An Integrated Portable Device for the Hand Functional Assessment in the Clinical Practice

Danilo Pani[1], Gianluca Barabino[1], Alessia Dessì[1], Matteo Piga[2],
Iosto Tradori[2], Alessandro Mathieu[2], and Luigi Raffo[1]

[1] DIEE - Dept. of Electrical and Electronic Engineering,
University of Cagliari, 09123 Cagliari, Italy
[2] Chair of Rheumatology and Rheumatology Unit,
University and AOU of Cagliari, Italy
`{danilo.pani,alessia.dessi,`
`gianluca.barabino,luigi}@diee.unica.it,`
`matteopiga@alice.it, iosto.tradori@tiscali.it,`
`mathieu@medicina.unica.it`

Abstract. The functionality of the human hand is of paramount importance for the daily life activity of a subject. Several chronic diseases can have localized lesions on the hands, causing disability, as for the Systemic Sclerosis and Rheumatoid Arthritis. In these cases the evaluation of the hand functionality is a necessary step for setting up the therapeutic and rehabilitation program. This research presents a novel device tackling this problem, allowing the evaluation of hand dexterity and strength on 4 simple rehabilitation exercises. Real-time controlled by a wirelessly connected PC where a C++ physician graphical interface enables a user-friendly management of the assessment, the device provides hitherto unavailable measurements. A first evaluation of the device in a real outpatient rheumatology clinic has been performed and the preliminary results reveal the potentialities of the approach.

Keywords: Functional Hand Assessment, Biomedical Embedded System, Rheumatic Diseases, Rehabilitation.

1 Introduction

Human hand is one the principal instruments enabling the interaction of a subject with the surrounding environment. For such a reason, hand disability is perceived as more invalidating from a functional perspective compared to other disabilities involving different districts. As a matter of fact, hand disability hampers the execution of normal daily life activities such as hair brushing, dressing or cooking. Both hand strength and fine movements are often compromised. From a medical viewpoint, hand functionality assessment represents a necessary evaluation to be performed both at the first examination and during the follow-up of the patient in order to quantify the disability level, to properly set up the pharmacological therapy and to define a personalized rehabilitation program.

J. Gabriel et al. (Eds.): BIOSTEC 2012, CCIS 357, pp. 97–110, 2013.

In particular, rheumatic diseases, such as Rheumatoid Arthritis (RA) and Systemic Sclerosis (SSc) could led to lesions localized on the hands, thus producing the aforementioned invalidating effects, requiring an integrated therapy including kinesitherapy and a pharmacological protocol. Differently from RA, where movement limitation is prevalently caused by arthritis, patients with SSc suffer a skin thickening whose consequence is a limited mobility which in turn exacerbates the problem. For these patients, the functional deficit is evaluated in a clinical setting using physician assessed biomechanical measurements such as the Range Of Movement (ROM), the hand extension and strength. Furthermore, physician-administered questionnaires are used to obtain the subject's perception of its disability, i.e. the Dreiser test [4] and the Health Assessment Questionnaire (HAQ) [11]. Only for some evaluations (e.g. grip and pinch strength or ROM) some digital devices are able to provide one-shot measurements but there is a lack of commercial functional evaluation tools able to measure the interesting parameters associated to the execution of typical rehabilitation exercises prescribed to these patients. They would probably help in the assessment procedures, especially if all the devices are integrated on the same hardware platform.

This chapter presents a system for the real-time assessment of the hand functionality on rehabilitation exercises usually exploited with patients affected by RA and SSc. Compared to the typical procedures at the state of the art for such evaluation, exploiting either subjective scores or one-shot measurements, the proposed system extracts the relevant information from the real-time monitoring of exercise repetitions with hitherto unavailable precision, reducing the background noise due to fatigue and distraction. The microcontroller-based device exploits 4 sensorized custom-made aids for the evaluation of the hand agility (finger tapping and dynamic rotation) and strength/mobility (isometric rotation and hand extension with counter resistance) and can be easily controlled by a PC connected via a Bluetooth link. A stand-alone C++ graphical user interface (GUI) has been implemented exploiting the Qt 4.7 framework to provide a license-free physician support for the real-time control of the device. The device has been evaluated in a real outpatient rheumatology clinic on 6 voluntary subjects affected either by SSc or RA and the preliminary results reveal the potentialities of the proposed approach.

