A VERSATILE SYSTEM FOR HOME REHABILITATION OF POST-SURGERY PATIENTS

D. Moga***, F. Neaga*, M.R. Dumitrean****, P. Dobra**, R.A. Munteanu***, and V.Trifa**

* Salaj County Hospital, MD, Zalau, Romania
** Technical University, Professor, Cluj-Napoca, Romania
*** Technical University/Automation, Lecturer, Cluj-Napoca, Romania
**** Technical University, PhD Student, Cluj-Napoca, Romania

daniel.moga@aut.utcluj.ro, f.neaga@yahoo.com, mihai.dumitrean@tedelco.ro, petru.dobra@aut.utcluj.ro, radu.munteanu@mes.utcluj.ro, viorel.trifa@mes.utcluj.ro

Abstract: A smart continuous passive motion (CPM) system was designed for both home rehabilitation and hospital care of post-surgery patients. The experimental system is interfaced to a PC via a wireless link. In order to provide a flexible remote configuration and monitoring of the patient evolution software application was developed. It allows to set exercises and to monitor the patient progress.

Introduction

The proposed application addresses one of the most important problems for the post-surgery patients who have had traumatic orthopedic surgery (for example a total joint arthroplasty). In this case the replacement of the osteoarthritic joint components significantly reduces the patient's joint pain and improves the likelihood of voluntary movement, but the trauma to the soft tissue and resultant immobility can cause long-lasting impairment and disability if not addressed immediately and appropriately. Continuous passive motion (CPM) is one of the primary methods for decreasing the deleterious effects of immobilization [1]. It is not relying on methods of stimulating the muscles for inducing a motion [2].

Materials and Methods

The proposed system has three main components: the CPM system, the CPM to PC interface and the distributed application for monitoring and control.

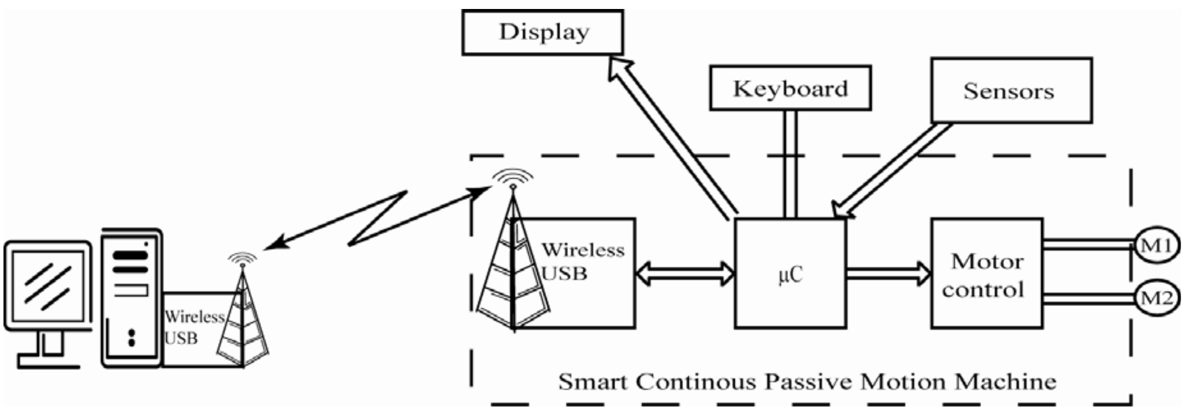

Figure 1: Smart continuous passive movement machine block diagram

The first component is a mixed hardware-software application, consisting in a wireless USB communication subsystem, a microcontroller unit with a display and keyboard, a stepper motor driver subsystem and a sensor acquisition subsystem (Figure1).

The CPM's USB wireless interface (which uses the unlicensed 2.4 GHz Industrial, Scientific, and Medical (ISM) band for wireless connectivity) is used to allow bidirectional communication with a host PC, from where the appropriate CPM routines can be received, and the CPM treatment results can be logged.

To ease the control of the CPM unit, a GUI based application is implemented. This application can be used to setup specific CPM routines. It also allows monitoring the feedback from the CPM's mechanical system and logging the appropriate information.

