A PORTABLE REAL-TIME MONITORING SYSTEM FOR KINESITHERAPIC HAND REHABILITATION EXERCISES

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Abstract: Rheumatic diseases, such as rheumatoid arthritis and systemic sclerosis, may seriously reduce the quality of life of the patients. Nowadays, their progress can be controlled only through personalised pharmacological treatments. Kinesitherapy can also help in faster movement recovery, also contrasting the disability worsening. This paper presents a portable low-cost system for the real-time quantitative monitoring and evaluation of hand rehabilitation exercises. The system, based on a MSP430 microcontroller central unit, provides a platform for the analysis of fine characteristics hitherto unavailable of 4 exercises required for the hand rehabilitation in rheumatic patients. The system can be controlled, through a Bluetooth connection, by a graphical user interface running on the physician's PC. The first prototypical systems have been developed for experimental outpatient trials.

1 INTRODUCTION

Rheumatic diseases, such as rheumatoid arthritis and systemic sclerosis, may severely reduce the quality of life of the patients, which are required to undergo an integrated therapy including kinesitherapy and a personalised pharmacological protocol. If the latter presently represents the only way to control the progress of the disease, the former both allows a faster recovery after inactivity periods caused by active disease and contrasts the progressive disability. For instance, patients with scleroderma suffer a skin thickening, typically localized on the hands, whose consequence is a limited mobility which in turn exacerbates the problem giving rise to a vicious circle. When the lesions are localized on the hand, such invalidating diseases hamper the execution of normal daily life activities such as hair brushing, dressing or cooking. Both hand strength and fine movements are often compromised.

Specifically designed physical exercises associated to an appropriate pharmacological therapy can help in restoring the motor function of the hand. In order to achieve the best results, such exercises must be properly performed, with the right number of series and repetitions. During outpatient examinations, an expert physician can evaluate the quality of the movements in order to effectively guide the patient through the training, avoiding the onset of inflammatory flares involving the hand. However, both a quantitative measurement and analysis of the patient's effort, and the definition of the best suited protocol for a specific patient, are hampered by the lack of instruments expressly designed and packaged to this aim. Beyond qualitative analyses including visual inspection and questionnaires administration, only for some exercises (typically grip and pinch strength) some digital devices are able to provide one-shot measurements. Unfortunately they are quite expensive and hardly integrable in a complete rehabilitation monitoring framework.

In this paper, a portable prototypical system for the real-time quantitative evaluation of hand rehabilitation exercises is presented. Compared to the typical procedures at the state of the art, the proposed system has been designed in cooperation with expert rheumatologists to monitor 4 agility/strength exercises, allowing to analyse with a finer resolution characteristics of the execution otherwise hitherto unavailable (e.g. speed, frequency, execution precision). On-line monitoring is provided by a MSP430 microcontroller (MCU) based subsystem able to perform real-time event detection and measurements on the incoming signals from the 4 sensorized devices. The system, battery-powered for patient's safety and conveniently accommodated in a metal briefcase, is controlled by

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a desktop PC via a Bluetooth connection which receives both the raw signals, the measurements collected until then and on-line refined statistics on them. A graphical user interface (GUI) developed in MATLAB allows a real-time qualitative and quantitative analysis of the exercise execution. The presence of different sensorized devices into a single system improves usability and it opens to the integration of additional devices. The system is going to be evaluated in a clinical trial in Italy from October 2011.

The remainder of this paper is structured as follows. In Section 2 a brief description of the state of the art is provided. Section 3 provides an overview of the proposed system, whose hardware structure is explained in Section 4, whereas the physician GUI is presented in Section 5. Section 6 concludes this work with final remarks and perspectives for future developments.

