ARMassist: A low-cost device for telerehabiltation of post-stroke arm deficits

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Abstract— **Motor deficits in the growing population of stroke survivors are creating a pressing need for new strategies and new tools to provide efficient and effective delivery of patient care. A summary if existing devices for upper-limb rehabilitation is presented, including the modes of feedback provided and whether the intended market is clinical or personal use. The design requirements for a new portable device are outlined from both patient and therapist viewpoints. Embodiments of the device combine planar gravitational support of the arm, low-cost sensors, passive or active movement assistance, visual and haptic feedback, and wireless communication protocol to produce an affordable but effective device for in-home therapy. The device targets the treatment of upper-limb motor deficits resulting from conditions such as stroke, traumatic injury, and disuse. The development of a passive first prototype ARMassist device is presented.**

Keywords— **Arm rehabilitation, stroke, upper-limb impairment, telerehabilitation, home health care.**

I. INTRODUCTION

New technologies to address arm deficits from stroke, traumatic injury, and other sources of motor impairment and disuse are needed. Considering (1) the increasing trends in stroke, (2) the known benefits of training duration, and (3) the existing devices in rehabilitation, it is expected that simplified, low-cost solutions hold the key. The aim of this research is to develop a simple human interface device that is portable, modular, easy to use, and includes only the essential components necessary to enable effective telerehabilitation. It is believed that a basic, low-cost system will produce the greatest outcome in terms of the number of patients treated while producing functional gains comparable to more complex systems. As background information, a brief review of the impact of stroke, past and present treatment methods, and existing rehabilitation robotics are presented.

A. Significance of Stroke

Prevalence: Stroke is one of the leading causes of long-term disability in Europe, The United States, and Australia. Each year in US, 780,000 persons sustain a new or recurrent stroke, and nearly 6 million persons are currently living with the long-term effects of a prior stroke [1]. Improved medical treatment of the complications caused by acute stroke has contributed to decreased mortality, but 90% of the survivors have significant neurological deficits.

Symptoms: The most common consequence of stroke is hemiparesis of the limbs contralateral to the brain lesion [2]. Hemiparesis can range from mild weakness to complete paralysis. Impairments in the upper limb tend to persist long-term with only 14-16% of stroke survivors with upper extremity hemiparesis regaining complete or nearly complete motor function [3]. Although the effects of stroke depend largely on the location of the obstruction and the extent of the brain tissue affected, movement disorders and stereotypic muscle synergies affect most individuals with stroke [4, 5].

Cost of stroke: The combined direct and indirect costs of stroke in the US in 2005 were estimated at over 56 billion US dollars. Furthermore, the demand for physical and occupational therapy for stroke survivors is expected to increase by a factor of three over the next 3 decades given the steady increase in life expectancy of the population and the high incidence of stroke in older adults [6].

B. Conventional vs. Robot-Assisted Rehabilitation

While there is no one standard technique that occupational and physical therapists use to improve upper extremity function, many of the techniques that are used require some manual assistance from the therapist to position, guide, and/or support all or some of the weight of the limb [7]. When provided with at least partial compensation of gravitational forces, it is possible for patients to perform controlled movements that could not otherwise be performed without assistance [8].

Using robot-mediated approaches, previous studies have shown that patients who performed progressive resistance exercises with adequate motor control for as little as 3-4 times per week for 6-12 weeks improved both strength and functional activities [9]. Furthermore, recently published research work confirms that better results in terms of rehabilitation outcome are obtained in specialized care centers where patients receive more therapy per day for extended periods of time [10].

C. Literature Review of Upper-Limb Devices

Commercial: A small number of systems for upper limb rehabilitation have only recently made their appearance on the market (Table 1). The most well-known device is the InMotion^2 (Interactive Motion Technologies, Inc.), the commercial successor to the academic MIT-MANUS, a 2-dof high-powered parallel manipulator. Hocoma has developed an upper limb product, Armeo®, based on the academic T-WREX device, a 5-dof passively counterbalanced exoskeleton. A third approach was taken by Motorika with the ReoRobot, now known as the ReoGo, a 2-dof mobile-robot-mounted joystick with an attached laptop. Additionally, there exists one portable commercial orthosis that

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provides powered assistance in response to measured EMG signals (Myomo e100). However, none of the above devices are sold for personal use.

Table 1 Commercial upper-limb rehabilitation devices

Device Name	Company (Location)	Feedback Provided	Clinical / Personal Use
InMotion2	Interactive Motion Technologies (Boston, MA)	V, H, A	Clinical
Armeo®	Hocoma AG, (Switzerland)	V, P	Clinical
ReoGo	Motorika (Mount Laurel, NJ)	V, H, A	Clinical
Myomo e100	Myomo, Inc. (Boston, MA)	A	Clinical

Note: Feedback provided: visual (V), haptic (H), active force (A), or passive force (P).

