ALLADIN: A Novel Mechatronic Platform for Assessing Post-stroke Functional Recovery

S. Mazzoleni, J. Van Vaerenbergh, A. Toth, M. Munih, E. Guglielmelli, P. Dario

Abstract—**In this paper the innovative ALLADIN platform for whole-body isometric force measurements to be used in neuro-rehabilitation for assessing post-stroke functional recovery is presented. A mechatronic approach was used in the design and development of this platform, which consists of an ergonomic mechanical structure embedding eight force/torque sensors that sample data about the performance of simulated activities of daily living in stroke patients. The overall ALLADIN system also includes a dedicated database, where all measures and other clinical scores are stored, and a PDA-based natural language system interface for the therapist. This paper only focuses on the mechatronic platform of the ALLADIN system. The proposed platform, which is currently being validated in three different clinical centers in Europe, aims at offering a brand new method for decision support in neuro-rehabilitation. It calculates and predicts the functional recovery of stroke patients and makes clinical assessments and quantitative measurements easily exchangeable among clinical stroke rehabilitation units.**

I. Introduction

Stroke therapy is one of the most important healthcare challenges. The application of robotics and mechatronics technology to post-stroke motor therapy has been already introduced [1], [17], [19], with very encouraging early clinical results [14], [16]. However, the deficits being treated are rarely clearly specified. Stroke patients, for example, tend to be grouped together according to very broad categories of severity. If, as seems likely, therapy should be tailored to specific deficits it is essential to identify the precise nature of such deficits. As the emphasis in stroke rehabilitation is on the improvement of functional performance, an ideal measuring tool must use Activities of Daily Living (ADL) tasks as principle for its quantitative measurements. ADL tasks are well described in textbooks for physical and occupational therapists [2], [3], [5], [18]. “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 strongly emphasized in these textbooks. The correctness of performing the tasks is in line with important functional milestones that stroke patients acquire during recovering. Moreover, the recorded data should show beyond mistake neural control parameters that declare brain plasticity. Neuroscience explains how control parameters can be derived from motor imagination and initiation. The basic assumption inspiring this research work, is that imagination and initiation of the task have the same functional properties as performing the task [6], [7], [9], [10], [11], [12], [15], [22]. Therefore the proposed platform uses 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 paper.

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II. Background

A device that pictures the complexity of the sensory motor representations, better known as internal models, should use isometric force/torque approaches with an “intending to do” paradigm [4], [8], [13]. This enables the detection of some remaining sensory motor representations early after stroke. The combination of movement imagination and initiation, verifies in particular the integrity of the “forward model”. This model maps motor commands onto their sensory consequences and will adapt according new situations. After stroke different control anomalies may appear and the parameters to measure must be implemented as such that they give information about day to day changes. In some patients the forward model is preserved but the motor output is reduced or disorganized, in others the forward model shows modifications with an adapted motor output. Worse is when the forward model fails or is abolished [20], [22]. The proposed new device explores the sensory motor reorganization after stroke by evaluating the six earlier described routine ADL tasks resumed from the literature.

III. Materials and Methods

The proposed platform (Figure 1) consists of a control and data acquisition workstation (1), transit lying wheelchair (2), monitor for the patient (3), trunk device (4), seat device (5), arm device (6), finger device (7), foot device (8), frame (9), and accessory storage board (10).

The main objective of the mechatronic platform here presented is to perform valid and reliable isometric force/torque measurements at stroke patients during the execution of the 6 ADLs.

Design requirements of the platform arised 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 will be used and the location where the wheelchairs will be stored when they are not in use, have been taken into account. Standardisation refers to reliability and validity.

The platform will provide repeatable and accurate results. Given this important requirement, the patient will be precisely positioned to the same set of ADL positions for each measurement during the clinical trials, started in February 2005.

The standardisation achieved both in terms of the mechanics of the device, the force/torque sensor unit, the measurement control software, and the unambiguous guidelines on the operation of the device will result 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 and development of three early prototypes, and 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 force/torque (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 I 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., Woodaland, 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 “drinking”, “turning the key” and “picking up a spoon” tasks, a second postion is selected for the “lifting the bag” task and a third for the “reaching for a bottle” and “bringing a bottle to the opposite side” tasks.