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2 STATE OF THE ART

Several diseases can affect the human hand, impairing its functionality and then negatively influencing the daily life. The largest part of studies in the field of the hand rehabilitation with biomedical devices deals with the post-stroke recovery (Dovat et al., 2008). In this case, cable-driven units connected to each finger by means of soft rings are exploited, being able to move the fingers with predefined patterns (passive movements) and/or to provide a tunable resistance to the hand movement. Other approaches make use of complex mechanical infrastructures (Huang and Low, 2008) or exoskeletons in order to assist the movement (Brokaw et al., 2011) or help in restoring the motor function (Iqbal et al., 2010).

For functional assessment only, the most common evaluation involves pinch and grip exercises. Both the Jamar dynamometer (isometric) and the Vigorimeter (dynamic) represent well established instruments for the clinical evaluation of the grip strength (Peters et al., 2011). Commercial devices such as Pablo by Tyromotion GmbH or the H500 Hand Kit by Biometrics Ltd. allow monitoring also the single finger pinch force. In principle, isometric wrist dynamometer can be also used to estimate the torque applied with the finger when the wrist is in a fixed position, in order to evaluate the hand performance with respect to this task. Usually the digital versions of these devices are able to provide maximum, average and standard deviation of the force, but without any temporal analysis within a series without additional electromyographic signals (Seo et al., 2009). In (Helliwell et al., 1987), a grip measurement device is presented, able to perform also some time measurements but only on a single 4.4s grip exercise for the performance assessment in rheumatic patients. A similar work has been presented in (Andria et al., 2006) for the parkinsonian patients. In both cases the aim is a one-shot functional assessment rather than the monitoring of a series of exercises, since multiple repetitions are sometimes used only for statistical purposes. An interesting device for rehabilitation mixing torque and grip force has been presented in (Lambercy et al., 2007), but is not intended for monitoring purposes.

The hand agility (severely affected by rheumatoid arthritis and scleroderma) can be in principle evaluated by means of finger tapping tests, originally conceived to assess both motor speed and control in neuropsychology. From the first mechanical devices, other approaches for the monitoring of this kind of exercise arose. Approaches including a passive marker-based motion analyser (Jobbágy et al., 2005) present a very complex setup not suited for a fast evaluation. Other approaches, based on sensorized gloves (Bustamante et al., 2010), are uncomfortable for patients with hand deformities caused by arthritis. In (Muir et al., 1995), a touch system based on a 4-finger active sensor (injecting on the hand a small sinusoidal current at 1.5 kHz) has been presented along with its support software. An App (Digital Finger Tapping Test 1.0) with limited functionalities is also available for IPhone users. An approach based on the detection of the exerted force in the tapping activity is presented in (Macellari et al., 2006).

It is worth to note that, to the best of our knowledge, the realization of a low cost device for the quantitative monitoring of both agility and strength kinesitherapy exercises for rheumatic patients has not been presented in literature until now.

Figure 1: A picture of the prototypical system.

3 THE SYSTEM AT A GLANCE

The system is conveniently packaged in a lightweight metal briefcase, as shown in Figure 1. With the proposed system, the patient can perform 4 exercises with a single hand a time, with as many sensorized devices.

There are 2 knobs on the vertical panel. The outer one allows the evaluation of the patient manipulation dexterity (exercise of *dynamic rotation*). The patient must rotate as fast as possible the knob using his fingers, shaped in a pinch grasp, without any wrist rotation and maintaining the forearm on the horizontal plane. The inner knob allows to evaluate the clockwise and anticlockwise rotation torque (*isometric rotation* exercise) with the same grasp type and restrictions of the previous exercise.

On the horizontal panel it is possible to perform the other two exercises. One is a revised version of the *finger tapping* exercise, which must be performed on the exposed printed circuit board (PCB). The patient must touch key-shaped pads on the PCB following a specific sequence (little finger, ring finger, middle finger, first finger and thumb) as playing the piano. It is allowed to have multiple finger on the keys provided that the sequence is correctly performed and closed with a thumb tapping. The last exercise allows evaluating the *hand extension* ability. The patient must rest the hand between the two L-shaped aluminium profiles, touching them with the thumb and the little finger. Then he must open and close the hand (always on the horizontal plane) in rhythm, allowing the system to appreciate opening and closing agility. A small counter-resistance is applied.

