Low-cost motivated rehabilitation system for post-operation exercises

Jan Brutovský and Daniel Novák

***Abstract*—The incidence of joint fractures is increasing and has become one of the major health problems in developed countries. Our low-cost motivated rehabilitation system enables clinicians to prescribe, demonstrate and monitor patient rehabilitation protocols during and between clinical visits. With its unique biofeedback feature it is useful for continuous patient's motivation. The proposed system can be used in wide spectrum of rehabilitation scenarios by simply downloading appropriate protocols. The hardware and software architecture (communication protocols, power management policies and application-level control) have been tuned to optimize cost, battery autonomy and real-time performance required for this application. The main advantages of the proposed system is home-based rehabilitation, low-cost and good user acceptability.**

I. INTRODUCTION

One of the most common injuries in sport and active life are joint injuries. The joints are the most important parts in our kinetic system, their injuries and malfunctions are profoundly limiting our movements. Good fixation and relaxation are very important during the treatment of the injured joint. Moreover, rehabilitation exercises also form a very significant part of the healing process and strongly contribute to the improvement of the injured joint functionality.

According to the statistics of The Institute of Health Information and Statistics of Slovak Republic [10] there were hospitalized 5746 patients (106,83 patients per 100.000 inhabitants) with patella and knee joint fractures in year 2003.

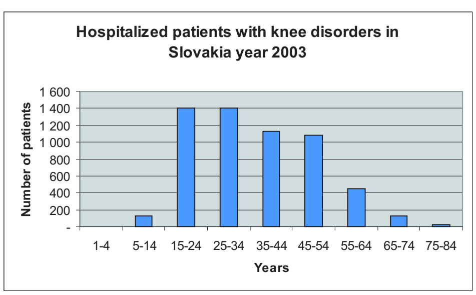

Fig. 1. Hospitalized patients with knee disorders in Slovakia 2003

The Figure 1 shows the fact, that people in the active age from 15 to 54 are the group with the highest risk of suffering from knee injuries. The rehabilitation process offers these patients the opportunity to get back to their active lifestyle as soon as possible.

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In order to improve the patients' health status various rehabilitation exercises and protocols are used in a traditional rehabilitation process. However, these processes require repeated visits of the patients in a rehabilitation center. The system intends to perform the rehabilitation process at home providing continuous motivation to the patient. Furthermore, the proposed solution is a telemedical approach enabling communication with clinician without need of frequently clinical revisions using advantage of motivated rehabilitation and telemedicine approach.

A. *Motivated rehabilitation*

We define motivated rehabilitation as a process which uses positive motivation to improve patient's health state and his quality of life. This motivation is based on goals to overcome, exercise history reviews and progress reports. The main concept applies real time biofeedback during rehabilitation informing patient about achieved results and further goals to succeed. The Figure 2 shows the principle.

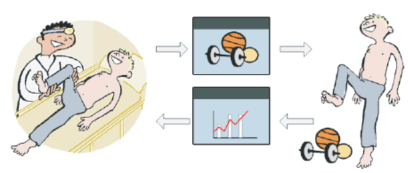

Fig. 2. Motivated rehabilitation

B. *Tele-rehabilitation*

Tele-rehabilitation is a type of rehabilitation, which uses information technologies to increase patients quality of life. Our system solution uses hand held monitors for the patients' health-care status monitoring. Data are processed, evaluated and transferred to the clinician to make adequate decision using client-server technology.

C. *Rehabilitation Systems*

1) Posture recognition: Most works concentrate on gesture and posture recognition to predict patient's position and movements for further evaluation [5]. Those systems measure functionality of limbs and different human body parts using accelorometers. However, the systems do not intend to offer any rehabilitation [6].

2) Universal monitoring devices: Universal monitoring devices (UMD) are systems that monitors health status by measuring whole range of physiological signals as ECG, EEG, EMG, GSR, motion or temperature. UMD intents to create universal rehabilitation platform, which can monitor long-term patient's health status at home with ability to communicate with medical support when needed [3], [4]. Disadvantage of universal systems are complexity and high cost.