The remainder of this paper is organized as follows. In Sect. 2 a brief analysis of the related works is provided. Sect. 3 provides an overview of the proposed device and the relative hardware implementation details, whereas the physician GUI is presented in Sect. 4. Sect. 5 presents the results of the device application in an outpatient clinic. Conclusions are presented in Sect. 6.

2 Related Works

For functional assessment of the human hand, the most common evaluation techniques involve 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 [10]. 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 except for the systems exploiting additional electromyographic signals [13]. In [5], 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 [1] for the parkinsonian patients. In both cases the aim is a one-shot functional assessment rather than the evaluation of a series of exercises. An interesting device for rehabilitation mixing torque and grip force has been presented in [7], but is not intended for performance assessment.

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 have arisen. Approaches including a passive marker-based motion analyzer [6] present a very complex setup not suited for a fast evaluation. Other approaches, based on sensorized gloves [3], are uncomfortable for patients with hand deformities caused by arthritis. In [9], 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 [8].

To the best of our knowledge, the realization of a low cost device for the quantitative monitoring of both agility and strength exercises for hand functional evaluation on rheumatic patients during real rehabilitation exercises has not been presented in literature until now.

3 The Hand Functional Assessment Device

The proposed device is conveniently packaged in a lightweight metal briefcase, as shown in Fig. 1. The patient can perform 4 exercises with a single hand at a time, with as many sensorized devices. 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 device 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. From this point of view the device can be conveniently used as a kinesitherapic monitoring system. The physician can stop the execution at any time but an upper bound is imposed by the predefined number of repetitions of the same exercise hard coded in the device firmware. During the exercise execution, the device automatically extracts the relevant measures from the signals and updates their statistics (min, max, avg, std, etc.) in order to provide at every time the parameters needed for the quantitative hand functionality assessment.

From the patient viewpoint, the interaction with the device is very simple. The hand to use is indicated by a led and the movements to be performed exploiting the sensorized embedded aids are well defined by the rehabilitation protocol, as follows.

Fig. 1. The prototypical device for the real-time hand functionality assessment

On the vertical panel there are two knobs. 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 adjacent 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 of the device 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 fingers 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 aid to appreciate opening and closing agility. A constant counter-resistance is applied.

The correct position of the patient's hand for the 4 exercises is depicted in Fig. 2.

3.1 Hardware Architecture

From an hardware perspective, the device leverages a mother board hosting the main MSP430FG4618 microcontroller unit (MCU) @1MHz, the analog front-end for the sensorized aids, all the power supply circuitry and the visible/audible feedback devices. The analog and digital sensorized aids are tightly connected to the device whereas the Bluetooth module for the PC connection is detachable being connected to the device by a 25-pole female D connector, guaranteeing also access to the JTAG ports to program the 2 MCUs embedded in the device. A single power supply at 3.3V is available on board, obtained from a single-cell rechargeable Li-ion battery.

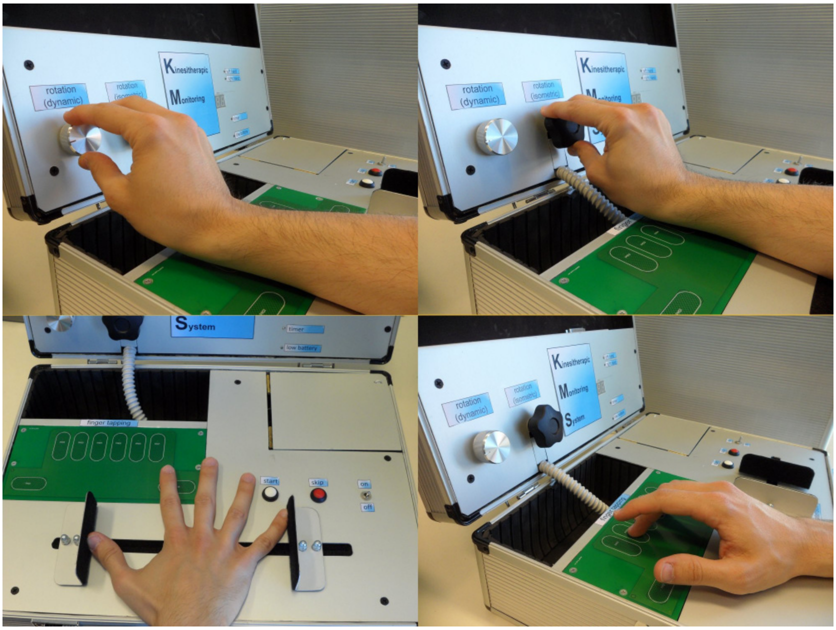


Fig. 2. From top left, clockwise: dynamic rotation, isometric rotation, finger tapping and hand extension exercises on the proposed hand functional evaluation device