The system considers the exercise completed after a number of repetitions, previously established by the physicians and hard coded in the system firmware, have been executed. By using a GUI installed on his PC, the physician can choose which exercise to execute, evaluating in real-time how the patient executes it not only in terms of correct position but also looking at barely perceptible execution parameters that the digital system is able to reveal. For instance, a real-time updated plot discloses sensors wave shape while numerical data such as peak and running-average values are displayed on the GUI, allowing a finer monitoring compared to a traditional visual inspection.

4 SYSTEM ARCHITECTURE

Figure 2 shows the most important parts of the system and their interconnection. Beyond the MCU subsystem controlling the whole system, we can see:

- the analogue sensorized devices;
- the digital sensorized device (for finger tapping);
- the analogue interface circuitry;
- a Bluetooth module, which provides a wireless link to the host PC;
- additional components to provide a visible/audible feedback to the user.

The system can be easily supplied by a single-cell Li-Ion battery. For improved safety, the internal battery can be recharged only when the system is switched off. Along with the DC power supply adaptor to recharge the internal battery, the Bluetooth module (Bluegiga WT-11) is the only device that is not embedded in the metal briefcase. The module implements the Bluetooth stack and communicates with the MCU via a standard UART port. A 25-pole female D connector has been included providing a clean way to access the Bluetooth module pins and the JTAG ports to program the 2 MCUs embedded in the system.

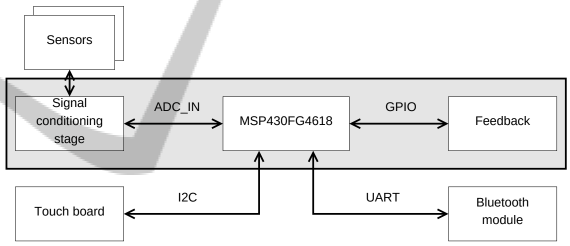

Figure 2: System block diagram.

4.1 The Sensorized Devices

The simplest device is that for the dynamic rotation exercise. In this case, a precision multi-turn potentiometer, equipped with a 30mm aluminium knob, has been used. The potentiometer (Vishay 534, 20kΩ, 2W) is able to perform 10 turns opposing a torque of 0.006 Nm. The resistance varies linearly with the rotation of the knob so that it suffices to measure the voltage on the wiper to detect the angular position at any instant. Due to the low opposing torque, the exercise can be considered without any load.

On the contrary, the isometric rotation device is composed of a 5-lobe 50mm plastic knob able to slightly turn on its own axis pulling along with it a T bar nut able to press one of two thin-film force sensors (the low-cost Tekscan FlexiForce A201, max 110N), for clockwise and anticlockwise rotations. These sensors linearly vary their conductance in response to the applied force. Being an isometric exercise, thanks to the aforementioned design, the knob cannot spin.

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The hand extension exercise is dynamic but it introduces a counter-resistance. It is evaluated by means of an analogue draw wire position sensor (LX-PA-15 by TME) mounted on a roller (CES30-88-ZZ by Rollon) free to move on a 40cm linear zinc plated guide (TES30-1040 by Rollon): the wire coming out from the sensor is attached to a second roller mounted on the same guide. The two rollers are attached to as many L-shaped aluminium profiles actuated by the patient opening and closing his hand. The sensor is characterized by a nominal wire rope tension of 3.9N, which must be overcome by the patient in order to extend his hand.

