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A NEW TELEREHABILITATION SYSTEM BASED ON INTERNET OF THINGS

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Abstract. *Internet of Things (IoT) applied in healthcare system has a huge potential to improve patients' quality of life. Representing network of devices embedded with electronics and sensors, IoT enables constant monitoring of vital body functions, tracking of physical activities of a person and aids rehab physical therapy. Such an IoT-based system would allow standalone recovery process, minimizing the need for dedicated medical personnel and could be used in both hospital and home conditions. In this paper, we present a telerehabilitation system that uses wearable muscle sensor and Microsoft Kinect to create interactive personalized physical therapy that can be carried out at home. Early experiments and results of pilot implementation validate the feasibility and effectiveness of the proposed IoT-enabled telerehabilitation system.*

Key words: *telerehabilitation, muscle sensor, Kinect, wearable sensor, telemedicine, physical therapy*

1. INTRODUCTION

Internet of things (IoT) is a contemporary technology with the potential to alter or replace the various methods of classical medicine [1] and improve healthcare. The advantage of measuring physical parameters using IoT devices instead of conventional ones is that the connected intelligent IoT devices can carry out measurements independently, and carry out a specific action based on the measurement results. Also, the results of measurements are available via Internet and can be recorded in electronic form, enabling medical personnel to monitor patient’s state from any location at any time. The most common application of IoT in healthcare is in wellness, using devices for measuring daily activities such as walking, running or riding a bicycle.

Telerehabilitation is recognized as a necessary form of treatment for numerous neurological, neuromusculoskeletal, cardiovascular and other conditions [2][3][4]. The

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number of people requiring telerehabilitation is rising. For example, according to World Health Organization Report [5], 5 million people survive stroke each year and half of them remain with hemiparesis (weakness of one side of the body). Medical and rehabilitation institutions are usually limited in space and personnel, so patients are forced to continue practicing physical therapy at home. Expenses for traveling to rehabilitation centres for daily therapy are not insignificant for disabled persons, which contributes to the need for telerehabilitation.

In this article, we present design of telerehabilitation system based on IoT, which will enable the implementation of effective physical therapy remotely, then ensure the insight into the recovery process to competent medical personnel from a remote location, and provide interaction of therapists with the patient via communication technologies. A special attention is given to fostering patient's motivation to repeat the same group of exercises daily through serous games.

2. Related Work and Motivation

Application of IoT in healthcare spans a few different areas: physiological monitoring, ambient assisted living and well-being solutions. However, there is a lack of researches and experiments of IoT usage in assisting and measuring performance of physical therapy.

IoT in rehabilitation therapy should ensure a wealth of information that can produce actions based on defined algorithms [6]. Different kinds of sensors designed for healthcare, like muscle sensor that is measuring muscle activation via electrical potential and devices specialized for skeleton detection and tracking, are used in this rehabilitation model of physical therapy for obtaining feedback and correctness of the performed exercises [7][8]. Readings from sensors are also used for the creation of future exercises and adaptation of interactive physical therapy to the patient's needs [9].

An industrial example of physiological monitoring system is *BodyGuardian* by *Preventico*, based on a band-like sensor patch placed on patient's body. Sensor is powered by batteries which enables mobility of the patient and is connected to a smartphone device. Smartphone transmits data to a cloud-based health platform which further delivers data and alerts medical personnel. Cloud is a logical choice for such a system, as it does not burden patients with configuration of telerehabilitation system [10]. Another example of IoT device, developed for monitoring vital functions like heart and pulse rate, oxygen saturation, blood pressure, and skin temperature is *Visi Mobile* by *Sotera Wireless Inc*. Visi Mobile communicates with e-health system using 802.11 WPA2/PSK security protocol which guarantees protection of wireless communication channel.