The Sensorized Aids. A precision multi-turn potentiometer, equipped with a 30mm aluminium knob, has been used as dynamic rotation aid. 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 aid 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.

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, the finger tapping aid exploits a capacitive touch board. Compared to the one presented in [9], 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 layout of the board is designed to easily accommodate both left and right-handed exercises and the sensor shape allows to find a comfortable hand position taking care of different hand sizes and deformities. This sensorized aid 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.

Signal Conditioning. 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. In order to let the signal processing algorithms running on the MCU work with an adequate time resolution, a sampling frequency of 150Hz has been chosen. 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. All the input stages have been especially designed in order to provide an adequate response when the exercises are performed by a rheumatic patient, even if this limits the operating range of the sensor.

Two different configurations have been employed. The first configuration is used for the Tekscan FlexiForce sensor, which 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). The second configuration, used for the potentiometric sensors, has a fixed gain and a variable input voltage. The potentiometric sensor is 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.

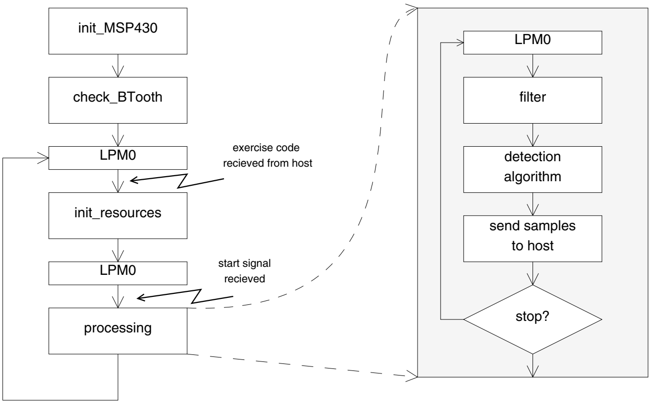


Fig. 3. Embedded control software flow diagram

Patient Interface. The device 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 device detects a successful event, letting the user know that the device has effectively captured his action. The device has been also provided with a double digit 7 segments display, which has different functions depending on the exercise, providing:

- 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, 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.

3.2 Embedded Control Software

The operation of the MCU is controlled by the firmware loaded onto its flash memory, written in C and developed under the CCS v4.0 IDE by Texas Instruments. The firmware flow is depicted in Fig. 3: as soon as all the initializations have been carried out, the MCU enters the low power mode (LPM), where both CPU and MCLK are disabled. The rest of the processing is then managed asynchronously by interrupt service routines (ISR). 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, waiting for the execution code of the exercise to launch coming from the PC. 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 (except for the finger tapping exercise) and the device patient interface is set accordingly. After that the MCU goes in LPM again, waiting the start signal (by pushing the white button), which unlocks the execution.

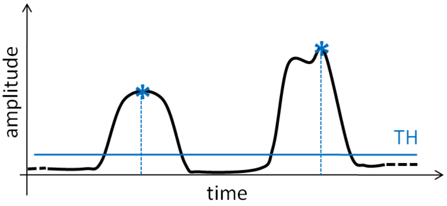


Fig. 4. Peak detection for the extension and isometric rotation exercises

From now on the processing is timed by a timer. 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. The current sample is sent to the host machine through the Bluetooth link, and only every second 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 MCU 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 device gets triggered again from the GUI.

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 smooth the signal. For the extension and isometric rotation evaluations the algorithm simply detects the signal peaks corresponding respectively to a hand extension or a torque application, as showed in Fig. 4. This is done by comparing each sample with a threshold, which is set to a specific value by inverting each sensor calibration curve. In particular the minimum acceptable values are 1 cm for the extension exercise and 0.8 Kg for the isometric rotation one. The mean value of the first acquired samples are used as the zero value of the subsequent measures. 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:

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

where $\bar{m}_i$ is the mean value computed over i samples, and s is the value of the new sample. The device also stores the absolute maximum and minimum values for the peak amplitude within the sequence. It is worth to underline that the variables which hold the average values are float numbers, though the MCU 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 signal features must be detected. The typical signal has a terraced wave shape as showed in Fig. 5, 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.