Lastly, for the finger tapping exercise it has been necessary to develop a capacitive touch board. Compared to the one presented in (Muir et al., 1995), the capacitive approach is still able to provide a detection of the touch without any counter-resistance from the measuring device but also avoids any direct current injection in the patient's hand. The touch board is based on the MSP430F2013 MCU, managing the reading of the capacitance associated to 8 key-shaped sensible areas on a PCB. The keys, which form a capacitor with the ground plane surrounding them, are sequentially charged by the MCU, which is able to measure the discharge time. Since the effect of touching a pad is the increase of the capacitance value, it is easy to detect whether a sensor is touched or not, comparing the measured discharge time with the base value obtained when the pad is untouched. The design of this device followed the guidelines given in (Albus, 2007) with some further consideration: the layout of the board must accommodate both left and right-handed exercises and the sensor shape should lead to an ergonomic device (it should accommodate different hand sizes and postures). Therefore the keys were made slightly larger than the suggested value, mesh-filled to keep the capacitance base value under an acceptable level. The device provides over an I2C bus, whenever required, the current status of the keys in a single byte: the interpretation of the data in the light of the exercise to execute is up to the main processor firmware.

4.2 The Main Board

The main board, highlighted with a grey-shaded area in Figure 2, hosts the MSP430FG4618 MCU, which takes care of the actual processing and manages the operation of the rest of the system. For the sake of simplicity, a single power supply at 3.3V is available on board.

The chosen processor embeds a 16-bit RISC CPU, an 8kB SRAM, a 116kB flash memory for program storage, different I/O ports, a 12-bit multi-channel ADC, three timers and other unused peripherals. It is clocked at 1MHz by means of an external quartz oscillator.

4.2.1 The Signal Conditioning Stage

Given the nature of the involved signals, which are slowly time-varying, it is possible to operate at rather low sampling frequencies, with consequent benefits in terms of real-time bounds for the signal processing algorithms. On the other hand, the event detection algorithms which underlie the system operations require an adequate time resolution: a fair trade-off between these two aspects led us to choose a sampling frequency of 150Hz. The signal conditioning stage must then implement a properly tuned anti-aliasing filter.

The analogue interface block is essentially composed of four non-inverting, active low-pass filters, implemented with an operational amplifier (TLV2375) and a single pole RC net. The value of its cut-off frequency has been set to about 48Hz to exploit the filter as anti-alias with guard band of about 25Hz under the Nyquist frequency, also limiting the 50Hz mains noise. The outputs of the four filters are connected to as many different channels of the MCU ADC.

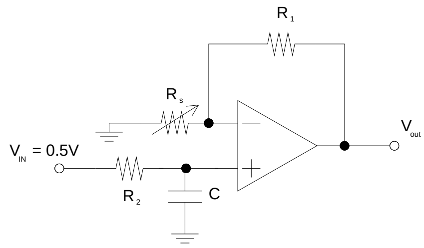

Figure 3: FlexiForce sensor conditioning stage.

Two different configurations have been employed: the one used for the FlexiForce sensors is depicted in Figure 3. The sensor has been connected between ground and the operational amplifier inverting input, making the stage a variable gain amplifier. Using a fixed input, provided by a voltage reference at 0.5V, the output varies linearly with the force applied to the sensor (between 0.5 and 3.3V), according to:

$$V_{out} = \left(1 + \frac{R_1}{R_s}\right) V_{IN} = V_{IN} + V_{IN} R_1 G_s = K_1 + K_2 G_s \quad (1)$$

where K_1 and K_2 are constants. Equation (1) shows the linear dependency between output voltage and the sensor conductance G_s. The optimal value of R_1 has been chosen in order to provide an adequate response when the isometric rotation exercise is performed by a rheumatic patient, even if this limits the operating range of the sensor.

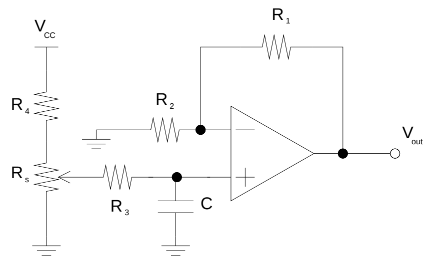

Figure 4: Potentiometer-based sensors conditioning stage.

