Telehealth Networks for Hospital Services:

New Methodologies

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Chapter 18
Sensorized Garments Developed for Remote Postural and Motor Rehabilitation

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ABSTRACT

Every day, all around the world, millions of people request postural and/or motor rehabilitation. The rehabilitation process, also known as Tertiary Prevention, intends to be a sort of therapy to restore functionality and self-sufficiency of the patient, and regards not only millions of patients daily, but involves also a huge number of professionals in medical staffs, i.e. specialists, nurses, physiotherapists and therapists, social workers, psychologists, physiatrists. The care is given in hospitals, clinics, geriatric facilities, and with territorial home care. For the large number of patients as well as the medical staff and facilities necessary to support the appropriate postural and motor training, the monetary costs of rehabilitation is so large, it is difficult to estimate. So, every effort towards a simplification of the rehabilitation route is desirable and welcome, and this chapter covers this aspect.

INTRODUCTION

Nowadays in the world there are about 600 million of people with various types of disabilities (Fifty-Eighth World Health Assembly) with respect to a total world population of around 7 billion of persons. This number is rapidly increasing since the population growth rate, the increasing average age, the malnutrition, the violence (especially domestic ones), the environmental degradation, the diseases (such as AIDS, malaria, Ebola,..), amputations, medical treatments, or finally because of injury reported in various type of accidents (work, road, sport, guns, etc.).

From an analysis of available statistical data on disability, it results that each country has a

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different concept of "disabilities" and their cares. There are situations for which the disabled person is considered who doesn't have a dignified life, and therefore live in extreme poverty. Other societies consider the disability the condition for which it is not possible to work continuously, and others that define people with disabilities just who needs government support to live. Finally, some countries consider disabled only those persons with a form of physical disability or who are suffering from physically debilitating diseases like multiple sclerosis can be.

Focusing only on people with physical impairments, the 80% of them live in poverty and therefore have no care taking, and it cannot be otherwise since in the world there are only just more than 300,000 accredited physiotherapists capable of giving support to physical deficit. The percentage of disability shows a great variability between countries from 0.2 to 20.9% with respect the population, especially regarding the degree of disabilities. The average prevalence is approximately 10%, half of which 5% is from moderate to severe conditions. In the year 2000, the 70% of disabled were living in developing countries and only 3% of them were appropriately treated (WCPT Quadriennal Report 2003-2007; Takahashi et al., 2003).

Rehabilitation care cannot reach all patients and this is a problem both for developing than developed countries. In fact only 50% of States are able to provide the necessary care and the disabled population that can be medical treated is about 20% of the total. All around the world there are Nations that haven't the capability to do this at all. The distribution of physiotherapists around the world is indicative: in developing countries there is 1 physical therapist every 550,000 patients while in developed countries this ratio is only 1 every 1,400 patients (WCPT, October 2003). The point is also that a patient who claim rehabilitation need not only of therapists but also of many other medical and non-medical staff figures, as Figure 1 summarizes.

The care can be given in hospitals, clinics, geriatric facilities and with territorial home care. So, we have to consider that not only the real treatments of the patients have their costs, but also costs which come from the necessary environmental structures. In Table 1 a brief summary of setting and purpose for the rehabilitation evaluation (Ganter et al., 2005).

Let's consider some detailed examples of data regarding consistent part of the world of numerical values to be considered in rehabilitation course.

The percentage of disability in the United States of America is around the 12.1% with respect the overall population. There a disabled person is defined as who is deaf or has serious difficulty in hearing; who is blind or has serious difficulty seeing even when wearing glasses; who has serious difficulty concentrating, remembering, or making decisions because of a physical, mental, or emotional condition; who has serious difficulty walking or climbing stairs; who has difficulty dressing or bathing or has difficulty doing errands alone such as visiting a doctor's office or shopping because of a physical, mental, or emotional condition (www.bls.gov). We can guess as the 1/3 of percentage of them regards people with motor deficit.