Ambient-assisted living represents a technical system for supporting elderly people in their daily routine to allow an independent and safe lifestyle. Sensors in those systems are wearable (for example, accelerometer or gyroscope) or fixed (proximity) and they gather data in order to monitor patient activities or detect a fall in patient's living environment [11].

One of the biggest IoT growth areas is measuring individual health metrics and well-being, through self-tracking wearable gadgets. The use of wearable sensors, together with suitable applications running on smartphone devices enables people to track their daily activities (steps walked, running performance, calories burned, exercises performed, etc.), providing suggestions for enhancing their lifestyle.

Combining all the three groups of application of IoT in healthcare, it is possible to create a model of telereahabilitation designed for physical therapy. Physiological measurements of interest in rehabilitation include heart rate, respiratory rate, blood pressure, blood oxygen saturation. Parameters extracted from such measurements can provide indicators of patients' health status. But in physical therapy higher focus would be on measuring and stimulating muscle activity using muscle sensors. Muscle sensor connected to microcontroller Arduino present a low-cost, low-power solution for gathering electromyography (hereinafter: EMG) data of skeletal muscle. EMG is traditionally used for medical research and diagnosis of neuromuscular disorder.

Repeating the same exercises in a long-term therapy may lead to saturation and skipping therapy. It is therefore important to constantly maintain the motivation of the patient. Serious game is a type of game designed for special purpose in industry of health, education, defence, engineering, and others [12]. Although serious games should be entertaining, their main purpose is to train or educate users. Recent researches [13] show that the cognitive and motor activity required by video games engage the user’s attention. In addition, users are focused on playing game which helps them in forgetting that they are performing therapy.

Microsoft Kinect was recognized as a low price and clinical practical body sensing device to be applied in rehabilitation [14]. Kinect can track a body part and can also reproduce 3D space with player in front of it which enables creation of virtual reality games. Therefore, Kinect is the basis of most interactive game-based rehabilitation solutions. Physical therapy exercises are performed while playing games, which aim to facilitate the implementation of therapy [15][16]. There are several clinically tested solutions of physical therapy using Kinect sensor [17][18]. In mirror magic neurorehabilitation clinical trial [19], Kinect influences positively the process of rehabilitation. In [20] five rehabilitation games using Kinect were evaluated, also with a positive outcome. One great example of application of Kinect in rehabilitation is *VirtualRehab* solution, developed by Spanish *VirtualWare*, which consists of web based control centre - administrator software platform and several games designed for Kinect (http://www.virtualrehab.info). The control centre is used by therapists to prepare a plan of exercises, to monitor and assess the progress of therapy.

3. TELEREHABILITATION SYSTEM ARCHITECTURE

As a substitute for physical therapy conducted in medical institutions, telerehabilitation therapy should include the same scope of exercises, but without physical presence of physiotherapist. In order to lead a patient through a therapy session, the system must have a virtual assistant in a form of a web based application and a set of games tailored specifically for the patient.

Telerehabilitation system architecture based on IoT is configured in two segments: a home based segment and cloud based Software as a Service segment (see Fig. 1).

Home based segment requires components such as Kinect body tracking sensor and muscle sensor, to be installed and setup at patient's living environment. Also, the patient must have a personal computer with Internet connection in order to receive therapy sessions and to send data collected by sensors.

