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The ALLADIN Diagnostic Device: An Innovative Platform for Assessing Post-Stroke Functional Recovery

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1. Introduction

Each year 920,000 new stroke cases are reported in Europe, and of that number more than 100,000 benefit from comprehensive inpatient rehabilitation. Transcranial magnetic stimulation, computed tomography, positron emission tomography (PET), functional magnetic resonance imaging (fMRI), electroencephalography (EEG), electromyography (EMG) and evoked potentials all have shown that cortical reorganisation after stroke exists, however it remains poorly understood which complex regulating system hides behind functional restoration.

Many years ago, robots and mechatronics technology were successfully introduced (Aisen, 1997; Reinkensmeyer, 2000) to support and quantify functional recovery (Krebs, 1998). However, the ability of classifying stroke patients according to a specific recovery profile is scarcely out of the egg.

As the emphasis in stroke rehabilitation is on the improvement of functional performance, an ideal measuring tool should use Activities of Daily Living (ADL) tasks as principle for its quantitative measurements. ADL tasks such as "Drinking a glass of water", "Picking up a spoon", "Turning a key", "Lifting a bag", "Reaching for a bottle" and "Bringing a bottle to the opposite side" are well described and emphasized in textbooks for physical and occupational therapists (Bobath, 1978; Brunnstrom, 1970; Carr, 1998; Perfetti, 1997).

An improved execution of these tasks is depending on changing neural control parameters and in line with important functional milestones that stroke patients acquire during recovery. The basic assumption inspiring this research work is that the initiation of goal intended movements has some of the functional properties as performing the task (Clark, 2004; Dechent, 2004; Ehrsson, 2003; Jackson, 2003; Johnson-Frey, 2004; Kilner, 2004; Lehericy, 2004; Wolpert, 2001). The focused interest in the very first goal directed muscle contractions after stroke motivated an isometric approach for post-stroke functional assessment. Till now this knowledge has never been implemented in a measuring

instrument; this is the ultimate goal of the effort being carried out by a multidisciplinary team of European researchers whose achievements so far are partly reported in this chapter.

2. Background

Nevertheless the existence of a vast number of studies dealing with brain reorganization and recovery, it was never investigated whether information derived from the very first, nearly invisible goal intended movements could conceal information about future functional performance and brain reorganization. Considering these very weak contractions as loose building blocks of a movement initiation pattern on their way for a meaningful blend, an acceptable idea might be that during recovery these blocks move from a disorganized to an organized status. An attractive hypothesis is that this so called organized status is reached far before recovery becomes obvious and contains information on the remaining internal sensory motor representation of a particular task (Buchanan, 1996; Dewald, 1995; Koo, 2003).
This is acceptable because it takes only the early start of the global movement into consideration and might be conceptualized as the fingerprint for a movement execution. However an organized status does not necessary stand for good recovery, it only tell something about how stable a reached condition is, it can be either good or bad, unless we know what an organized status means for able bodied people (Sejnowski, 1998; Wolpert, 2001). The good news is that with this approach a condition shortly after a stroke can be compared with a condition also present in normal controls.
To test the hypothesis that precocity of sensory motor reorganisation in functional movement initiation after stroke is demonstrable far before a complete movement becomes possible, a special device was developed for the analysis of movement onset of the six earlier described routine ADL tasks.

3. The ALLADIN system

A diagnostic platform using an isometric approach for recording forces and torques from the whole body during the movement imagination and initiation of ADL tasks was designed and developed. This methodology has never been implemented so far: it represents an original contribution in the domain of functional assessment in neurorehabilitation.
The following paragraphs presents the clinical requirements, the functional specifications, the design methodology of the Alladin Diagnostic Device (ADD) and the Alladin software: the system reveals great potentials as a platform for clinical practice and as a tool for research in Neuroscience.

3.1 Clinical requirements

An interactive design process involved rehabilitation specialists and engineers toward the definition of specifications for an innovative diagnostic device. According to the state-of-the-art in the domain of Neuroscience and to the above mentioned specifications, the novel platform had to meet the following basic requirements:

- able to record forces/torques (F/T) data from the thumb, index finger and middle finger, from the arm, the trunk, the seat, from the whole foot and, separately, from the big-toe from a patient seated on a standard wheelchair. The measurement input ranges have been derived partly on the basis of existing references about typical data on human subjects (Mathiowetz, 1985; Deutsch, 2004; Bozec, 1997; Walsh, 1996) and partly on the basis of preliminary measurements;

- easy and quick to adjust for different anthropometrical characteristics of the population;
- to be used on both the right and the left body side;
- requiring a minimum of physical effort and time to the operator;
- able to record measurements in different postures;
- to be a modular system.

3.2 Functional specifications

The ADD is capable of measuring isometric F/T trajectories during the imagination and initiation of the selected ADL tasks. Stroke patients have been invited to perform six different ADL tasks according to a protocol which will be described in paragraph 3.4. The isometric F/T patterns have been simultaneously measured by 6-axis F/T sensors at different body segments during the imagination and initiation of each ADL task. The main objective of the isometric F/T measurements is to obtain quantitative evidence for recovery from stroke during rehabilitation.

Every isometric measurement is used to determine the actual status of the patient. Therefore, it was necessary to measure a large number of patients with the same device and in the same anatomical starting position. This assured a high reproducibility during the entire period of data acquisition in clinical trials. The data acquisition system has recorded isometric F/T data from:

- the trunk (at the patient's back),
- the lower trunk (at the patient's fundament),
- the impaired lower arm,
- the impaired foot and toe,
- the impaired middle finger, index finger and thumb.