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 force/torque data for all eight F/T sensors.

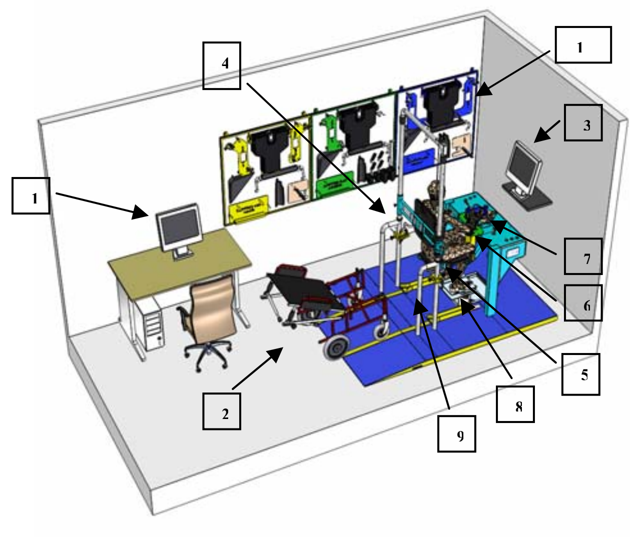

Figure 1. The platform for the assessment of post-stroke patients

Several young volunteers participated in a preliminary testing that aimed at verifying the output of the proposed isometric procedure. The data of one of them is further described in this paper. Informed consent was obtained from the subject.

The volunteer was seated in a special designed wheelchair and driven into an anthropometrical adaptive measuring instrument that has three discrete positions (small, medium and large).

The preliminary tests included only the task “lifting the bag”. Appropriate size accessories and device settings were 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 (Figure 3). The posture 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.

TABLE I
Basic Characteristics of the 6-axis F/T Sensors

Description	N = 8	Lateral forces (Fx, Fy)	Axial force (Fz)	Torques (Tx,Ty, Tz)
Type-H(and)	3	150 N	300 N	8 Nm
Type-A(rm)	1	150 N	200 N	10 Nm
Type-B(ack)	1	250 N	250 N	20 Nm
Type-P(osterior)	1	550 N	1100 N	50 Nm
Type-F(oot)	1	400 N	800 N	25 Nm
Type-T(oe)	1	150 N	300 N	8 Nm

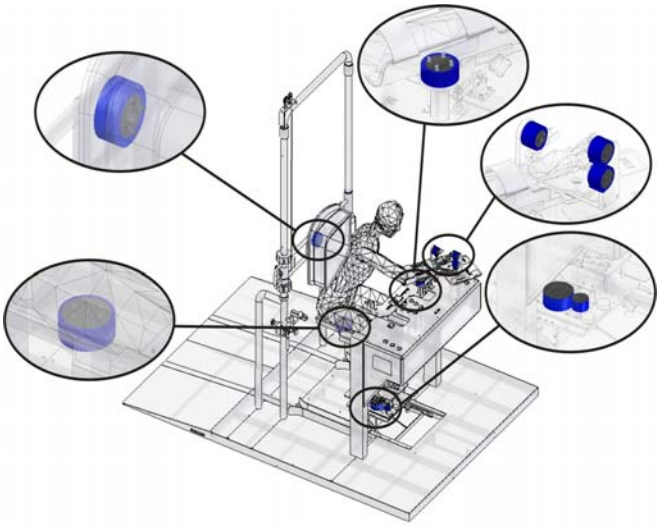

Figure 2. 6-axis F/T sensors in the ALLADIN Diagnostic Device

IV. Preliminary Results

Figure 4, 5, 6 and 7 present the data acquired from the hand, big toe, foot, arm and back F/T sensors. A strip of two seconds is considered as the task initiation. Notable variations in the values of the data appear for each sensor and represent the used strategy of lifting the bag.