Figure 1. People involved in patient's motor rehabilitation

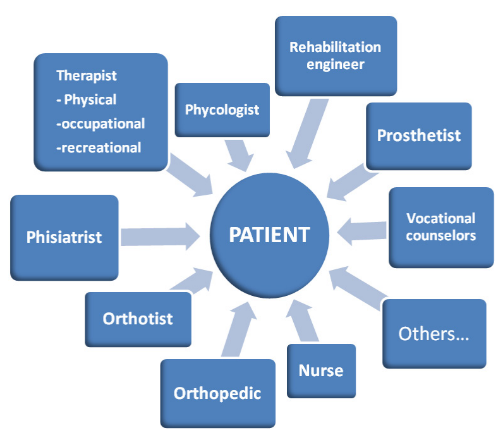


Table 1. The rehabilitation evaluation: setting and purpose

Hospital	Inpatient rehabilitation unit	Comprehensive evaluation by team
	Off-service consultation	Assessment by physician of potential for rehabilitation benefit
Clinic	General rehabilitation clinic	Comprehensive evaluation by team
		Assessment by physician of potential for rehabilitation benefit
		Limited evaluation of specific disease group (e.g., muscular dystrophy, sports injury)
	Day rehabilitation program	Comprehensive evaluation by team
	Impairment/disability clinic	Evaluation determined by requirement of referring agency (e.g., workers' compensation, social security)
	Community nursing home	Comprehensive evaluation by team
		Limited assessment by selected numbers of rehabilitation team
		Assessment by physician of potential for rehabilitation benefit
	School	Limited evaluation of physical disability
		Limited evaluation for participation in sports
	Transition living facilities	Comprehensive evaluation by team
		Limited assessment of specific problem

Table 2 shows the number of people with/without disabilities with respect the level of employment in the U.S.A., comparing the same months of the current and last year.

Reporting another example, we focus on the situation of disability in Europe, represented in the chart below (ANED, 2009), in terms of overall costs with respect to the percentage of Gross Domestic Product of each Country (see Figure 2). The overall costs are here be considered the mere rehabilitation ones and the social costs supported by the community too.

The decision to propose the situation in economic term is due to the fact that the European Union is composed of very different countries, each of one with its definition of "disability" and with its own budget and health policies (without differencing between public and private expenditure), done with respect to the Gross Domestic Product. So there are objective difficulties to compare otherwise than referring to the expenses paid for the disability conditions of European people.

The annual cost incurred pro capital is rather in the chart of Figure 3.

To try to solve the problems of disabilities, each Country assesses proper rehabilitation courses. Their management is very expensive from a monetary point of view, but also from personnel and facilities needed to carry out the health service.

As another example, let's consider the situation of the disability only in Italy (author's country), respect to a total population of around 60.6 million of people. There are about 2,830,000 disabled people, divided as follows (Ministero della Salute - Ufficio di Direzione Statistica, January 2011):

- **Patients assisted at home:** 494,204 (the 81% of them are over 65 years old);
- **Physical disabled:** 12,220 users in nursing homes, 10695 patients cared for day hospital;
- **Mobility disabled:** 21,747 patients in nursing homes (47 days in hospital on average for each patient), 4,550 patients cared for day hospital (57 days of hospitalization for each patient), 2,311,136 disabled assisted in the surgery.

Table 2. Persons with/without disabilities with respect the employed status, sex and age in USA

Employed status, sex, and age	Persons with a disability		Persons with no disability	
	May 2010	May 2011	May 2010	May 2011
TOTAL, 16 years and over				
Civilian non institutional population	26,547	27,669	210,952	211,644
Civilian labor force	5,930	5,828	147,936	147,621
Participation rate	22.3	21.1	70.1	69,7
Employed	5,060	4,917	134,437	135,11
Employed - population rate	19.1	17.8	63.7	69.7
Unemployed	870	911	13,499	12,510
Unemployment rate	14.7	15.6	9.1	8.5
Not in labor force	20,617	21,841	63,016	64,024
Men, 16 to 64 years				
Civilian labor force	2,729	2,682	75,601	75,258
Participation rate	37.5	35.3	83.1	82.5
Employed	2,282	2,218	68,019	68,474
Employed - population rate	31.3	29.2	74.7	75.1
Unemployed	448	464	7,582	6,784
Unemployment rate	16.4	17.3	10.1	9
Not in labor force	4,555	4,911	15,399	15,948
Women, 16 to 64 years				
Civilian labor force	2,381	2,280	66,472	66,109
Participation rate	30.9	29.2	71.5	70.9
Employed	2,052	1,919	60,856	60,748
Employed - population rate	26.6	24.6	65.5	65.2
Unemployed	330	360	5616.00	5,361
Unemployment rate	13.8	15.8	8.4	8.1
Not in labor force	5,321	5,531	26,452	27,107
Both sexes, 65 years and over				
Civilian labor force	820	867	5,862	6,254
Participation rate	7.1	7.1	21.7	23.0
Employed	727	780	5,561	5,889
Employed - population rate	6.3	6.4	20.6	21.6
Unemployed	93	87	301	365
Unemployment rate	11.3	10.0	5.1	5.8
Not in labor force	10,741	11,399	21,166	20,969