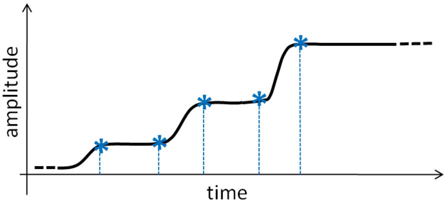
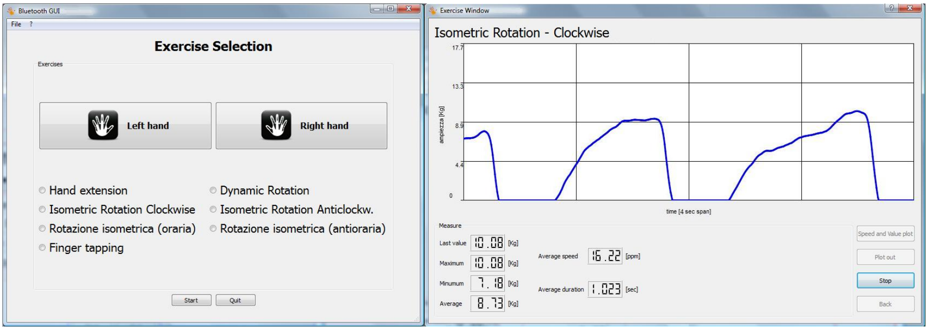


Fig. 5. Detection of the edges onset and end of the typical dynamic rotation signal for segmentation

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 (one bit for each key in the touchpad) provided by the sensorized aid whenever the sampling timer expires. For this exercise, the timer has been set differently for a sampling frequency of 50Hz, which is in line with the state of the art [6] and allows the complete scanning of the 8 keys in a sampling period, in the worst case (when all the keys are touched). 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.

4 The Advanced Stand Alone Physician Interface

By means of a standalone GUI based on the Qt 4.7 framework (a C++ graphic framework), the physician can monitor in real-time on a host PC the execution quality of the exercises, also extracting the information needed for the hand functionality assessment. Since the Bluetooth device driver exports a serial interface towards the user applications, it can be managed using the QtExtSerialPort class which is not included in the framework by default but can be integrated with minor effort. Once the link has been established the device sends its calibration values to the host, which will be used to perform the scaling of the received data on the PC, in order to lighten the processing on the device microcontroller. The communication is handled by means of a simple protocol made of 8 bit wide control codes. In the main window it is possible to choose the exercise and the hand to use whereas the exercise progress can be analyzed in a different window, specific for the selected exercise, which pops up as soon as the exercise is started. Both windows are depicted in Fig. 6. In every exercise-specific window there is the possibility both to stop the execution and to go back to the main window, where the physician can select a new exercise.



Measure

Last value 10.08 [Kg]
Maximum 10.08 [Kg]
Minumum 7.18 [Kg]
Average 8.73 [Kg]
Average speed 16.22 [ppm]
Average duration 1.023 [sec]

Fig. 6. Physician interface main window (left) and exercise monitoring (right)

Even though the signal is sent to the PC on a sample-by-sample basis, its plot is refreshed only every 75 input samples, shifting towards left the previous blocks in the plot linear buffer, for the sake of efficiency. All the received samples are logged thus, at the end of the execution, the user can visualize a static plot of the whole signal including the relevant delineation markers extracted in real-time by the device (Fig. 7). The GUI receives the functional assessment 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), to be presented on the GUI, every 150 samples of the signal.

Beyond the whole plot of the acquired signal, the interface also enables the visualization of the "Speed and Value plot" (Fig. 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. It should be noted that traditional assessment techniques do not consider time as discriminative factor, thus reducing the informative content of the measurements.