The second configuration, used for the potentiometric sensors and depicted in Figure 4, has a fixed gain and a variable input voltage. The sensors are inserted in a voltage divider, with the wiper connected to the stage input, so that the output value is proportional to the voltage present at the wiper. A series resistor limits the current sunk but the side effect is that the voltage at the wiper cannot reach V_{cc}, so a gain greater than one must be used, which can be calculated as $\frac{V_{outmax}}{V_{inmax}}$.

4.2.2 Patient Interface

The system includes low-level user interface elements and some patient feedbacks, motivating him and aiding a correct execution of the exercises. Two leds indicate which hand must be used to execute the exercise and another led gives a time reference blinking at 1Hz, which is useful for sustained position tests. They are placed on the front panel for improved visibility. Moreover, a buzzer chimes whenever the system detects a successful event, letting the user know that the system has effectively captured his action. The system has been also provided with a double digit 7 segments display, which has different functions depending on the exercise. It displays:

- the percentage of the effort with respect to the maximum bound (extension and torque),
- the number of correct sequences performed (finger tapping),
- the percentage of rotation over 10 turns (dynamic rotation).

Two buttons, white and red coloured, placed on the horizontal plane and connected to two different external interrupt pins of the MCU, provide a way for the patient to interact with the device. The first one starts the exercise when the patient is ready, allowing to correctly position the hand, whereas the second one can be used to skip a single repetition of an exercise (the whole exercise can be aborted from the GUI).

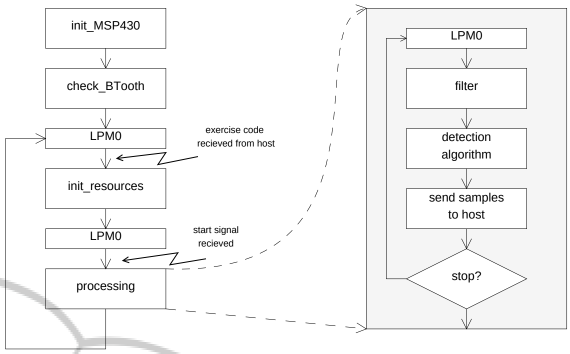

Figure 5: Firmware flow diagram.

4.3 Firmware

The operation of the MCU is controlled by the firmware loaded onto its flash memory. This piece of software is written in C and has been developed under the CCS v4.0 IDE by Texas Instruments.

The firmware flow, depicted in Figure 5 is quite simple: as soon as all the initializations have been carried out, the MCU enters the low power mode (LPM). The rest of the processing is then managed asynchronously by interrupt service routines (ISR). In the first phase:

- the USCI A port, devoted to communicate with the Bluetooth module, is configured in serial mode;
- the USCI B port, assigned to the communication with the touch board, is configured in I2C master mode;
- the timer A and timer B, respectively used to beat the sampling time and generate the reference time for the timing led, are configured;
- the ADC is set to perform a single conversion on a single channel and initially left disabled;
- the general purpose pins are set.

All the resources present on the board, as operational amplifiers, finger tapping MCU and Bluetooth module, are initially held in reset. Then the Bluetooth module is set up and configured by setting the operating mode, device name and password. The firmware enters an endless loop, where each iteration corresponds to the execution of an entire exercise. Inside the loop the MCU goes immediately in LPM (both CPU and MCLK disabled), waiting for the host to receive the execution code of the exercise to launch. Receiving the exercise code triggers the USCI A port

ISR, which wakes up the MCU. Depending on the selected exercise, some initializations are carried out, the ADC input channel is set to the corresponding input pin and it is started (except for the finger tapping exercise). After that the MCU goes in LPM again, waiting the start signal (by pushing the white button), which unlocks the execution. From now on the processing is timed by the timer A. In the corresponding ISR, either the value at the ADC input is sampled and stored or the new digital word from the tapping board is read. A global counter is incremented, to keep track of the number of samples gathered and hence to extract time measurements from it. Then the actual signal processing takes place on a sample-by-sample basis, in different ways depending on the specific exercise, as explained in the following session. The current sample is sent to the host machine through the Bluetooth link, and only every second (150 samples) a vector containing statistics which characterize the execution is sent too. If the stop condition which identifies the end of an exercise is not met, the core enters the LPM again from which it will be released by the acquisition of a new sample, otherwise the processing steps back to the main loop, entering in LPM until the system gets triggered again from the GUI.