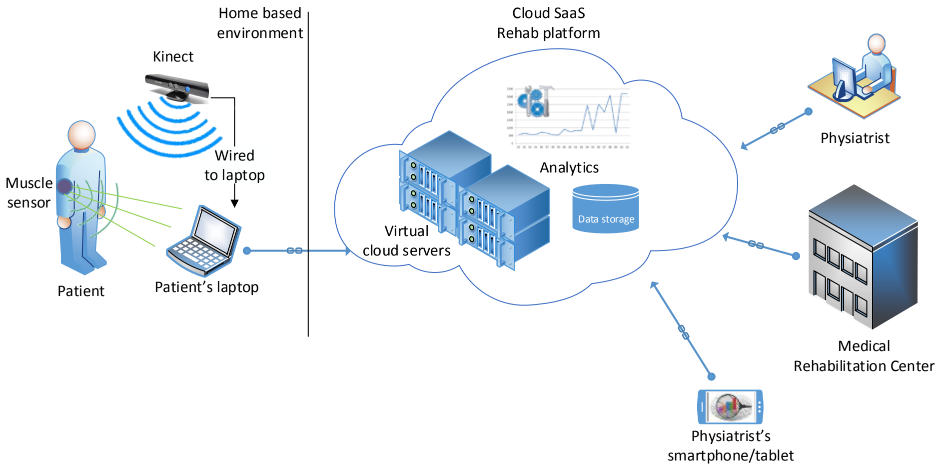

Fig. 1 Components of telerehabilitation system

Software as a Service cloud based segment serves several purposes:

- provides software for telerehabilitation therapy,
- collects feedback after performed therapy for each patient,
- analyses collected data and represents it in comparative and progressive form, and
- allows physiatrists to follow patient's condition remotely and manage further therapies.

3.1. Intelligent sensors and actuators

The role of sensors and actuators in telerehabilitation is twofold: to diagnose patient's physical abilities based on measurements and to use read values for adaptation, and tailoring rehabilitation game in order to meet patient's mobility.

Sensor applied in the pilot implementation of this model is *muscle sensor v3*, electromyography sensor for microcontroller applications, including three electrodes, connected to microcontroller Arduino. Using the muscle sensor, it is possible to measure muscle activation via electrical potential EMG, 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 to get skin cleaned using alcohol. This step is mandatory in order to provide a better grip of electrodes and reduce the electrical resistance of the skin. Proper placement of EMG electrodes is crucial for accurate measurement of muscle contraction. Unfortunately, if a muscle has more body fat, EMG signal will be weaker and difficult to record. The motivation for using muscle sensor in pilot telerehabilitation of physical therapy is the need to strengthen muscles and also to measure progress of reinforcing muscles, depending on the type of exercises. For example, if the patient is required to alternately contract and relax the muscle, they will experience it as an effort, compared to a situation when they are performing same actions while playing a game, unconsciously. In the second case, the patient will probably perform more repetitions of muscle contractions and relaxations because they are unaware of those actions. Based on the above, the use of muscle sensor in rehabilitation games should lead to improvements in patient's muscle structure.

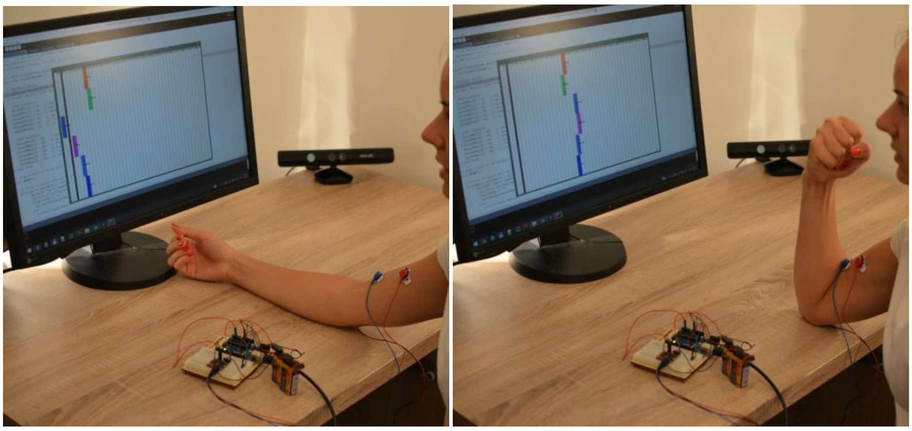

Fig. 2 Example of reading data from the muscle sensor with electrodes connected to the microcontroller Arduino Uno. Relaxed biceps places blue slider to 0 (left). Contracted biceps places blue slider to a specific value measured by the sensor (right)