5 Device Application in an Outpatient Clinic

In a rheumatologic clinical setting, 6 volunteers were enrolled with the aim to test the portable prototypical system presented above. All the patients were enrolled from the outpatient clinic of the Chair of Rheumatology, Department of Medical Sciences, University of Cagliari, Italy. They were evaluated in order to participate to the clinical test if they fulfilled the following inclusion criteria: age $18 - 75$ years, ability to give informed consent, clinical remission of the inflammatory disease phase, no change in antirheumatic treatment in the three previous months, need to perform a rehabilitation program due to limitation in ability to perform usual self-care, vocational, and avocational activities because of an inactivity periods that preceded the clinical remission of inflammatory phase.

All patients are female, underwent a clinical examination and were assessed according to international guidelines. Three of them present SSc and suffered from flexion contractures, caused by retraction of skin, subcutaneous tissues and tendon sheats.

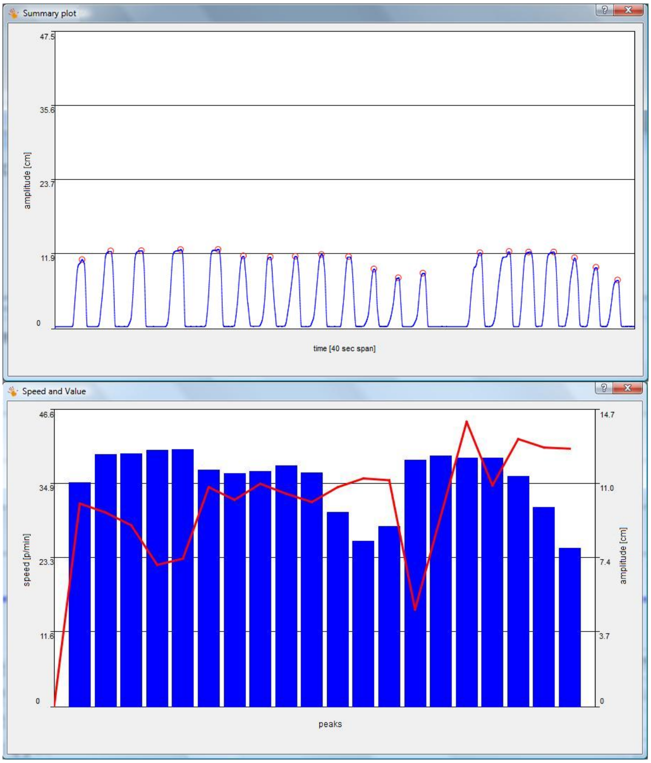


Fig. 7. Marked whole signal plot (top) and "speed and value" plot (bottom) for the extension test

Three of them are affected by RA and suffered from muscular hypotrophy, capsular and tendon sheats fibrosis of the hands and wrists without deformities. Before starting the rehabilitation phase, they underwent a functional assessment through the traditional tools and the portable prototypical device to test its ergonomics and functionality.

Traditional assessments of hand function were performed using the Dreiser test, the HAQ, the ROM. For the latter, the movements leading to the hand positions presented in Fig. 8 have been considered, namely wrist flex-extension, wrist lateral-lateral and finger lateral-lateral. Hand extension ability was evaluated through the experimental device and by traditional tools. The patient dexterity (exercise of dynamic rotation and finger tapping exercise) and the rotation torque (isometric rotation exercise) were assessed only by the experimental device since no instruments are currently available for such evaluations. Demographic characteristics and results are shown in Tab. 1 and Tab. 2.

Although it is not possible to compare the results obtained with the traditional tools against those recorded using the experimental device, because of the low number of subjects, it is worth mentioning that the latter seems to fit with the former. As an example, the SSc2 patient, who showed the highest Dreiser's and HAQ scores and the poorest ROM and traditionally evaluated extension performances, due to high disability levels, had the poorest performances at the finger tapping, dynamic rotation and extension exercises evaluated through the experimental device. Since previous studies

Fig. 8. ROM maximum excursions for angles measurements

Table 1. Demographic characteristics and results of the traditional assessment. RA 1 to 3 are patients with RA whereas SSc 1 to 3 are patients with SSc. Normal values, if any, are presented in the *range* column.(R:right, L:left, F-E: flex-extension, L-L: lateral-lateral)