ISSN: 1727-1983 © 2005 IFMBE

That is a feature required for keeping track of the progress of the treatment.

Once the physician's prescribed movements are loaded into the microcontroller unit (in the form of a treatment routine), it will be its task to assure appropriate sequence of movements, at the appropriate speed.

A driver board allows this microcontroller to control two stepper motors in order to perform the prescribed movements. Stepper motors were preferred in this setup because the possibility to use them not only for rotating the mechanism but also for breaking the mechanism into a certain position and holding it in that position.

As indicated in Figure1, a set of sensors are used to provide a feedback loop.

By reading sensor data, the embedded software computes the angle of the different segments of the mechanism, so that at any moment a complete description of the passive movements executed by the patient is available. These descriptions, together with other salient information (both technical and medical) are sent to the host PC for archiving.

The physician can use this information to monitor the progress of the treatment. A valuable feedback can be obtained this way, allowing the physicians to adjust the treatment routine so that it will fit more closely to the specific evolution of each patient.

Results

A CPM unit equipped with a display and a keyboard was implemented.

In this way, the patient can monitor the execution of the prescribed routine, and, if the physician has allowed this, can control the execution of the exercise (it might be wanted, for example, to accommodate to an acceptable level of pain).

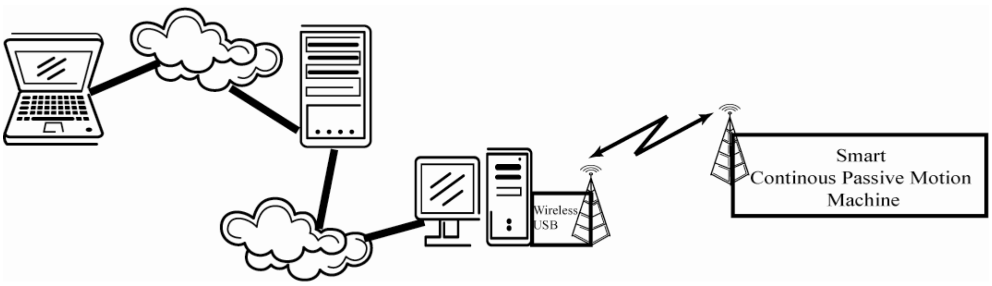

Figure 2: Distributed system

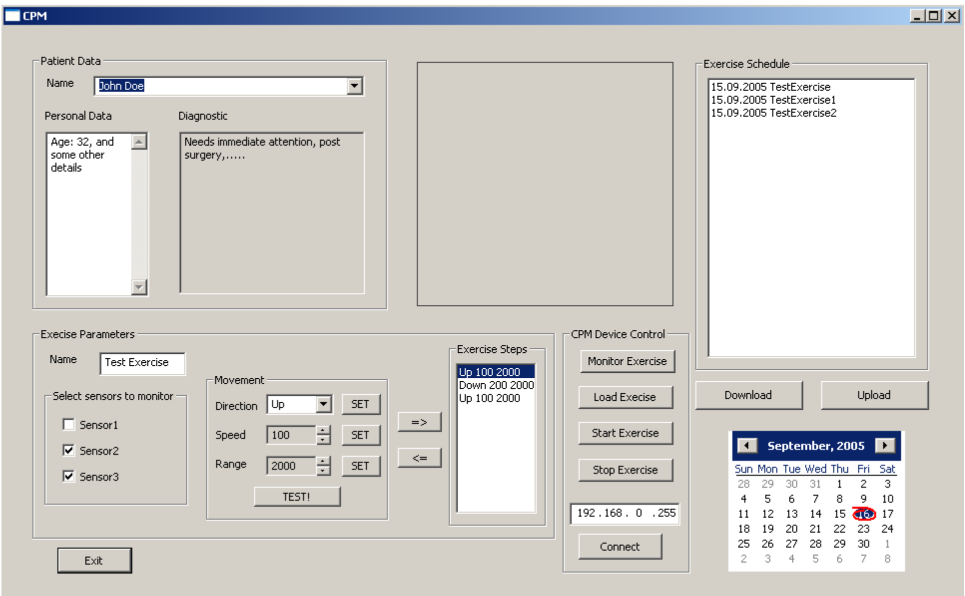

Figure 3: The control application

ISSN: 1727-1983 © 2005 IFMBE

In order to provide a flexible way for supervising the patient's treatment, we provide a distributed application (Figure 2) that provides following features:

- remote visualization of the current status of the CPM system (type of exercise, exercise's parameters, user feedback, technical data, etc.),
- visualization of the history of the patient's treatment,
- setting up the exercises.