4.3.1 The Processing Algorithms

For all the exercises but the tapping one, the samples are first low-pass filtered by an 8-tap moving average filter in order to further smooth the signal.

For the extension and isometric rotation exercises the algorithm simply detects the signal peaks corresponding respectively to a hand extension or a torque application. This is done by comparing each sample with a threshold, which is computed by averaging the first ten samples acquired. This value is stored and used as lower limit for the threshold, which is updated after the detection of a new peak to $0.3 \times peak\_value$. All the values are referred to a *zero* represented by the initial condition of the sensorized device when the user is ready to start. The peak event is validated only if at least 75 consecutive samples are above the threshold and only as soon as the samples go under the threshold again. The peak maximum value, its duration and position are determined and used to compute their incremental mean values as:

$$\bar{m}_N = \frac{(\bar{m}_{N-1}(N-1)+s)}{N} \quad (2)$$

where $\bar{m}_i$ is the mean value computed over i samples, and s is the value of the new sample. The system also stores the absolute maximum and minimum values for the peak amplitude. It is worth to underline that the variables which hold the average values are float numbers, though the CPU is a 16 bit platform and floating point is not supported in hardware. Nevertheless all these operations are translated by the compiler in the proper microcode without additional coding effort.

The algorithm is different in the case of the dynamic rotation, since different features are needed. The typical signal has a terraced waveform, where the edges correspond to the spinning of the potentiometer whereas the plateaus indicate that the transducer is still. The duration of both edges and plateaus, and the amplitude of each edge, are computed. To detect both onset and end of an edge, a simple detection mechanism based on thresholds has been designed, exploiting the smoothness of the filtered signal. A FIFO buffer of 14 samples is linearly updated at every new sample. The mean value of the oldest 4 samples is computed and compared with the most recent sample. If the difference is greater than an empirically determined threshold, the algorithm detects an edge and marks the onset n samples before the most recent one. When the difference falls back under the threshold, the edge end is marked and the processing is repeated, until the potentiometer reaches the limit. By using absolute values, the processing is the same for both clockwise and counter-clockwise exercises.

The finger tapping exercise differs from the others because there are no analogue signals involved. The MCU on the main board acts as the master of the I2C channel, requesting the 8-bit word provided by the sensorized device whenever the sampling timer expires. For this exercise, the timer A has been differently set, in order to have a sampling frequency of 50Hz, which is in line with the state of the art (Jobbágy et al., 2005) and allows the complete scanning of the 8 keys in a sampling period. As a new word is received, it is mirrored, if necessary, in order to have the least significant bit always referred to the thumb key. When the first not null data is received, the algorithm detects the less significant bit set to 1 and creates a mask used, at the next touch, to check if the next key tapped corresponds to a less significant bit or not. If this is true, the mask is updated and the processing goes on, otherwise an error flag is set. The sequence terminates when the thumb touch is detected (lsb = 1). If the number of touches is equal to five the valid sequence counter is incremented or, if either the error flag is set or the sequence length differs from five, the bad sequence counter is. This processing is performed in real-time and when the exercise is complete, an additional routine computes the relevant statistics, including average touch duration for each finger, average distance between them, total consecutive touches and total duration of the exercise.

5 THE PHYSICIAN GUI

By using a user friendly GUI developed in Matlab, the physician can monitor in real-time on a host PC the execution quality of the kinesitherapic exercises, also extracting useful information to evaluate the rehabilitation progress over time. As already said, the link between the system and the host PC exploits a Bluetooth technology. The Bluetooth device driver exports a serial interface towards the user applications, which is easy to manage using the built-in Matlab functions.