Parameter	Range	RA 1	RA 2	RA 3	SSc 1	SSc 2	SSc3
Age		47	53	58	45	43	47
Dreiser	0-30	15	16	20	18	21	21
HAQ	0-3	1.2	1.7	2.0	1.2	1.8	1.3
ROM wrist F-E R/L $[deg]$	65-90	90/42	70/60	50/40	80/90	75/65	90/75
ROM wrist L-L R/L $[deg]$	90	35/25	25/15	25/30	70/60	45/60	55/70
ROM fingers F-E R/L $[deg]$	90	65/85	60/60	70/65	88/88	65/80	90/95
Extension R/L $[cm]$		6.5/4.5	4.8/5.5	8.5/8	8/8.2	5.5/5.3	10.5/10.5

have reported that ROM was related to some kinds of hand function in patients with SSc [12,2] and ROM seems related to the performances recorded by the experimental device, it is conceivable that in the future the latter might represent an instrument to quantify the hand function, or disability, in SSc patients. As another example, patient RA3, who showed the poorest wrists but the best fingers ROM performances, because of a prevalent anatomical damage at wrists level, had a good performances at the dynamic rotation exercise which do not involve wrist movement. Moreover, in the same patient, the low values recorded at the extension exercises evaluated using the experimental device as compared to those traditionally recorded might be ascribed to the counter resistance or to a difficulty in the execution of the exercise, as demonstrated by the low extension speed recorded. Therefore, the experimental device appeared able to differentiate the anatomic level of disability as well as ROM but differently from Dreiser or HAQ which are general indicators. Moreover, allowing the registration of speed parameters, the experimental device might estimate the quality of the exercise or the difficulty in performing it.

Table 2. Results of the assessment through the experimental device. All the parameters are given for Right/Left hand. RA 1 to 3 are patients with RA whereas SSc 1 to 3 are patients with SSc. Data expressed in sec represent the mean time interval between consecutive repetitions. (FT: Finger Tapping, ICR: Isometric Clockwise Rotation, ICcR: Isometric Counterclockwise Rotation, DR: Dynamic Rotation)

Exercise	RA 1	RA 2	RA 3	SSc 1	SSc 2	SSc3
Extension $[cm]$	7.1/4.4	4.0/5.0	3.6/3.2	8.2/7.9	5.2/5.3	12.2/11.7
Extension $[s]$	1.8/1.3	2.2/5.0	2.9/2.2	1.5/1.4	2.9/2.3	1/0.8
Extension speed $[ppm]^\dagger$	22.1/24.2	40/40	8.7/10.9	28.7/27.6	10.9/16	38.4/50.2
FT correct $[\sharp]$	20/20	11/18	20/13	20/20	3/9	2/20
FT wrong $[\sharp]$	0/4	19/12	2/7	10/10	27/21	28/9
FT speed $[tps]^{\dagger\dagger}$	2.4/2.8	1.4/1.7	1.8/1.6	2.6/3.1	0.8/1.4	0.4/2.5
ICR $[Kg]$	2.0/2.5	3.8/3.3	2.4/3.3	2.6/5.0	3.9/3.6	1.2/3
ICR $[s]$	1.1/1.3	1.1/1.1	1.5/0.8	0.9/1.2	2.0/2.3	1.1/0.8
ICR speed $[ppm]^\dagger$	28.3/23.0	26/19.0	21.3/35.0	34.0/21.9	12.1/21.0	26.3/32.0
ICcR $[Kg]$	3.6/2.3	1.2/3.3	2.5/2.7	6.3/4.1	5.2/4.7	2.9/2.9
ICcR $[s]$	1.3/1.3	1.4/1.1	1.1/0.8	1.1/1.2	1.5/1.1	0.8/0.8
ICcR speed $[ppm]^\dagger$	27.8/24.8	25.0/26.0	24.6/28.2	30.0/31.3	22.0/30.0	39.0/41.0
DR $[deg]$	195/81	195/113	183/272	224.5/229	119/139	163/110
DR speed $[deg/s]$	340/472	257/189	381/388	334/387	544/869	646/297