Figure 2 shows connection of muscle sensor with Arduino Uno microcontroller. The sensor requires 9V power, and since Arduino Uno can provide operating voltage of 5V, muscle sensor must be power supplied by two 9V batteries. In these settings, Arduino Uno is connected to a computer using a serial connection, but it is preferred to switch to wireless connection using Arduino WiFi Shield. Arduino would use the 802.11 b/g/n protocol for communication with application on laptop computer and, as a result, patient wouldn't be limited in space. In the settings as in Fig. 2, muscle sensor is placed on biceps, and values representing muscle contractions are displayed on the monitor. When the biceps muscle is relaxed, blue slider (third rectangle on the left side of the figure) shows the voltage of 0 V. When the biceps contracts, blue slider (third rectangle on the right side of the figure) shows the voltage higher than 0. The voltage values depend on the physical condition and muscle function.

3.2 Body tracking sensor

The system was implemented using the Kinect body tracking sensor which consists of an RGB camera, infrared (IR) camera and IR projector. RGB camera is a standard colour camera. IR projector emits infrared rays in space which bounce off objects and return back to IR camera and measures the distance between Kinect and objects [21]. This feature is useful in the creation of therapy when the patient has to position the hand in front of or next to his/her body. All three components: RGB camera, IR camera and IR projector allow the creation of 3D images. With the depth stream, it is possible to estimate human motion in real-time. However, the acquired depth data can be quite noisy and the image can consist of pixels with no depth because of multiple reflections. To cope with that it is mandatory to perform denoising. For further information about denoising, refer to paper [22] which presents new data-driven-based denoising technique.

Kinect can distinguish parts of the body and it can determine the position and orientation of the body. Validity and reproducibility are important characteristics of this device [23] which makes it applicable in telerehabilitation applications.

In addition to objects, Kinect can detect sound. This feature is not sufficiently exploited although Kinect can determine the source of sound very accurately.

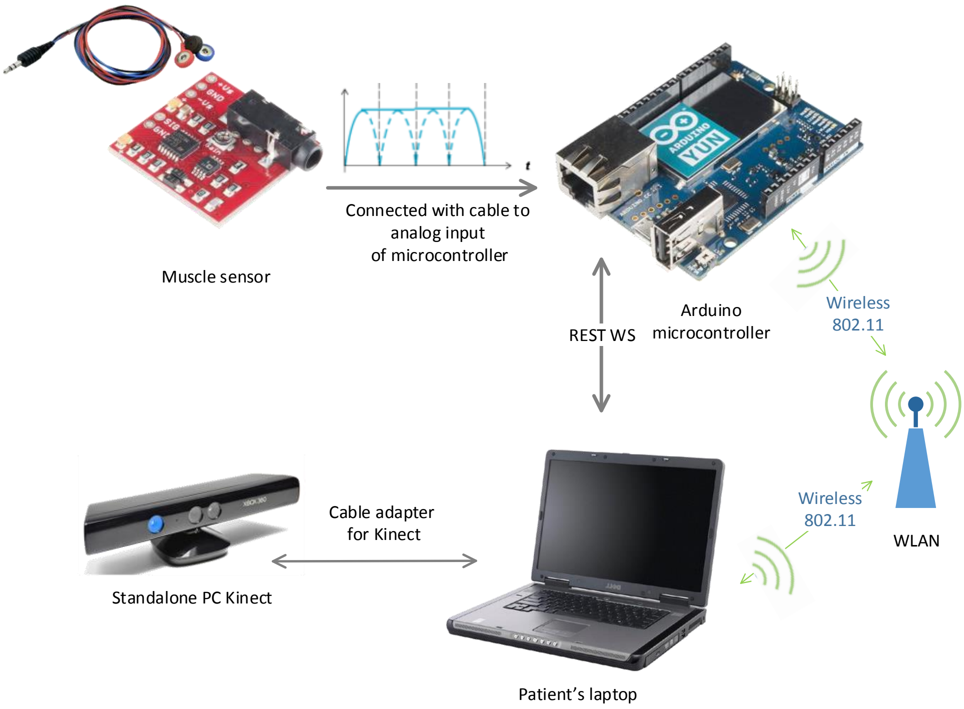

Fig. 3 Home based equipment of telerehabilitation system - schematic view

Fig. 3 represents a schematic view of the equipment required for home base segment of telerehabilitation and shows the type of communication protocols and device connection.