The control application was developed in Microsoft Visual Studio. Through its interface, the main control features of the CPM system can be set up, as shown in Figure 3.

The layout of the interface is split in several frames :

- patient information,
- (rehabilitation) program data,
- CPM system (remote) control.

The personal data and the diagnostic provide the physician with relevant information for setting up the exercise. Each exercise has a name that can be used to identify in the schedule which exercise is queued for execution, and to ease the tracking in the corresponding exercise log.

An exercise is made of a series of steps. Each step defines the parameters of the movement that will be used to control the CPM device.

The movement is characterized by three parameters:

- direction ("Up" or "Down"),
- the speed ,
- the number of steps to perform.

The steps that describe the movement are used to control the stepper motor (they are not related to the exercise steps, which describe the building blocks of the exercise). Before adding an exercise step to the current exercise, it is possible to test the parameters.

Once the exercise is defined, the next thing is to schedule the exercise. This can be done using the "Load Exercise" button on the CPM device control panel. Using the associated calendar control, the exercise gets a date associated with it. This feature can be useful in the situations when a schedule for the rehabilitation program is required to be created.

Once the schedule is complete, using the Upload button the whole schedule is sent to the CPM unit.

Using the Download button, the existing schedule can be visualized, and each exercise can be modified, if needed.

The Monitor Exercise button, allows the physician to track the evolution of the exercise, through visualisation of the feedback data received from the CPM unit.

In the case that the CPM unit is not locally connected, a TCP/IP connection can be established with the remote machine. In this way the remote application will receive the data from the control interface and will then transfer it to the CPM unit.

The feedback data is also transmitted using the TCP/IP connection. In this way the physician will be able to asses live the execution of the exercise. If it is the case he can stop the exercise, change the parameters and then start the exercise again.

The CPM unit will execute by default only the exercises that were already scheduled (uploaded) to it. However it is possible that the CPM unit is controlled on-line, that is the physician can define and execute an exercise at once.

The logging facility is always available, all the executed exercises being logged so that at any time the history of the exercised can be visualised.

The experimental CPM unit is shown in Figure 4. Three tilt sensors are mounted in order to have information on the position of all segments. These sensors are highlighted in Figure 4 by surrounding circles. They are constructed based on a 2-axis accelerometer. The analog signal of the accelerometer sensor is converted in digital signal by an A/D converter. The A/D converter is connected to a microcontroller board through I^2C bus. The microcontroller board reads the data from each channel of the A/D converter. An embedded application is filtering these samples and is computing the tilt angle.

The values of the acceleration measured on the x and y axes of the accelerometer can be used to obtain the values of the sine, cosine or tangent for the angle that has to be estimated.

The computation of the tilt angle is based on the computation of the arctangent function. Since the Taylor series approximation of arctangent converges to a desired error (ex.10^{-8}) using no less than 7000 terms a computation of the angle based on such algorithm is hardly feasible on a microcontroller implementation. That was the reason for looking for alternate solution whose requirements in terms of computing power and memory needs are matching better with the architecture of a low cost microcontroller.

The solution we experiment is to approximate the arctangent by a ratio of two polynomials. The approximation error is about 10^{-8} .

The prototype board responsible with reading sensor data and displaying messages can be seen in Figure 5.

A low cost microcontroller with 4 Kbytes of flash memory was used. In order to provide an easy extension of the system (in the sense of adding supplementary sensors or actuators), the microcontroller board is equipped with an RS485 transceiver, so other boards can be added to a multipoint bus if needed.