ADL tasks to be performed during isometric F/T measurements are listed in the following sequence, together with the corresponding object:

1. *Drinking a glass (no reaching)*: the arm is placed close to the body, close to the midline, the position of the foot is standard, the fingers of the hand are prepared for a cylindrical grasp. *Object*: glass placed close to the hand.
2. *Turning a key*: the starting position is the same as for grasping the glass. *Object*: a key in a lock located in front of the hand. The key should be oriented horizontally in the lock.
3. *Taking a spoon*: the starting position is the same as for grasping the glass. The reaching movement towards the spoon is measured. The position of the foot is standard. *Object*: a spoon is placed a bit higher than the glass and on the side of the back of the hand.
4. *Lifting a bag*: the starting position of the arm is at the side of the body, the elbow is in a natural position (slightly flexed), the position of the hand and the foot are standard, the fingers of the hand are prepared for a cylindrical grasp. *Object*: a bag placed on the ground.
5. *Reaching for a bottle*: the starting position is an almost extended arm over the midline. The starting position of the hand is the same as for drinking the glass. The position of the foot is slid backward, and the back should be leaned forward. *Object*: a bottle placed in front of the hand.
6. *Bringing the bottle to the other side*: the starting positions of the arm, hand, and the foot are the same as for reaching for a bottle. *Object*: a bottle placed in front of the affected shoulder at arm reach distance.

ADL tasks are performed during isometric F/T measurements in three different positions: position 1 covers ADL task #1, ADL task #2 and ADL task #3, position 2 is related to ADL

task #4, and position 3 covers ADL task #5 and ADL task #6. The anatomical angles in position 1, position 2 and position 3 are listed in Table 1, Table 2 and Table 3 respectively, except those that are in neutral position. The above functional specifications have been included into the design methodology presented in the following section.

Articular movement	Anatomical angles (degree)
Shoulder abduction	15
Shoulder flexion	50
Shoulder internal rotation	45
Elbow flexion	35
Thumb abduction	50
Finger metacarpophalangeal flexion	15
Finger proximal interphalangeal flexion	20
Finger distal interphalangeal flexion	20
Hip flexion	90
Knee flexion	90

Table 1. The anatomical angles in position 1.

Articular movement	Anatomical angles (degree)
Shoulder abduction	5
Shoulder extension	7
Elbow flexion	12
Thumb abduction	50
Finger metacarpophalangeal flexion	15
Finger proximal interphalangeal flexion	20
Finger distal interphalangeal flexion	20
Hip flexion	90
Knee flexion	90

Table 2. The anatomical angles in position 2.

Articular movement	Anatomical angles (degree)
Shoulder flexion	100
Shoulder internal rotation	45
Elbow flexion	20
Thumb abduction	50
Finger metacarpophalangeal flexion	15
Finger proximal interphalangeal flexion	20
Finger distal interphalangeal flexion	20
Lumbar-thoracic flexion	30
Lumbar-thoracic rotation	20
Lumbar-thoracic lateral flexion	18
Hip flexion	90
Knee flexion	110
Ankle dorsiflexion	8
Toe metatarsophalangeal flexion	7

Table 3. The anatomical angles in forward reaching tasks (position 3).

3.3 Design methodology

A human-centered mechatronic design approach has been followed by starting from anthropometrical considerations and iteratively refining the design choices in a tight debate with end-users (i.e., therapists, patients). Simulations, mock-ups and early prototypes have been extensively used to obtain a direct feedback from end-users and to enable experimental preliminary tests in the real application domain.

The proposed method for isometric F/T measurements requires fixed, very stiff, anatomically standard and, at the same time, repeatable individual setting of the device for each patient in order to ensure reproducibility, reliability and good precision in the isometric measurements.

Design requirements of the platform arose from three different areas. Firstly, standardisation of the measurement, secondly safety standards, as well as medical certification requirements.

Finally, space limitations in hospitals regarding the room where the device was used and the location where the wheelchairs was stored when they are not in use, have been taken into account. Standardisation of the posture and measurement procedure assures reliability and validity to the recorded F/T measurements.

As a reference position, the user is seated on a wheelchair at height of 580 mm from the floor of the platform. The back of the user is 330 mm back from the rear side of the device. In this configuration, isometric contractions in two reference postures of the lower extremities can be performed by using the proposed platform (Figure 1). In the former, the user is seating in a neutral posture. This position is typical for the initiation of most common tasks, such as lifting or grasping an object: it is the starting position for ADL task #1, ADL task #2, ADL task #3 and ADL task #4. The latter takes into account a different posture, as the user moves the trunk forward and the feet backward. Starting from this position, other tasks, such as a forward reaching tasks, can be performed: it is the starting position for ADL task #5 and ADL task #6.
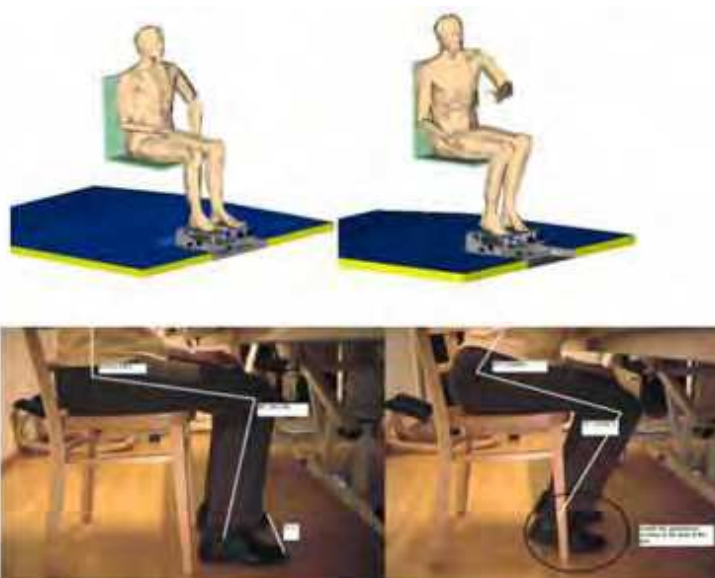

Fig. 1. CAD models used in the ergonomic study (top) and the two selected postures for the lower extremities and the feet (bottom).