3.3 Software as a Service

Nowadays, cloud-based data storage, computation, software, platform and computing infrastructure are widely used for many different applications. Using content and services from the cloud eliminates time and costs of buying hardware and installing and maintaining software. With cloud infrastructure health monitoring systems become low-cost, platform-independent, and rapidly deployable. Applications deployed via cloud can be easily updated without forcing a patient to install any software on their devices, thus making system maintenance quick and cost effective.

In Fig. 4 we propose the concept of telerehabilitation platform based on Software as a Service cloud model containing four services: telerehabilitation application for patient, setup and analytics application for therapist, game session manager and processor for sensor information, database for persisting of rehabilitation information and web and application servers for running the above described services. We envisage integration of telerehabilitation system with medical information system and using information from Electronic Health Record, EHR, of the patient for precise diagnosis.

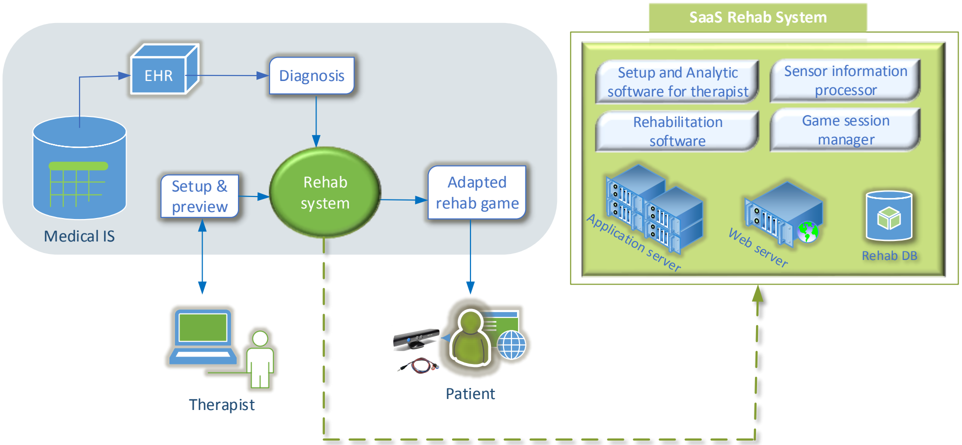

Fig. 4 Proposed concept of cloud based Software as a Service rehabilitation platform

In this system, Kinect is used in rehabilitation therapy to determine the patient's mobility and limitations, before the beginning of therapy. By testing patient's limitations in movements (for example, height to which he/she can raise the affected hand or move it to the right, left, or bend) and the actual speed of movement, a set of parameters is obtained, upon which the system may recommend a list of games. During therapy, body position is very important, and it is detected and recorded by Kinect, because the patient is tilted to the right if they find it too hard to lift their left arm.

After the patient finishes the session, raw data gathered from the muscle sensor and Kinect are sent to the cloud SaaS application server. The received data are filtered and transformed into meaningful information, linked to the patient and stored in cloud data storage. The new session is then provided to the user until they decide to finish the therapy. Data stored for each performed session can be used for various purposes and benefits. Analytic software for therapists may present diagrams of patient's performance and progress. Great amount of gathered data gives an opportunity for medical data mining and opens the door to a vast source of medical data analyses. Finding patterns in the impact of a certain exercise to the establishment of the lost physical function, classification and prediction will create a knowledge base able to recommend a set of sessions to any new or existing patient.