Academic: Despite a large and growing number of academic robotics research aimed at upper-limb therapy, the research is overwhelmingly focused on the clinical setting (Table 2). Only two devices to our knowledge are under study for therapy in the home. The MEMOS device is a 2-dog Cartesian platform that rests on a table and is currently involved in clinical trials through the end of 2009. RUPERT is a lightweight exoskeleton that uses pneumatic muscles as the driving actuators to provide 4-dof assistance. Both devices remain relatively large and cumbersome for regular in-home use by the patient population. Additionally, the question of true affordability remains a concern.

Table 2 Academic upper-limb rehabilitation devices

Device	Institution	Feedback Provided	Clinical / Personal Intended Use
MIT-MANUS	Massachusetts Institute of Technology (Boston, MA)	V, H, A	Clinical
ACT3D	Northwestern U. (Chicago, IL)	V, A	Clinical
MIME	VA Palo Alto (Palo Alto, CA)	V, H, A	Clinical
GENTLE/s	U. Reading (Reading, UK)	V, H, A	Clinical
ARMin	Swiss Federal Institute of Technology (Zurich, Switzerland)	V, H, A	Clinical
ARM Guide	Rehabilitation Institute of Chicago (Chicago,	V, A	Clinical
Haptic Drive	Institute for Rehabilitation (Ljubljana, Slovenia)	V, H, A	Clinical
EXO-UL7	UC Santa Cruz (Santa Cruz, USA)	V, H, A	Clinical
MGA	Georgetown U. (Washington DC, USA)	V, H, A	Clinical
MEMOS	Scuola Superiore Sant'Ánna (Pisa, Italy)	V, H, A	Clinical / Personal
RUPERT	Arizona State (Mesa, AZ)	A	Clinical / Personal

Note: Feedback abbreviations are provided in Table 1.

From the review of existing rehabilitation systems, it is clear that the inclusion of an engaging visual feedback coupled with actively powered assistance are considered vital aspects of robotic therapy. However, there are also studies indicating that passive compensation of gravitational forces is sufficient to enable users to regain movement coordination, at least in low levels of impairment severity [8]. Of the devices listed in the above tables, Armeo® is the only device that takes advantage of this simplification.

II. METHODS

The proposed system will first be developed as a passive prototype. A later active version will follow, building from the lessons learned in the passive development phase. The envisioned system will be a portable unit (Figure 1 - left) that straps to the user´s forearm and can be operated in the patient home on a standard table (Figure 1 - right). As a first step in the process, a set of system requirements were outlined in order to direct the further development of system hardware and software. These requirements are outlined and discussed below.

Figure 1. The ARMassist (left) is a wireless human interface device that connects to the user forearm and is operated on a standard table (right).

A. System Requirement

Affordability: The target production cost for the passive unit is 100 Euros, such that it can be sold a price comparable to other computer peripherals. The target production cost for the active unit is 500 Euros. Maintaining affordability requires the use of inexpensive stock parts (motors, sensors, raw material) and standard processes (basic machining, high-volume manufacturing practices).

Simplicity: Utilizing a simple robust design with minimal moving parts plays a role in both ultimate affordability (price) and product life cycle (value).

Portability: The unit should be small enough to be carried easily from a store in a standard grocery bag, and should weigh less than 4 kg.

Usability: For a system to be easy to use, it should be intuitive and clearly understandable without explanation. It should allow simple one-handed donning and doffing. Considering use in a virtual environment, mappings between actual and on-screen motions that are not readily intuitive should be avoided.

Functionality: From a functional standpoint, the design should (1) provide a large workspace for user, (2) ensure repeatable movement tracking, (3) store a log of movement trajectories and performance information for therapists to review, and (4) be able to run on a single charge for up to 3 hours per day over a 1 week duration.

Modularity: The human-machine-interface should be adjustable in terms of relative position with the device, user fit, and should be removable to accomodate different end-effecters, forearm or wrist, for example. A separate module for the hand should also be attachable in conjunction with the forearm support.

B. Telerehabilitation Architecture

As the ultimate deployment of this technology will be in the home, the relationship between this new training modality and the expertise provided by medical staff should be considered. The concept for use in a telerehabilitation environment is that the prototype will communicate wirelessly with a local pc that is connected by internet to a care center or medical professional. While this model should be considered, it is important to note that even before such tele-health networks are established, portable devices can serve a valuable purpose. In addition to allowing greater amounts of training, data can be stored locally and sent periodically to health providers for analysis and periodic treatment updates.