The anthropometric data of the European population was studied for such design (Peebles, 1998). The ergonomic study was performed through CAD simulations (Pro/Engineer): a 3D mannequin model, created by using the Mannequin Pro tool, has been inserted into the CAD environment with the aim of (i) simulating the different postures according to the gender and percentile and (ii) fitting the design of the platform to the anatomical positions accordingly.

The results of this study enlightened the possibility of implementing a limited number of discrete settings on the platform, henceforth named S (Small), M (Medium) and L (Large), corresponding to the percentile values of the 25%-ile female (S size), the mean of the 50%-ile male and 50%-ile female (M size), and the 75%-ile male (L size).

Therefore, the device can be set without error to the above mentioned percentiles of the population, which represents a vast majority of the population. The adjustability of the device to the three discrete patient sizes was implemented.

The adjustability of the device to the three discrete patient sizes was implemented as follows. To minimize the error in the anatomical angles to be set at each of the six ADL tasks, as well as to keep the handling complexity of the diagnostic device on a tolerable level for the operating physiotherapist, the patients recruited for the isometric F/T measurements have been classified into three groups according to their height. During the measurements the appropriate size accessories and device settings must be used. The size groups are denoted by the S, M, L labels and colour codes have been used in order to make the operations easier (Table 4).

Label	Colour code	Height (h)
S	Yellow	h <1625 mm
M	Green	1625 mm < h < 1751 mm
L	Blue	h >1751 mm

Table 4. Definition of the three groups of patients sizes.

As a consequence of the mentioned approach, the set of the anatomical angles described in subsection 3.2 is fixed for any patient size. The calculated deviation from the ideal anatomical angles remains in the range ±0.5°.

The anthropometrical and ergonomic design approach, by identifying only a very limited number of adjustments required to the therapist, clearly simplified the design and the development of the overall system, presented in the following section, and represents a benefit for the therapists.

3.4 The ALLADIN diagnostic device (ADD)

The main objective of the mechatronic platform here presented is to perform valid and reliable isometric F/T measurements at stroke patients during the execution of the 6 ADL tasks. The ADD has to provide repeatable and accurate results: given this important requirement, the patients were precisely positioned to the same set of ADL positions for each measurement during the clinical trials, started in February 2005 and ended in September 2006.

The standardisation achieved both in terms of the mechanics of the device, the F/T sensor unit, the measurement control software and the unambiguous guidelines on the operation of the device have resulted in high reproducibility and comparability of the force torque measurements.

Since April 2004 a complete product design and development cycle which included the computer aided design, the development of three early prototypes and the feedback from the testing were implemented. Refinement and detailing of the conceptual design was a natural result of this cyclic process. The eight 6-axis F/T sensors are respectively installed behind the trunk, below the posterior, at the affected lower arm, at the affected thumb, index and middle finger, at the affected foot and toe (Figure 2).

They output detailed data on the ADL tasks to be performed. Table 5 shows the basic characteristics of the 6-axis F/T sensors (50M31A-I25, 67M25A-I40, 90M40A-I50, 90M40A-I50, 90M40S-I50, 90M40A-I50, 50M31A-I25; JR3 Inc., Woodland, USA). The orthogonal reference frame for the force and torque vectors is located inside the sensor. The platform has three positional settings for the patient according to the tasks to be performed. The first operational position is associated to the ADL task #1, ADL task #2 and ADL task #3, a second position is selected for the ADL task #4 task and a third for the ADL task #5 and ADL task #6. All operating instructions are presented on a screen in front of the patient. A first instruction is the video presentation of the task to be initiated by the patient; the second instruction is an invitation to "memorize the task" and then to "execute it". The measured behaviour is the combined output of 48 channels representing the x, y, z F/T data for all eight F/T sensors.

The diagnostic device includes the following main units (Figure 2):

1. Accessory storage board
2. Transit lying wheelchair
3. Monitor for the patient
4. Podium
5. Trunk Device
6. Foot Device
7. Arm Device
8. Finger Device
9. Seat Device

The Arm Device, the Finger Device and the Foot Device are shown in Figure 3. A customized software has been developed in order to allow the recording of different types of data: F/T data, clinical scales and natural language descriptions made by the physiotherapists (See subsection 3.5). Several young volunteers participated in a preliminary testing that aimed at verifying the output of the proposed isometric procedure. Altogether 250 subjects (150 hemiplegic patients and 120 normal control) were recruited during the clinical trials at the three hospitals. The centres participating in the multi-centre clinical trials were:

- Algemeen Ziekenhuis Maria Middelares Sint-Jozef Hospital (AZMMSJ), Gent, Belgium,
- Adelaide & Meath Hospital (AMNCH), Tallaght, Dublin, Ireland,
- Szent János Hospital, Budapest, Hungary.

All the three clinical trial centres obtained the approval of the relevant ethics committees. An informed consent was obtained from the subjects participating the clinical trials.

Subjects were measured and assessed twice a week during the first two months period and once a week during four consecutive months. They were seated in a special designed wheelchair and driven into an anthropometrical adaptive measuring instrument characterized by the above mentioned three discrete positions (Small, Medium and Large).