At launch, the very first window contains a list of radio buttons enabling the selection of the exercise and the hand to use. By pushing the *start* button on the GUI, a numerical code which identifies the chosen exercise and the hand to use is sent to the device. The callback function associated to this button also creates a new window which is specific for the selected exercise. All the exercise windows, except that of finger tapping one, contain an area where the raw signal acquired by the sensor can be plotted over time. The signal is sent to the host PC on a sample-by-sample basis. Since every sample is a 16 bit integer, before reading the GUI waits inside a while loop the availability of at least 2 bytes in the serial port input buffer. The received samples are then converted to the corresponding real physical quantity by means of the calibration values. For the sake of efficiency, the time plot is refreshed only when a block of 75 input samples has been acquired, shifting towards left the previous blocks in the plot linear buffer: the oldest block is overwritten and the new one is inserted on the right. All the received samples are logged thus, at the end of the execution, the user can visualize a static plot of the whole signal.

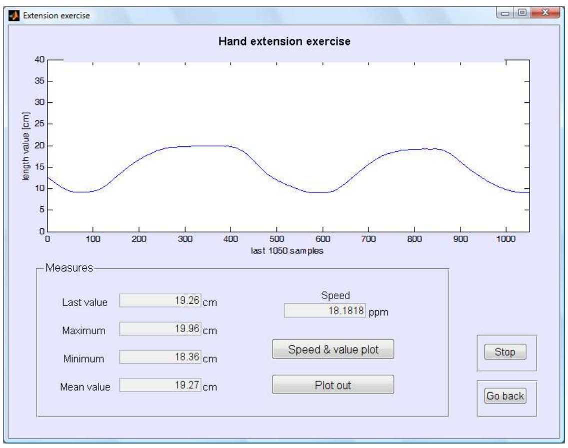

Figure 6: GUI screenshot.

The GUI also receives the peaks position detected in real-time by the system and used to analyse the signal, together with other relevant parameters (e.g. speed of execution, position and the amplitude of the last peak, the maximum, the minimum and the mean value of the executions). These values are sent by the system to the host PC only every 150 samples of the signal and the most important ones are presented on the GUI (Figure 6). Counting the received sample, the GUI is able to properly receive such parameters as a data chunk. A flag at the end of the chunk is used by the system to signal the end of the exercise. The interface uses this flag to allow the visualization of the whole signal plot, including the markers to the peaks found by the system during the execution. The interface enables the visualization of the “speed-value plot” (Figure 7), which overprints to a bar graph showing the peak values, a line graph representing the frequency of the repetitions. This information can be useful to evaluate how much the performance is dependent by the execution speed, being important to know if smaller values achieved by the patient are caused by a higher execution speed or by fatigue.

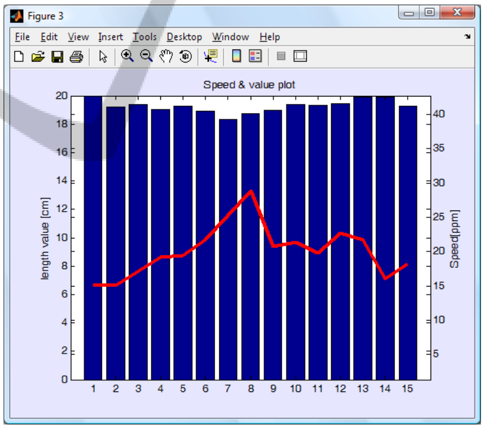

Figure 7: GUI speed-value plot.

In every window there is the possibility to stop the execution by using a push button, whose callback function sends a numerical code to the system in order to signal the premature end of the exercise. Another push button enables going back to the main window, where the user can select a new exercise.