III. RESULTS

The hardware of a first prototype of the ARMassist was developed using low-cost components for motion and force sensing and for passive gravitational support of the limb.

In order to fulfill the above requirements, the design of the device was divided into two component assemblies: the forearm support and the main structure. The two-component design makes the unit easy to assemble and feasible for different patients, in addition to increasing portability.

The forearm support is composed of a foam liner inside of a 3mm thermoplastic shell. The shell attached to a stiffening aluminum rib provides rigid support against longitudinal bending while providing flexibility in the radial direction for a secure fit with the arm when fastened by two Velcro straps. The straps are oriented such that the user can secure by pulling toward the user with the intact limb.

The main structure is a square module where the following components have been integrated:

- **Ball transfers**: Three ball transfer units allow for a large planar workspace with sufficient device stability and low friction motion. Both load ball and minor balls of each transfer unit are made of nylon in order to reduce the noise of operation.
- **Movement sensors**: Two Logitech Value optical USB mice boards provide position data.
- **Processing and communication unit**: A portable computer processes position and force data and provides the communication with the user computer through Bluetooth, and connects to the sensors through a USB hub.
- **Force sensor**: A load cell is incorporated in the center of the structure providing force data to the microprocessor.
- **Battery**: A 6000mAh 5V battery powers the sensors and the processing and communication unit.
- **Forearm rocker**: A single-axis pivot with interchangeable forearm springs allows the stiffness of the forearm support to be varied depending on the user's support needs.

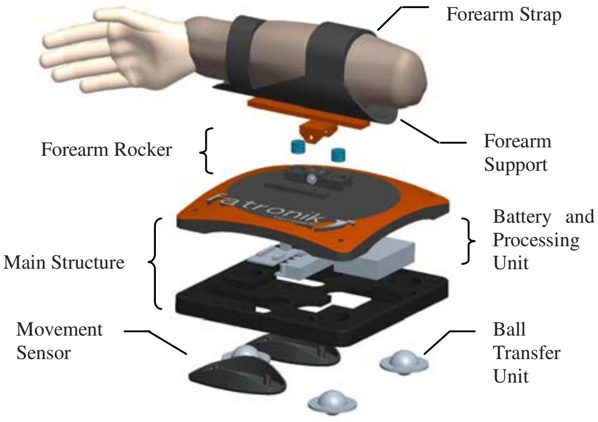

Figure 2. Exploded CAD view of first prototype design.

In order to monitor movements and forces exerted by the arm, the prototype (Figure 3) is equipped with two types of low-cost sensors: 2-axis position and 1-axis force.

Position Sensors: Two Logitech Value optical scroll USB mice boards have been attached to the base of the device. The mice are based on the ADNS-2610 optical mouse sensor which processes 1512 frames per second. Each frame contains a rectangular array of 18 x 18 pixels, and each pixel senses up to 64 shades of gray. The mice provide information about displacement in the X and Y directions with a maximum resolution of 400 counts per inch.

Force Sensor: To measure the vertical (Z-axis) force exerted by the forearm, the main structure is also equipped with a low-cost 1-axis force sensor with a 10 kg capacity in both positive and negative directions. The analog output of the load cell is connected to an Analog Devices AD727 instrumentation amplifier and read by the 10 bit A/D converter of the processing and communication unit at 1 kHz. The signal is low pass filtered using a simple moving average filter. It was found that using a window frame of 20 ms obtained the optimum tradeoff between the stability of the signal and the delay from buffering.

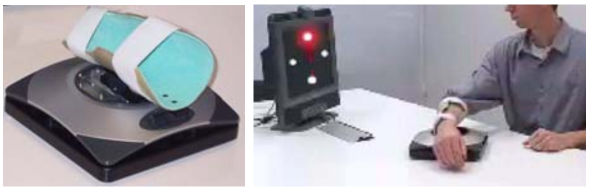

Figure 3. First ARMassist prototype (left) during initial testing (right).

IV. CONCLUSIONS

From the trends of aging populations throughout the world, and the increasing prevalence of stroke with age, it is clear that more treatment modalities must be extended beyond the borders of the in-patient setting to locations outside of the hospital. We believe that the combination of requirements outlined in this paper and used in the development of this first prototype ARMassist device are sufficient to successfully meet this need.

Current efforts are being devoted to the development of fundamental movement strategies in using the ARMassist in simulated 3D training environments. It is anticipated that the measure of X and Y position and Z force will be sufficient to control three dimensional reach tasks in the on-screen virtual environment for the purposes of functional motor relearning in patients with motor impairment of the upper limb.

Additionally, future development will produce an actively driven prototype for planar motion assitance, as well as modular device add-ons for hand training.

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