Appropriate size accessories and device settings were also used to ensure that the error in the anatomical angles is minimal, as well as to keep the handling complexity of the diagnostic device on a tolerable level for the operating physiotherapist (See the accessory storage board in Figure 2).

Fig. 2. The components of the Alladin diagnostic device.

Description	Quantity	Lateral forces (Fx, Fy)	Axial force (Fz)	Torques (Tx,Ty, Tz)	Dimensions
Type-H(and)	3	150 N	300 N	8 Nm	Ø 50 x 31 mm
Type-A(rm)	1	150 N	200 N	10 Nm	Ø 67 x 35 mm
Type-B(ack)	1	250 N	250 N	20 Nm	Ø 90 x 40 mm
Type-P(osterior)	1	550 N	1100 N	50 Nm	Ø 114 x 40 mm
Type-F(oot)	1	400 N	800 N	25 Nm	Ø 90 x 40 mm
Type-T(oe)	1	150 N	300 N	8 Nm	Ø 50 x 31 mm

Table 5. Basic characteristics of the 6-axis F/T sensors.

The postures chosen for the measurements represents a trade-off between a good approximation of the natural posture and the anthropometric characteristics of the subject. This choice assures sufficient conditions of repeatability to the measurements.

The clinical assessment was performed through the Fugl-Meyer Scale (Lindmark adaptation), the Motor Assessment Scale and the Stroke Impact Scale. The physiotherapists used a Portable Digital Assistant (PDA) in order to record the score for each assessment scale and patients' functional recovery.

The aim of the study is to identify if there are significant links between the recovery that occurs post stroke as measured by the diagnostic device and this recovery as measured by clinical scales and natural language descriptions. As described in section 3.2, six different ADL tasks with a varying complexity were used for F/T measurements.

The data acquisition followed a detailed protocol (Van Vaerenbergh et al., 2004). For each task, the patient watches a video showing the movement (recording #1). Secondly he is asked to mentally imagine and reproducing it with open eyes (recording #2). Finally, for three times he actually tries to perform it, exerting the forces at a comfortable level (recording #3, recording #4 and recording #5).

Fig. 3. Devices for measurements on the upper limbs and lower limbs. Left: the Arm Device (7) and the Finger Device (8). Right: the Foot Device (6).

3.5 The ALLADIN software

This section presents in detail the functional and technical specifications and the design approach of the software of the diagnostic device and describes the implementation of the different software modules as well as for their integration.

A general architecture of the diagnostic device software has been defined according to the functional specifications of the diagnostic device defined reported in previous section, and also taking into account the additional information provided through a close collaboration with end users (i.e., clinicians and physiotherapists) on this specific topic (Figure 4).

Specifications of the Database Module were given using the UML (Cantor, 1998) notation and diagrams in order to provide a definition of the functionality of this module which can be easily interpreted both by the software developers and by the clinicians. UML notation was also used to define the interface between the Cover Application (CA) module and the Database (DB) module. All other modules, i.e. Data acquisition (DAQ), Data viewer, Automatic Speech Recognition (ASR), were described by using simpler notations, such as flowcharts or direct presentation of the low level functions definition.
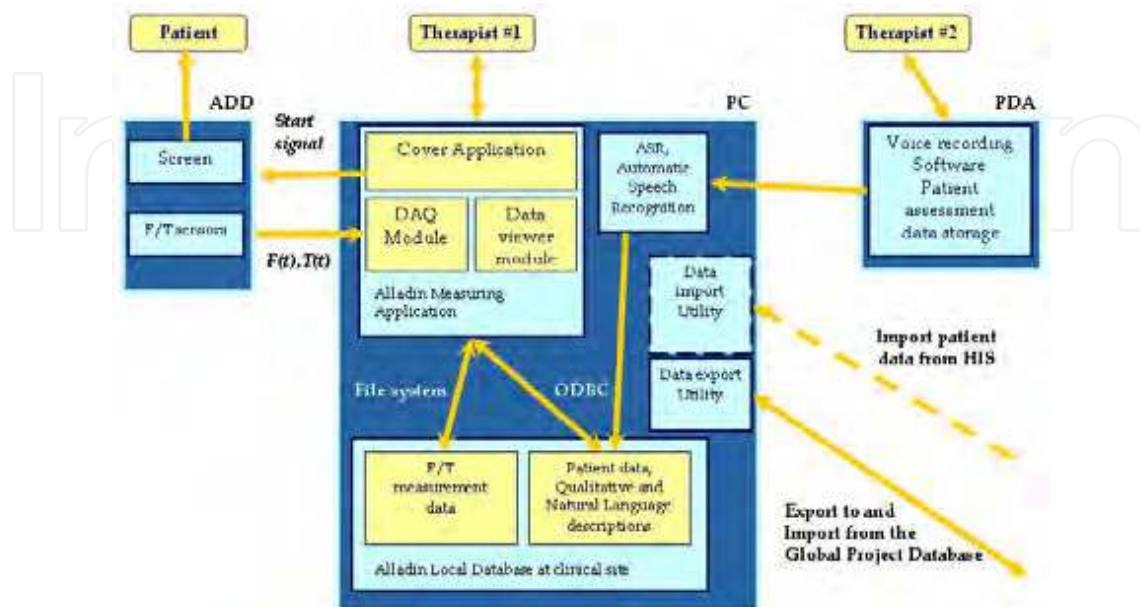
Fig. 4. The ALLADIN Software Architecture.