In order to promote physical and psychological condition of the patient, training sessions should be designed for a specific type of disability. Based on stroke statistics report [24], conducted in the United Kingdom, there are 77% of post-stroke patients with upper limb disabilities, and 72% of post-stroke patients with lower limb disabilities. According to these findings, the first trial game (Fig. 5) is designed for practicing motor skills and coordination of stroke affected hand, especially elbow and shoulder.

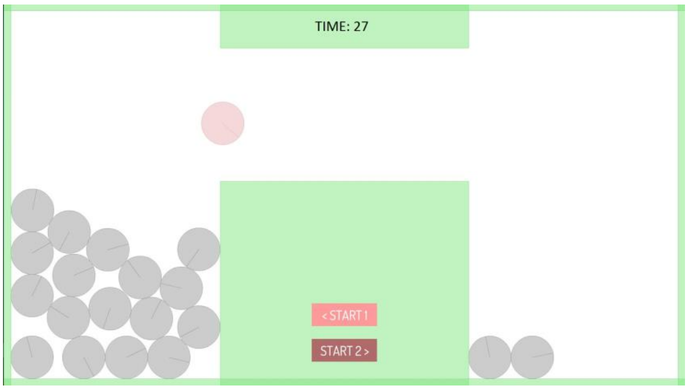

Fig. 5 Serious game for hand and elbow rehabilitation consisting of virtual box with green barrier and twenty balls

Trial game is designed to contain only essential elements, without details that could draw patient's attention. Elements in the game are virtual box filled with virtual balls located at one side of the box and adjustable barrier placed in the middle of the box, separating the box into two parts. Patient's movements are tracked using Kinect body sensor and their task is to take a virtual ball, placing their palm at the ball position and to drag the ball to the opposite side of the box, over a virtual barrier. The barrier height is adjustable in order to match patient's capabilities. If a patient is able to contract any muscle of the stroke affected hand, it should be insisted on muscle sensor usage in the game because it will increase muscle strength and endurance. In a trial game with a virtual box, EMG muscle signals can be used for grabbing the ball when the palm covers it and for releasing the ball after passing the barrier.

4. Patient Trials and Results

In order to test telerehabilitation system in the domain of patient environment and patient's reaction to the new type of therapy, we setup a home based equipment containing Kinect, Arduino Uno and muscle sensor in the patient's home environment. The patient was requested to play an interactive telerehabilitation game with a virtual box and the results of playing were recorded to patient's computer and uploaded to the remote computer. The goal of this trial was to test one part of the proposed telerehabilitation system - interactive telerehabilitation game. Interactive serious game has been tested on a single patient during one month pilot trial. The patient is a 60 year old male, who sustained a right hemisphere stroke a year before trial testing and as a consequence has hemiparesis of the left side of the body. The mobility of his left hand is very low and the goal is to increase it.

One week prior to the start of the rehabilitation trial, the patient had gone through baseline rules to play virtual telerehabilitation game with a virtual box. The patient played the game using the stroke affected hand, in the three week period, five to six days per week, one hour per day. Unfortunately, the patient was unable to close the fist and therefore contract the biceps, therefore the readings from the muscle sensor are omitted and the virtual ball is considered captured when the patient holds the hand over the ball position for several seconds and the ball is considered released when the patient's hand passes the barrier and a half of the box after the barrier. The results obtained after the three week telerehabilitation period was completed, are shown in Fig. 6. That figure shows that transferring balls from the left to the right side lasts longer, which confirms that the patient slowly focuses the left, stroke affected side. Comparing the measurements in the first five days and the last five days of the session, the duration of the session was reduced by 27% when moving twenty balls from right to left, and 15% when moving them from left to right.