† ppm = peaks per minute; †† tps = touches per second

6 Conclusions

The device developed in this research is a valuable aid for the assessment of the hand functionality in chronically ill subjects requiring a quantitative evaluation for the proper set up of the personalized pharmacological and rehabilitation programs. Compared to other devices at the state of the art, it embeds the sensorized aids necessary to execute different kinds of exercises in a single low-cost framework, allowing the extraction of the relevant parameters from the analysis of several repetitions of the same movement performed in real rehabilitation exercises typically prescribed to RA and SSs patients. In this way the noise given by fatigue and distraction can be better identified compared to one-shot measurements, and also the temporal features of the acquired signals can be accurately recorded in order to enable a more complete analysis. The device, easily controllable exploiting a stand-alone software interface on the physician PC, has been preliminary evaluated in the outpatient clinic of the Chair of Rheumatology of the University of Cagliari, Italy. All patients completed the assessment through the experimental device without complaining of pain or discomfort. Furthermore, at this stage of development, the prototypical system is easy to use and well perceived by both patients and physicians representing a promising new tool in a clinical field that apparently lacks of devices allowing the real-time quantitative assessment of the hand functionality. Further studies in larger population are needed to evaluate if such device might be considered a reliable instrument to quantify the hand function in patients affected by rheumatic diseases.

Acknowledgements. The research leading to these results has received funding from the Region of Sardinia, Fundamental Research Programme, L.R. 7/2007 "Promotion of the scientific research and technological innovation in Sardinia" under grant agreement CRP2_584 Re.Mo.To. Project. The authors wish to thank V. Lussu, L. Piras, I. Secci, N. Zaccheddu, F. Boi and M. Crabolu. Alessia Dess gratefully acknowledges Sardinia Regional Government for the financial support of her PhD scholarship (P.O.R. Sardegna F.S.E. Operational Programme of the Autonomous Region of Sardinia, European Social Fund 2007-2013 - Axis IV Human Resources, Objective l.3, Line of Activity l.3.1.)

References

1. Andria, G., Attivissimo, F., Giaquinto, N., Lanzolla, A., Quagliarella, L., Sasanelli, N.: Functional evaluation of handgrip signals for parkinsonian patients. IEEE Transactions on Instrumentation and Measurement 55(5), 1467–1473 (2006)
2. Badley, E., Wagstaff, S., Wood, P.: Measures of functional ability (disability) in arthritis in relation to impairment of range of joint movement. Ann. Rheum. Dis. (43), 563–569 (1984)
3. Bustamante, P., Grandez, K., Solas, G., Arrizabalaga, S.: 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), pp. 302–307 (2010)
4. Dreiser, R., Maheu, E., Guillou, G., Caspard, H., Grouin, J.: Validation of an algofunctional index for osteoarthritis of the hand. Rev. Rheum. Engl. 6(suppl. 1), 43S–53S (1995)
5. Helliwell, P., Howe, A., Wright, V.: Functional assessment of the hand: reproducibility, acceptability, and utility of a new system for measuring strength. Ann. Rheum. Dis. 46, 203–208 (1987)
6. Jobbágy, A., Harcos, P., Karoly, R., Fazekas, G.: Analysis of finger-tapping movement. Journal of Neuroscience Methods 141, 29–39 (2005)
7. Lambercy, O., Dovat, L., Gassert, R., Burdet, E., Teo, C.L., Milner, T.: A haptic knob for rehabilitation of hand function. IEEE Transactions on Neural Systems and Rehabilitation Engineering 15(3), 356–366 (2007)
8. Macellari, V., Morelli, S., Giacomozzi, C., Angelis, G.D., Maccioni, G., Paolizzi, M., Giansanti, D.: Instrumental kit for a comprehensive assessment of functional recovery (2006)
9. Muir, S.R., Jones, R.D., Andreae, J.H., Donaldson, I.M.: Measurement and analysis of single and multiple finger tapping in normal and parkinsonian subjects. Parkinsonism Related Disorders 1(2), 89–96 (1995)
10. Peters, M.J.H., van Nes, S.I., Vanhoutte, E.K., Bakkers, M., van Doorn, P.A., Merkies, I.S.J., Faber, C.G.: Revised normative values for grip strength with the jamar dynamometer. Journal of the Peripheral Nervous System 16, 47–50 (2011)
11. Poole, J., Steen, V.: The use of the health assessment questionnaire to determine physical disability in systemic sclerosis. Arthritis Care. Res. 4, 27–31 (1991)
12. Poole, J., Steen, V.: Grasp pattern variations seen in the scleroderma hand. Am. J. Occup. Ther. (48), 46–54 (1994)
13. Seo, N.J., Rymer, W.Z., Kamper, D.G.: 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 (2009)