The software has been based on the general user requirements and specifications which have been defined in a preliminary phase. The software allows to manage all the functionalities provided by the ADD, including the recording and exchange of different kind of data between the CA module and the other modules and between the CA module and the DB. The main data to be collected and managed are:

- Patient data and case history
- Standard Outcome Measure (SOM)
- Natural language descriptions of the patient's status
- Voice records of the descriptions
- F/T measurement records of the ADL tasks

All data, after having been collected, are uploaded to the Local Database (Figure 4).

The main software requirements and specifications formed the framework for the Cover Application software design and development.

The CA was implemented using the Microsoft Visual Basic (VB) Environment Release 6.0, which allows the creation of friendly graphical user interfaces and simplifies the integration of modules developed with heterogeneous techniques. In particular it provides a means to connect the CA module with the ALLADIN database and with the other ADD modules, as for instance, the dynamic link libraries (DLLs) which implements the DAQ module and the Data Viewer Module. The DB was implemented in Microsoft Access 2000 and the other software modules were developed according to the CA module specifications in terms of I/O interfaces and functionality. The CA module allows the user to create, retrieve and modify records by queries on the patient information and clinical assessment in the DB.

The CA module was developed in order to allow the user to record the different information related to each patient and the data which come out from the measurements.

The main menu (Figure 5), offers different functionalities, such opening a patient record, starting a new session of measurements, creating a new patient record, editing and creating an user's profile, synchronizing with the global DB, system settings adjustment and remote assistance.

Four different types of users were identified (ADD physiotherapist, Natural language physiotherapist, Principal Investigator and System administrator); for each user profile an access rights policy was defined.
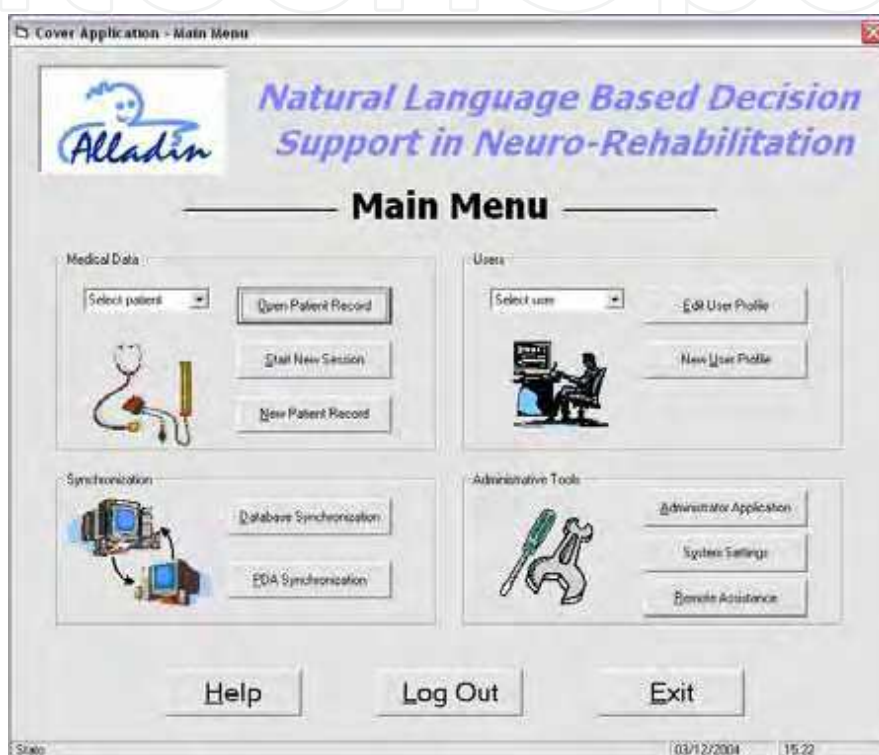

Fig. 5. The Cover Application main window.