3) Goal oriented rehabilitation manager: The systems are goal oriented, e.g. only for post operation rehabilitation exercises without need of universality. One example is Donjoy Vista Rehab Management which uses an interactive brace with sensors attached for providing continues biofeedback for the patient during rehabilitation exercise [11]. The Donjoy system is oriented only for knee rehabilitation.

The proposed system in this work was designed to meet the following requirements, i) goal oriented only for the post-operation rehabilitation, ii) low-cost, iii) available for patients for home use, iv) durability. The system is equipped with 3D motion sensors [9] that could provide biofeedback not only for knee, but also for ankle, wrist and hip.

The User Interface between patient and sensor unit is a mobile device (Personal Digital Assistant-PDA or mobile phone). This approach offers an audio-visual interaction with the patient.

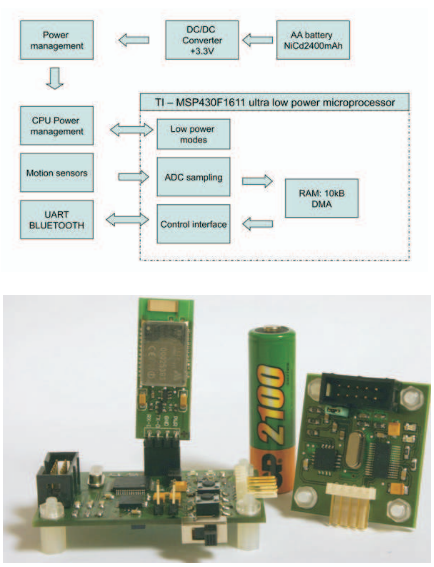

Fig. 3. Sensorial unit, master and slave

II. Methodology

The whole architecture is a simple telemedical system which operates as a virtual rehabilitation manager. The device consists of sensorial unit with motion sensors, visualization and communication unit and virtual clinical revision server. The patient according to clinician prescription can download his rehabilitation protocol using visualization unit (e.g. PDA). Every day he places the sensor unit around his affected leg - see Figure 4. At first, the patient is supposed to read instructions for the selected exercises. Then during exercise PDA guides and informs patient using audio-visual interface and such a way the quality of performed exercise is assured.

A. Sensor Unit

The sensorial unit, which measures the limb movements, consists of 3D acceleration sensor, microprocessor and BLUETOOTH module. In order to be wearable [2], it fulfils the following requirements: the sensor unit has to be lightweight, small, low-power and low-cost. Those specification are met by 3D MEMS acceleration sensor MMA7260Q, 16bit ultra low-power microprocessor MSP430, BLUETOOTH module from BR-C30 and Step-Up DC-DC Converter MAX1674.

The measurement of the tilt is the easiest way to monitor knee, elbow and head movements during slow rehabilitation exercises. Tilt is a static measurement where gravity is the acceleration being measured. Therefore, to achieve the highest degree resolution of a tilt measurement, a low-g, high sensitivity accelerometer is required [9]. Therefore, MMA7260Q acceleration sensor was selected. This accelerometer has the range of +1g to -1g as the device is tilted from -90 degrees to +90 degrees. The analog values are sampled by microprocessor's Analog to Digital Convertor (ADC) in 12bit resolution at 10Hz. These data are filtered and tilt angles in x, y, z axis are calculated by the equation 2, and lookup table for arcus sinus function [9].

$$Vout = Voff + (\frac{V_d}{g_d} gsin(alfa)), \tag{1}$$

$$alfa = arcsin(\frac{Vout - Voffset}{\frac{V_d}{g_d}}), \tag{2}$$

where, V_{out} is accelerometer output in Volts, V_{off} is accelerometer 0g offset, V_d/g_d is sensitivity, g is Earth's gravity, $alfa$ is angle of tilt.