The expenditure which the Italian State claims for treatment and rehabilitation activities are very high: all patients hospitalized for physical rehabilitation cost 135.50 €/day, patients cared in day hospital cost 82.50 €/day, while people treated in surgery cost 38.50 €/day and finally the people cared for at home cost 47.00 €/day.

Figure 2. Invalidity in % of GDP in European countries, 2006 (all schemes, non means-tested benefits and means-tested benefits)

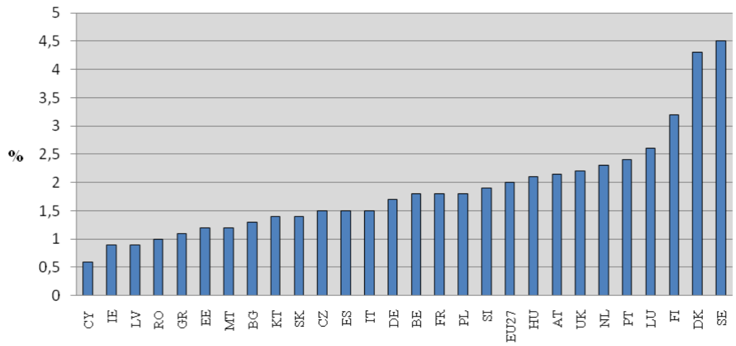
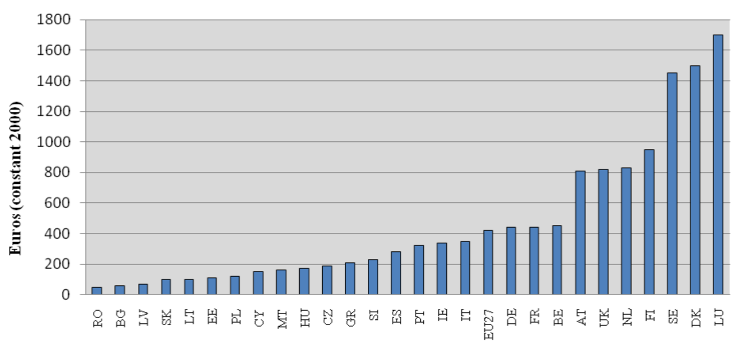


Figure 3. Tested benefit, invalidity 2006 (all schemes, non means-tested benefit and means-tested benefits)



The medical and paramedical staff employed in public facilities is as follows: Orthopaedics: 681, Physiotherapists: 1,526, Speech therapists: 278, Other staff: 2,012.

The staff employed in private structures: Orthopaedics: 4,007, Physiotherapists: 14,480, Speech therapists: 2,896, Other staff: 20,685

The annual working hours for each patient are:

- **In hospital:** Orthopaedics: 21.2, Therapists: 51.1, Speech therapists: 11.1;
- **In day hospital:** Orthopaedics: 19.9, Therapists: 83.4, Speech therapists:13.8;
- **In surgery:** Doctors: 0.1, Therapists: 0.8, Speech therapists: 0.3.

These data demonstrate that rehabilitation is onerous for both the State and patients, especially because the treatment often lead to only partial motor recovery.