4. Results and discussion

Some preliminary results from a normal control subject and a pathological subject are here presented. The choice of the task and the sensors is based on the preliminary results of data mining algorithms applied to the pre-processed data (Van Djick et al. 2006). Let's consider the task *"Drinking"* in a normal control (AHS-028, male, 45 years old, right dominant hand, measurement of the left side) and in a pathological subject (AHS-064, male, 43 years old, right dominant hand, right side of hemiparesis, date of stroke 15/12/2005, measurement on the right side), 25 days and 131 days following the stroke onset. The number of samples from force measurements shown in Figure 6-8 is 5400: as already stated, the sample frequency for data acquisition is 100 Hz, therefore the task lasts 5.4 seconds. Figure 6 show the force measurements from the thumb in the normal control (top plot), in the hemiplegic patient, 25 days following the stroke onset (middle plot) and 131 days following the stroke onset.
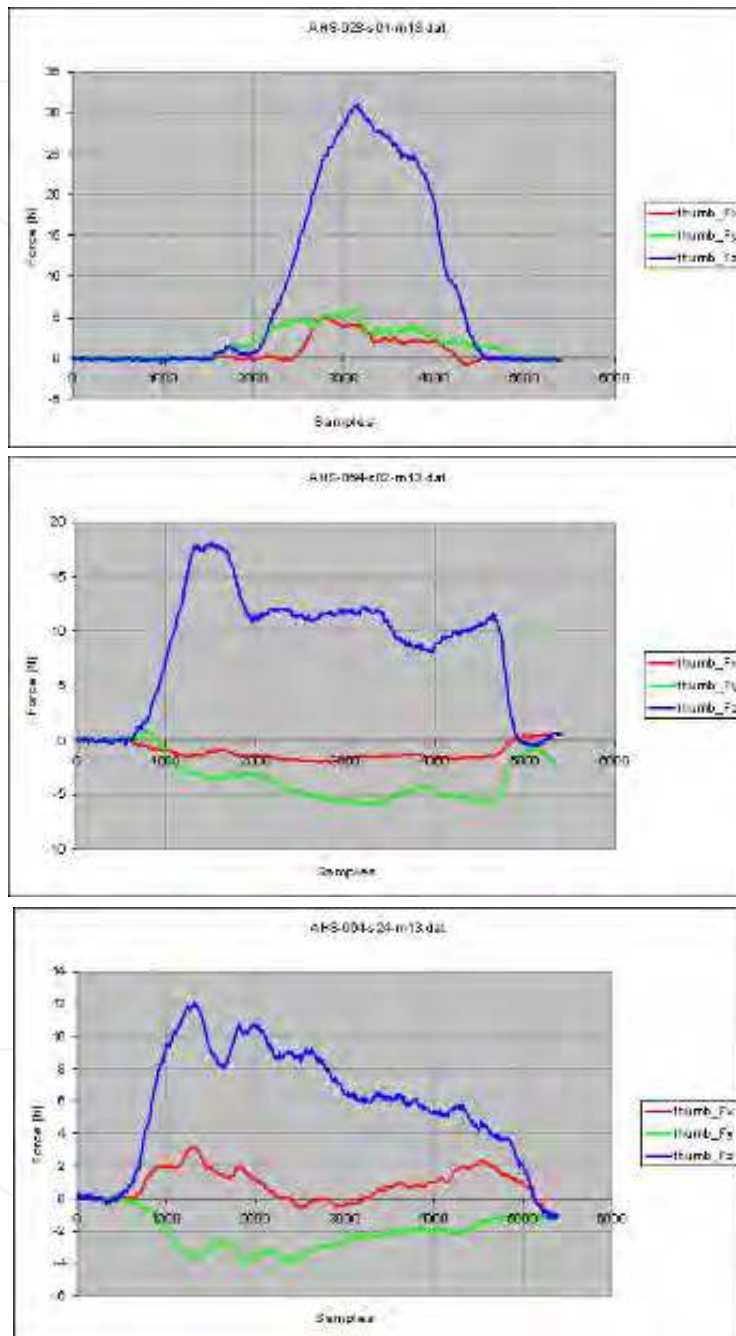
Fig. 6. Force measurements from the thumb in a normal control subject (top), in a hemiplegic patient, 25 days following the stroke event (middle) and 131 days following the stroke event (bottom) for the task "*Drinking*".
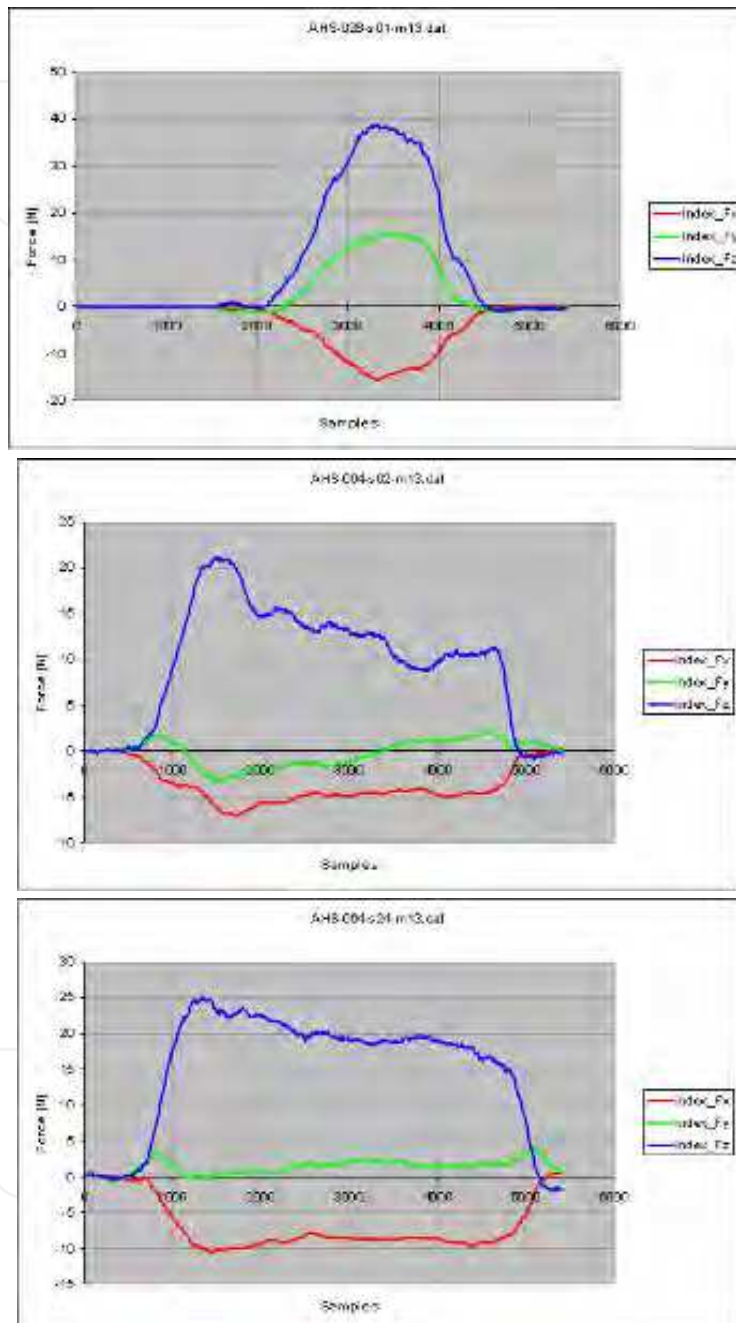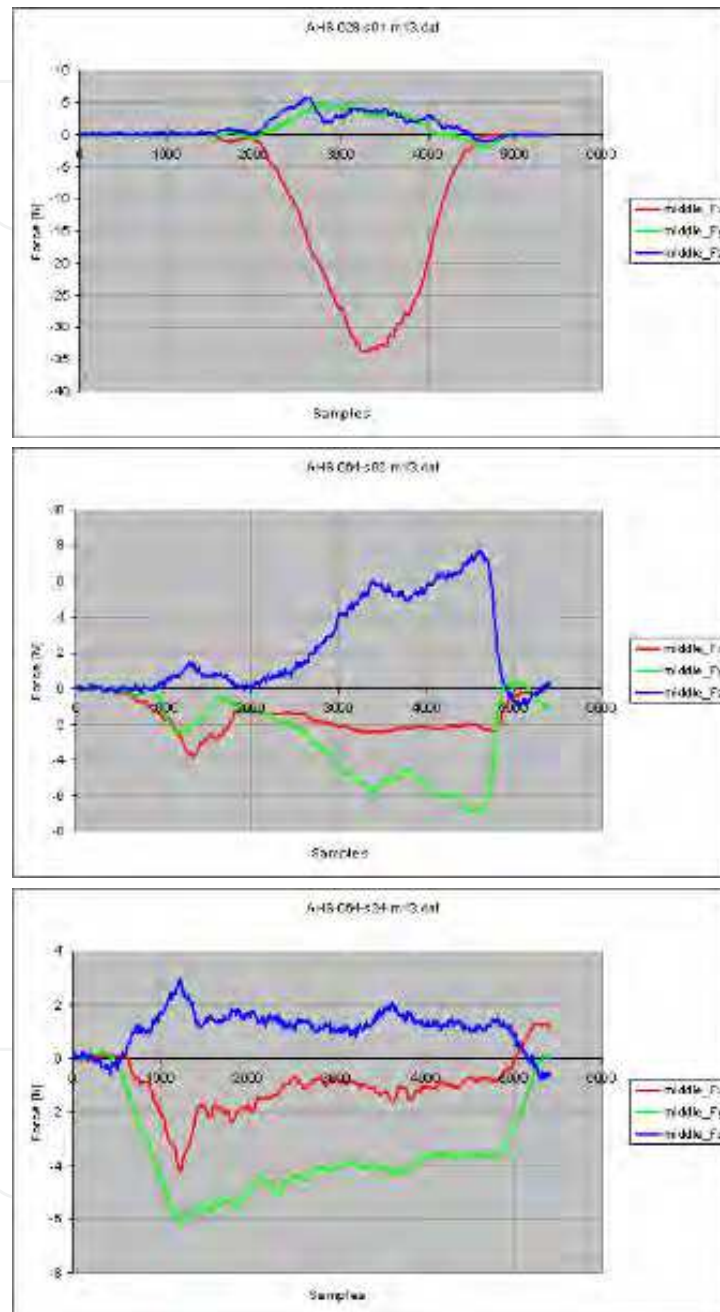
Fig. 7. Force measurements from the index finger in a normal control subject (top), in a hemiplegic patient, 25 days following the stroke event (middle) and 131 days following the stroke event (bottom) for the task *"Drinking"*.