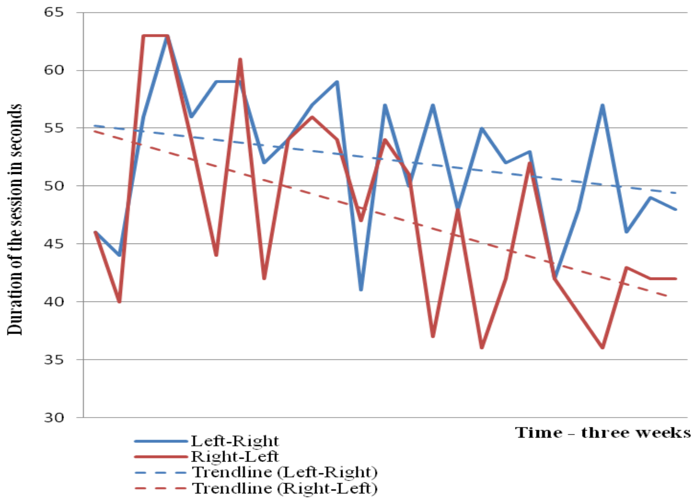

Fig. 6 Progress in playing the game between the first and the last day of telerehabilitation home based trial

5. Discussion

The results of the pilot trial of three week telerehabilitation session using serious game showed noticeable improvements in rehabilitation. After the trial, the patient showed increase of concentration, faster reflexes, and higher mobility of affected hand and better focus of left side when reading.

The trial reveals that compared with in-clinic rehabilitation process, telerehabilitation process offers several benefits. In-clinic rehabilitation is by its nature repetitive and command based, which may reduce patient motivation. Serious game telerehabilitation tends to demand movements based on purpose (pick the object, move the object, clean the surface, etc.) and tries to motivate the patient to achive better score in every game iteration. Traditional rehabilitation requires one therapist per patient and both have to be in the same place. In telerehabilitation therapy session, one therapist can lead several patients, a session can be designed in advance for each patient and the therapist and patient can be miles apart. Thus, telerehabilitation model reduces travelling costs, and reduces the time therapist spends for preparing a single patient therapy – compared to the time when the therapists works with one patient, showing exercises and waiting for the patient to complete it. The distribution of therapists over the territory is usually uneven, with higher concentration in urban regions and city centres, and there is a lack of skilled therapists in rural and remote locations. It is exactly here that telerehabilitation model can give most contribution in providing an opportunity for each patient to be treated equally well.

However, hereby presented telerehabilitation model is highly dependent on Internet accessibility, availability of Kinect body sensor, muscle sensor and personal computers. Also patients or their caregivers should have basic computer knowledge in order to setup telerehabilitation equipment.

Validity and reliability of Kinect body sensor has already been tested and confirmed [23][25]. Kinect detects body skeleton automatically, but it requires at least two square meters clean place. Compared to Kinect, muscle sensor is not that simple to calibrate and to properly set. EMG signal is usually very poor, which requires repetition. To improve the EMG signal stability, the muscle sensor should be placed on a large muscle. Second potential problem regarding muscle sensor is noise. Interaction between the electrolytes in the skin and the metal of the detection surfaces of the electrode can produce noise. Noise can be reduced employing conductive electrolytes to improve the contact with the skin and also by removing dead dermis from the surface of the skin.

6. CONCLUSION

The telerehabilitation model described in this paper allows for a faster recovery of patients who have survived a stroke. Kinect device is used as a sensor for detection and tracking of body movements. Muscle sensor records the muscle strength. Cloud architecture model enables building a stable, scalable, reliable, cost effective and easy to use telerehabilitation system. This telerehabilitation system eliminates the need for mandatory presence of the therapist and enables a patient to perform post-stroke rehabilitation therapy at home, reducing the cost of treatment. Therapist has access to patient's virtual records and may check his/her activities and remotely guide the therapy at any moment.

This model developed for research and experiment purposes serves as a foundation for creating a product which will be widely used in post stroke telerehabilitation and evaluation of the recovery degree.

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