Regarding the software implementation, the proposed Java 2 for Micro Edition (J2ME) technology allows to run java application on mobile phones with Mobile Information Device Profile 2 (MIDP2) and on PDAs with MIDP2 emulator [13]. MIDP2 application was created, which can connect the sensorial unit via BLUETOOTH [14], read the tilt angles and draw a leg model to the screen with additional indicators. The collected data are saved to the inner database - Record Management System (RMS) [7]. The PDA acts as a communication unit with client-server capability. Furthermore, the PDA is able to connect to the virtual rehabilitation server and to transfer exercise results. The exercises are defined in XML format like The description of one exercise consist of definition of steps, images for visual guideline, sounds for audio guideline and selection of sensitive axis. Then the resulting XML structure is parsed with kXML package [8].

B. Virtual Rehabilitation Manager

The Visualization Unit (VU) works as a guideline of rehabilitation exercises providing biofeedback feature. Before the exercise starts, the VU offers a simple instruction guide. During the exercises the system monitors patient's

Fig. 4. Sensor position and preparation for exercise

body movements, in our case movements of his leg with sensors attached on his leg - see Figure 4. The patient see the actual position of his leg in the form of simple leg model on VU. Additionally, those information are displayed: Range of Motion (ROM)-the difference between start leg position and final leg position of one exercise step, number of exercise repetitions and the remaining exercise step to accomplish. At the same time the patient is guided throughout exercise by auditory support system.

Finally, progress bar is shown at the end of each exercise recapitulating achieved results in comparison to the past performance history - Figure 6. Compliance report is further generated for both clinician and health insurance needs. The report contains the detailed description of all performed exercises. Using the generated report, the clinician is able to analyze rehabilitation progress and to make adequate decision in patient's rehabilitation protocol.

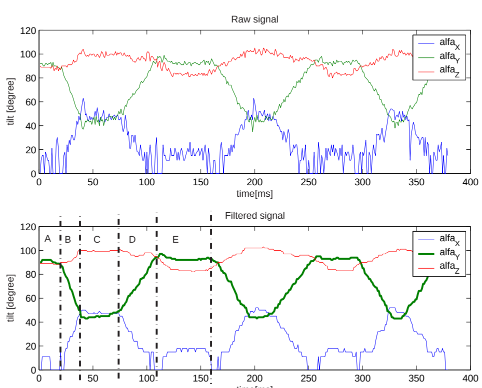

Fig. 5. Captured signals

C. Example of Rehabilitation exercise

This sample exercise Supine - Straight Leg Raise was chosen for its simplicity [12]. This exercise is intended as a strengthening exercise for the quads. It is based on increasing strength and control throughout the quad muscle group. Figure 7 describes the exercise along with visualization of patients' movements.

1) Step: Lye on your back, straight your injured leg straight as possible, toes pointed to the ceiling. Uninjured leg bent up to 90 degree. Slowly lift up your injured leg from the ground. Figure 7-A,B.

2) Step: Hold your leg for 5 seconds in this position, then slowly lower your leg down to the ground. Figure 7-C.

3) Step: Relax your leg for 5 seconds, then repeat the exercise. Figure 7-D,E.

III. Results and Discussion

The system is being validated in a small pilot study including six persons after joints injuries. Patients can see their e.g. weekly progress in the form of bar graph as shown in Figure 6. The goal of the clinical study is to examine the effects of rehabilitation using the motivated approach compared to a traditional rehabilitation protocol that utilizes written instructions and physical therapy visits. Subjective (questionnaires), clinical, and functional outcomes will be measured to evaluate the differences between rehabilitation protocols.

In the upper part of Figure 5 the raw signals polluted by noise are shown: $alfa_X, alfa_Y, alfa_Z$. An average filter was applied to remove the noise and the resulting signals are shown at bottom of Figure 5. The signals are segmented according to the correspondence between each exercise step A,B,C,D,E in Figure 7. Since no complex algorithms for prediction and human body modelling were used, the proposed system is simpler in comparison to other solutions for limbs rehabilitation [1], The movements are derived by calculating tilt in *x,y,z* axis according to the Earth's Gravity.