Fig. 8. Force measurements from the middle finger in a normal control subject (top), in a hemiplegic patient, 25 days following the stroke event (middle) and 131 days following the stroke event (bottom) for the task "*Drinking*".

In the normal control, positive values in the F_x-direction can be observed. In normal circumstances, for a grasping movement, the thumb will be brought to the point where the index and the middle finger touch each other. In the diagnostic device, the thumb is fixated on the same height as the index finger. This causes a downwards movement of the thumb when the subject grasps the glass to drink. The positive values in F_y-direction means that the subject moves the thumb forwards when he positions the fingers around the glass to drink. The positive values for F_z-direction points out that the subject grasps the glass to drink.

The force measurement from the thumb recorded 25 days following the stroke onset show negative values on the x-axis: the force is directed in the opposite direction than the motor performance in the normal control subject, pointing out that the subject moves the thumb upwards to bring the glass to the mouth, instead of moving downwards. The negative values observed along the F_y-direction mean that the subject pushes the thumb forwards to bring the glass to the mouth. The positive values along the z-axis allow to conclude that the subject tries and grasps the glass to drink. The force is exerted in advance than the normal control subject and it lasts till to the end of the attempt.

The force measurement from the thumb recorded 131 days following the stroke onset show the positive values on the x-axis, same direction as the motor performance in the normal control subject, meaning that the subject moves the thumb downwards to bring the glass to the mouth, even if the force reaches the zero at about the half of the measurement, before still rising to positive values. The negative values observed along the y-axis point out that the subject pushes the thumb forwards to bring the glass to the mouth. The positive values along the z-axis mean that the subject tries and grasps the glass to drink. The force is exerted in advance than the normal control subject and it lasts till to the end of the attempt.

Figure 7 show the force measurements from the index finger in the normal control (top plot), in the hemiplegic patient, 25 days following the stroke onset (middle plot) and 131 days following the stroke onset.

In the normal control subject, the negative values along with the x-direction point out that the subject moves the index upwards to bring the glass to the mouth, while the positive values along with the y-axis points out that the subject moves the index backwards to bring the glass to the mouth. The positive values along with the z-axis means that the subject grasps the glass to drink.

