the line (left side) during the reading. By comparing the measurements in the first five days and the last five days of the session, the duration of the session was reduced by 15% when moving twenty balls from right to left, and 27% when moving balls from left to right.

The other group of games is a substitute for therapist checking of the patient condition in rehabilitation center. The aim of this group of games is to determine current abilities of the patient and the progress of recovery after a period of practice. “Box and Block” test, published in 1957, is a method to evaluate the mobility of the upper limbs and coordination of movements. The box is placed in front of the patient. In the center of the box, barrier is positioned with cubes on one side of the box. The patient should take one cube at a time and pass over the barrier. If a cube drops out of the box on the other side of barrier, or if the patient moves two cubes over barrier, it is counted as one cube moved. The test is time limited, and progress in recovery is measured on basis of the number of transferred cubes. The game “Move items”, can be easily transformed into “Box and Block” test by modifying game parameters.

Fugl-Meyer test [7] is fundamental in measuring degree of impairment of motor function after stroke. Except for objectively measuring the damage, this test is used to periodically evaluate the degree of recovery of the patient. Reliability of Fugl-Mayer scale has been tested with success in many studies [8][9]. A large set of movements, performed during test, could be traced by Kinect.

V. CONCLUSION

The results of two pilot rehabilitation games showed noticeable improvements in the patient's home therapy. After weeks of playing, patient showed increase of concentration, faster reflexes, higher mobility of the affected hand and smoother reading.

The model described in this paper should enable faster recovery of patients who survived stroke. Kinect device is used as a sensor for the detection and tracking body segments. Embedded system records the muscle ability. Cloud architecture model provides remote access to rehabilitation system. This model eliminates the need for mandatory presence of therapist. The patient can perform all measurements at home, which reduces the cost of treatments. Therapist has access to patient's virtual record and may check its activities at any moment.

This model is developed for research and experiment purposes. The further development can create a product which will be widely used in post stroke telerehabilitation and evaluation of recovery degree.

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