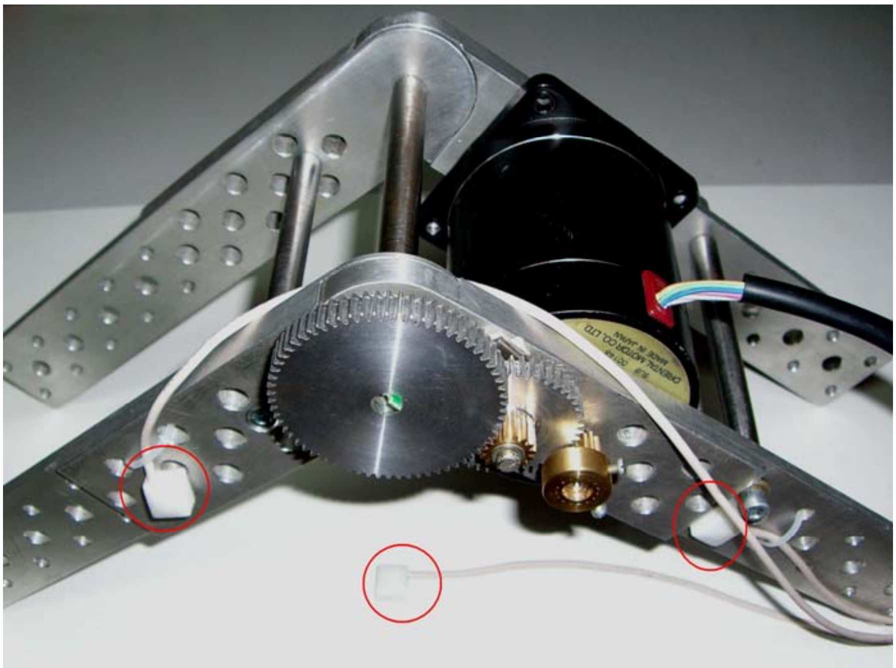

Figure 4: The experimental system

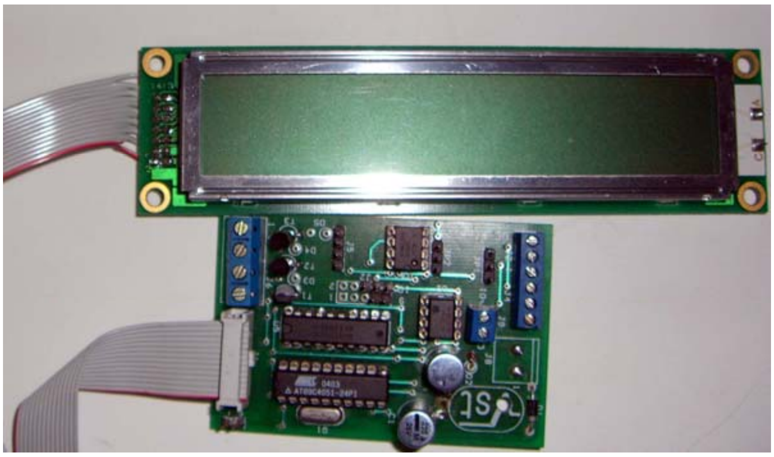

Figure 5: The prototype microcontroller board with LCD display

Conclusions

We propose a complex, yet low-cost, distributed system that can allow a patient to start a rehabilitation treatment in hospital and continue the CPM rehabilitation treatment at home, under the remote supervision of the physician.

The guidelines of the proposed design are flexibility for easy expansion and usage of low cost electronic components for making the system affordable.

It is hoped that such systems can be of real value for post-surgery patient rehabilitation.

References

[1] HAMMESFAHR R., MD, AND SERAFINO M.T., MS, PT. (2002): 'CPM: The Key to Successful Rehabilitation', *ORTHOPEDIC TECH. REVIEW*, Vol. 3, No 2, March/April

[2] IANNO M., FERRARIN M., PEDROCCHI A., AND FERRIGNO G., (2002): 'Neuro-adaptive Control System for Knee Joint Movement Using Quadriceps Electrical Stimulation: Experimental Results', Proc. of 2nd European Medical and Biological Engineering Conference EMBEC'02, Viena, Austria, December 04-08, 2002, p. 788-789.