The force measurement from the thumb recorded 25 days following the stroke onset show negative values along with the x-direction: the subject moves the index in the same direction as the normal control subject (upwards) to bring the glass to the mouth, even if with lower values and for a larger range of time. The positive, negative and positive values along with the y-axis points out that the subject first moves the index forwards, backwards and then forwards to bring the glass to the mouth. The positive values along with the z-axis means that the subject grasps the glass to drink, even if the exerted force doesn't shows a bell shaped form, as in the normal control subject. It shows a peak and then a falling to a lower value.

The force measurement from the thumb recorded 131 days following the stroke onset show negative values along with the x-direction: the subject moves the index in the same direction as the normal control subject (upwards) to bring the glass to the mouth, approaching the

force values of the normal control subject even if for a larger range of time. The rather positive values along with the y-axis points out that the subject first moves the index forwards to bring the glass to the mouth, with a less fragmented trend, compared to the measurement recorded 25 days following the stroke onset. The positive values along with the z-axis means that the subject grasps the glass to drink, with a quite bell shaped form, as in the normal control subject.

Figure 8 show the force measurements from the middle finger in the normal control (top plot), in the hemiplegic patient, 25 days following the stroke onset (middle plot) and 131 days following the stroke onset. In the normal control, the negative values on the x-axis means that the subject moves the middle finger upwards to bring the glass to the mouth. The positive values observed along the F_y-direction point out that the subject pulls the middle finger backwards to bring the glass to the mouth. The positive values along the F_z-direction means that the subject grasps the glass to drink.

The negative values on the x-axis recorded from the hemiplegic patient, 25 days following the stroke onset means that the subject moves the middle finger upwards to bring the glass to the mouth, showing lower amplitude values than the normal control. The negative values observed along the F_y-direction and the positive values along the F_z-direction mean that the subject pulls the middle finger backwards to bring the glass to the mouth and grasps the glass to drink respectively, but showing a fragmented trend. The negative values on the x-axis from the middle finger force measurements recorded 131 days following the stroke onset means that the subject moves the middle finger upwards to bring the glass to the mouth, showing lower amplitude values and a more fragmented trend than the normal control.

The negative values observed along the F_y-direction and the positive values along the F_z-direction point out that the subject pulls the middle finger backwards to bring the glass to the mouth and grasps the glass to drink respectively, with a more regular trend if compared to the force measurements recorded 25 days following the stroke onset.

5. Future directions and conclusions

A large set of features characterizing the clinical recovery have been extracted from the data according to the preliminary results from data mining techniques (Van Djick et al., 2006b) in order to track the recovery process through milestones and to foresee the rehabilitation outcome through predictive markers.

The positive results obtained so far through the extensive use of the proposed diagnostic device during the clinical trials for functional assessment of post-stroke patients allow to foresee new possible scenarios for the neurorehabilitation domain. The use of the diagnostic device together with systems for brain imaging (PET, fMRI, MEG) and techniques for monitoring brain activity (EEG) will allow to monitor the degree of learning and the changes in motor performances induced by the rehabilitative treatments through traditional and robotic therapies. Alternative applications for the proposed platform are:

- isometric motor exercise. Many clinical protocols for motor therapy of different type of patients prescribe the execution of isometric exercises. The proposed system could allow to accurately tune, monitor, measure and record the

forces/torques exerted by the patient during such exercises. To this aim, a self-calibration routine will be added to the system, such that forces/torques due to the body's weight will be automatically set to zero at the start of the motor therapy;

- human-machine interface. The proposed system can be associated to a virtual reality environment for motor rehabilitation, as recently implemented with similar devices for isometric measurements in the upper limb (Kurillo et al., 2005) or it can be used as novel human-machine interface for many different applications where the use of the hand and the foot is required, e.g. pedal and handle interfaces for game, surgical robots, vehicles for enabling independent living to citizens with residual abilities.

Further possible developments comprise also:

- a migration to a mechatronic platform embedding actuators to produce perturbations and assisted constrained motion of the affected limbs;
- the application of the proposed platform for research in neuroscience, e.g. by comparing isometric performance of healthy controls and different patients, and for studying anticipative and high-level planning capabilities based on the study of whole-body dynamics in isometric conditions at the inception of voluntary movements.

The proposed platform is the first device which acquires a great deal of different data (F/T data, clinical scales, natural language descriptions made by the physiotherapists) till now. It is a versatile research tool, which records heterogeneous fields in a complete and detailed way. It has been used in clinical trials in order to verify the clinical hypotheses.

The proposed platform, which has been validated in three different clinical centres in Europe, proved to be effective as a tool for experimental use in novel functional assessment procedures of post-stroke patients, according to the original specifications provided by the medical doctors and therapists. The platform has also a range of other potential applications, from motor therapy to human-machine interface.

The reduction of its level of complexity and the development of an optimized version for clinical uses are the next steps, after the completion of the analysis of data collected during the clinical trials. The use of actuators in the platform can be also considered as a further development of the platform as tool both for functional assessment and rehabilitative treatment.

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Rehabilitation Robotics

Edited by Sashi S Kommu

The coupling of several areas of the medical field with recent advances in robotic systems has seen a paradigm shift in our approach to selected sectors of medical care, especially over the last decade. Rehabilitation medicine is one such area. The development of advanced robotic systems has ushered with it an exponential number of trials and experiments aimed at optimising restoration of quality of life to those who are physically debilitated. Despite these developments, there remains a paucity in the presentation of these advances in the form of a comprehensive tool. This book was written to present the most recent advances in rehabilitation robotics known to date from the perspective of some of the leading experts in the field and presents an interesting array of developments put into 33 comprehensive chapters. The chapters are presented in a way that the reader will get a seamless impression of the current concepts of optimal modes of both experimental and ap- plicable roles of robotic devices.

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