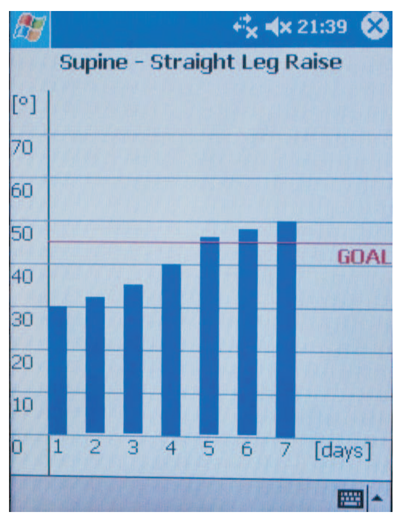

Fig. 6. One week progress report

A. Advantages of motivated approach instead of traditional

1) Patients positive motivation: The positive motivation can be seen in two ways. Firstly, during the rehabilitation exercise patient sees actual state of each exercise step and its relation to the best result achieved in the actual session. Secondly, during the whole rehabilitation any small improvements summarized in the progress report gives further motivation to patient.

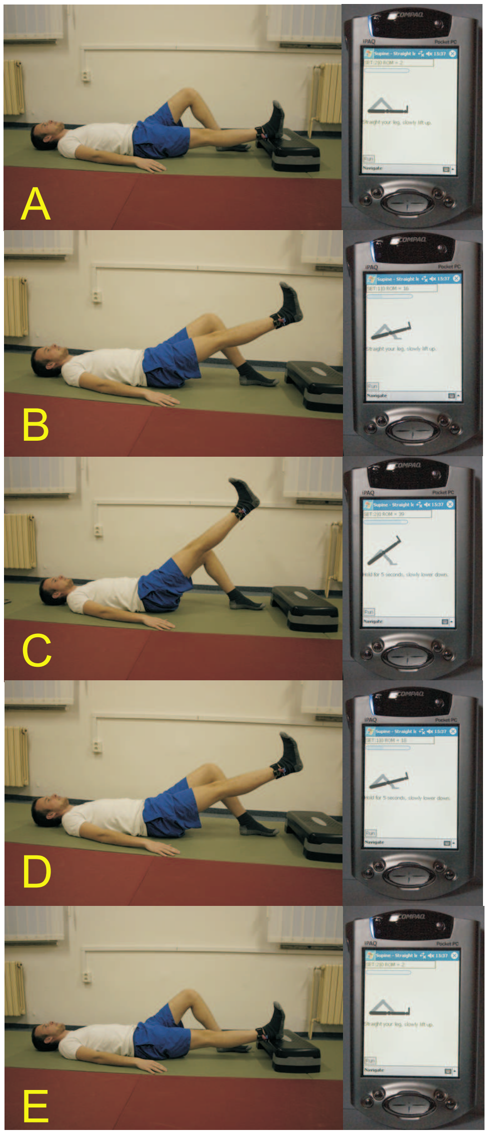

Fig. 7. Sample exercise

2) Telemedical approach: The patients keeps contact with the clinician through visualization unit, e.g. PDA or mobil device without leaving him home. The system automatically sends compliance and progress report to the clinician for further consultation. Based on patient history, the clinician adjust the rehabilitation protocol.

3) Transparent rehabilitation protocol: The progress and compliance reports are very transparently designed and can be directly used for purposes of health insurance company or clinician.

IV. CONCLUSIONS AND FUTURE WORKS

In this work a simple and low-cost solution for patient's continues rehabilitation at home-use has been presented. The proposed system can be used in wide spectrum of rehabilitation scenarios by simply downloading appropriate protocols. In major cases the sensor system can be connected directly to existing new-generation of smart hand-held devices. The main advantage is that the user can experience the rehabilitation procedure using his favorite mobile phone lowering thus the total costs.

Future work will include further investigation and experimental sessions to complete the system validation and to optimize the system performance and rehabilitation protocols.

ACKNOWLEDGMENT

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