Figure 4 shows the attempt of grasping the handle. Figure 5 demonstrates the force reactions of the foot and the big toe during resisted bag lifting where Figure 6 reflects the associated trunk compensations.

The sensor at the arm level (Figure 7) shows the torques around the 3 axes expressing the attempt of the subject to flex, adduct and rotate his arm during the bag lifting task

Figure 3. A view of the proposed mechatronic platform (ALLADIN Diagnostic Device) after final integration

V. Discussion and Conclusions

In this paper, the design, integration and testing of the novel ALLADIN mechatronic platofrm for post-stroke funtional assessment has been presented. The system is the first tool provided to neuro-rehabilitators for whole-body isometric measurements.

After integration of the platform, experimental testing demonstrated the feasibility of the proposed approach to extract quantitative markers on the integrity of the ability of post-stroke patients to generate internal forward models of motor actions. These preliminary results must be interpreted with caution. Nevertheless, they are encouraging since they capture an ADL task in a quantitative way.

The combined data output during restraint task initiation seems to give a detailed motor map of the task to be performed and points to the presence of the forward model. It's higly expectable that the abnormalites in the model can be indentified with this new approach and that quantitative evidence for recovery during rehabilitation can be shown. The latter improves decision making on admission and discharge from rehabilitation facilities [21].

The presented new mechatronic device will be tested in clinical trials hosted in three different EU hospitals from February 2005 to December 2006 with the aim to evaluate a large pool of stroke patients.

Ongoing and future work will address the problem of in-depth measurement data analysis through extensive clinical trials involving more than 200 stroke patients and clinical interpretation in view of the definition of novel protocols for functional assessment enabled by the ALLADIN platform.

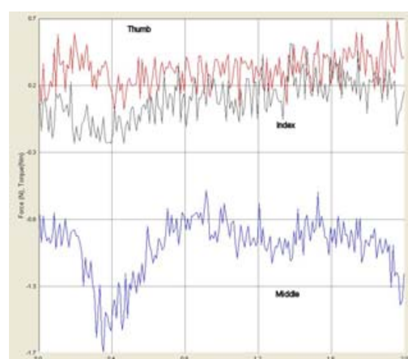

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Figure 4. Measurement force data from thumb, index and middle finger (z-axis component)

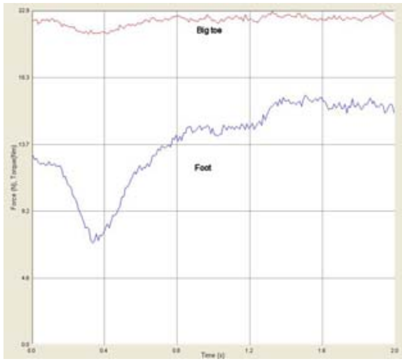

Figure 5. Measurement force data from the foot and the big toe (z-axis component)

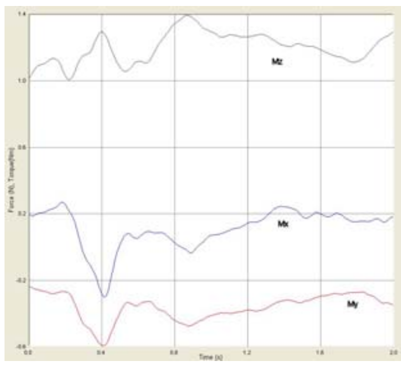

Figure 6. Measurement torque data from the arm (x-, y- and z-axis components)

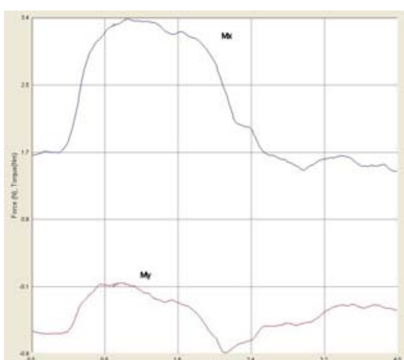

Figure 7. Measurement torque data from the back (x-, y-axis components)

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