6 CONCLUSIONS

The portable kinesitherapic monitoring system presented in this paper is proposed as a support tool to exploit along with the latest treatment techniques in the rheumatic patients hand rehabilitation practice. Com-

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pared to other devices at the state of the art, the proposed system presents several advantages. In fact it embeds the sensorized devices necessary to execute different kinds of exercises in a single low-cost framework, exporting the main real-time monitoring features to a host PC via a wireless connection. Here, an accurate analysis of the patient's performances can be easily performed, thanks to a user-friendly GUI. In particular the real-time performance simplifies the physician's task of evaluating and correcting the patient's training, being immediately available quantitative measurements also involving the time-related aspects of the exercise. In the next future the system is going to be employed in clinical trials on rheumatic patients, with the aim of verifying the effectiveness of the approach and the usability. The system could be further expanded including additional sensorized devices, in order to offer a wider selection of exercises. Furthermore, being a compact and portable device, it could represent a good solution to delivery rehabilitation services in the patient's home.

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REFERENCES

Albus, Z. (2007). *PCB-Based Capacitive Touch Sensing With MSP430*. Texas Instruments Inc. SLAA363A Application report.

Andria, G., Attivissimo, F., Giaquinto, N., Lanzolla, A., Quagliarella, L., and Sasanelli, N. (2006). Functional evaluation of handgrip signals for parkinsonian patients. *IEEE Transactions on Instrumentation and Measurement*, 55(5):1467–1473.

Brokaw, E. B., Black, I., Holley, R. J., and Lum, P. S. (2011). Hand spring operated movement enhancer HandSOME: A portable, passive hand exoskeleton for stroke rehabilitation. *IEEE Transactions on Neural Systems and Rehabilitation Engineerig*, 19(4):391–399.

Bustamante, P., Grandez, K., Solas, G., and Arrizabalaga, S. (2010). A low-cost platform for testing activities in parkinson and ALS patients. In *12th IEEE International Conference on e-Health Networking Applications and Services (Healthcom)*, pages 302–307.

Dovat, L., Lambercy, O., Gassert, R., Maeder, T., Milner, T., Leong, T. C., and Burdet, E. (2008). HandCARE: A cable- actuated rehabilitation system to train hand function after stroke. *IEEE Trans. on Neural Systems and Rehabilitation Engineering*, 16(6):582–591.

Helliwell, P., Howe, A., and Wright, V. (1987). Functional assessment of the hand: reproducibility, acceptability, and utility of a new system for measuring strength. *Ann Rheum Dis*, 46:203–208.

Huang, Y. and Low, K. (2008). Initial analysis and design of an assistive rehabilitation hand device with free loading and fingers motion visible to subjects. In *IEEE International Conference on Systems, Man and Cybernetics, SMC 2008*, pages 2584–2590.

Iqbal, J., Tsagarakis, N., Fiorilla, A., and Caldwell, D. (2010). A portable rehabilitation device for the hand. In *2010 Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, pages 3694–3697.

Jobbágy, A., Harcos, P., Karoly, R., and Fazekas, G. (2005). Analysis of finger-tapping movement. *Journal of Neuroscience Methods*, 141:29–39.

Lambercy, O., Dovat, L., Gassert, R., Burdet, E., Teo, C. L., and Milner, T. (2007). A haptic knob for rehabilitation of hand function. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 15(3):356–366.

Macellari, V., Morelli, S., Giacomozzi, C., Angelis, G. D., Maccioni, G., Paolizzi, M., and Giansanti, D. (2006). *Instrumental kit for a comprehensive assessment of functional recovery*.

Muir, S. R., Jones, R. D., Andreae, J. H., and Donaldson, I. M. (1995). Measurement and analysis of single and multiple finger tapping in normal and parkinsonian subjects. *Parkinsonism related disorders*, 1(2):89–96.

Peters, M. J. H., van Nes, S. I., Vanhoutte1, E. K., Bakkers, M., van Doorn, P. A., Merkies, I. S. J., and Faber, C. G. (2011). Revised normative values for grip strength with the jamar dynamometer. *Journal of the Peripheral Nervous System*, 16:47–50.

Seo, N. J., Rymer, W. Z., and Kamper, D. G. (2009). Delays in grip initiation and termination in persons with stroke: Effects of arm support and active muscle stretch exercise. *J Neurophysiol*, 101(6):3108–3115.