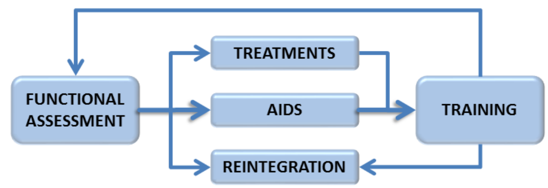
2. THE MEASURE OF STATIC AND DYNAMIC PATIENT'S POSTURES

After traumatic accidents, injuries, diseases, strokes, amputations and so on, a loose of partial or total motor abilities can follow. So, postural activities are compromised, but these are a precondition for any successful voluntary action execution (Arbib, 1981). Even a non-accidental event, such as a cosmetic surgery, with the slightest modifications (even less than 400 grams) can meaningfully affect the postural system, also if for a limited time (Bellomo et al., 2011). In all these occurrences, it is mandatory to try to return to full motor functionalities and to a convenient postural structure of the body. This can be obtained with a specific rehabilitation route, as Figure 4 schematizes.

As a starting point, a functional assessment of the patient is needed so to resolve a medical diagnosis. This stage consists in the evaluation of the historical clues and physical findings of the patient, evaluated taking into account his/her residual motor functionalities. Nurses and therapists measure, as a current practice, the patient's static postures and/or articulation's Range Of Motion (ROM) and, sometimes, joint instability and/or alignment, by manual stuff such as goniometer, reflex hammer, finger circumference gauge, Gulick anthropometric tape, plastic posture grid as reference, baseline scoliosis meter, chest calliper, inclinometer, adjustable sit and reach flexibility tester, digitometer finger motion gauge, universal protractor, and so on (in Figure 5 some examples).

These systems of measure surely occur in the preliminary stage but, quite often, they remain the only common procedures of measure, eventually adopted again if a new functional assessment is necessary (returning to functional assessment after training in Figure 4). Only for some specific cases, other more sophisticated technical measuring procedures are utilized. We refer, for instance, to patient's locomotion analysis which,

Figure 4. The rehabilitation route



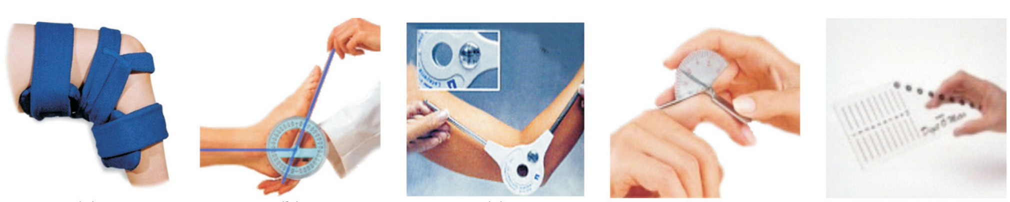
only when necessary, is performed by passive infrared cameras and/or embedded force platforms, as Figure 6 reports.

But these latter systems remain far away from be adopted as a standard rule in all circumstances, since their higher costs in terms of money, spaces and involved personnel.

Returning to the rehabilitation route, if the first stage of functional assessment reserves non negative results we can think about a reintegration of the patient in the society, otherwise treatments or aids are necessary. The treatments consist of functional recovery by means of rehabilitative procedures, or functional replacement by means of technical equipment, or functional surgery aimed at modify/replace the malfunctioning organ. On the other side, the aids are intended as technical facilities useful to allow the patient to reach the maximum possible degree of independence.

After the treatments or the aids stage, a training procedure is necessary. In fact, the patient must be educated to his/her novel condition or be re-educated to gradually return to his/her pre-trauma status of motor ability.

Figure 5. (a) Knee goniometer, (b) biplane goniometer, (c) Gollehon extendable goniometer, (d) finger goniometer, (e) digitometer finger motion gauge



(a) (b) (c) (d) (e)

Figure 6. Platform with embedded force sensors, courtesy of ITOP

In any case, during all the rehabilitation steps, the measures play a fundamental rule, especially in clinical decision-making as already underlined and demonstrated (Giani, 2011). Furthermore, the measures can be carried on not only for the evaluation of treatment procedure, but also for a feedback to the patient, for the assessment of work capacity or, even, for research purposes. These repeated necessity to measure, claims efforts and time both from the professionals and from the patient and are, as already mentioned, performed with overcome methodologies, since anchored to manual stuff. The manual methods of measure can be highly inaccurate and can offer important disadvantages: they strictly depend on the abilities of the expert (often nurse or therapist); they can be performed only for a very limited period of time (typically few minutes or, even, seconds); necessarily the patient must be present in the medical structure (hospital, nursing home, sanitarium or what else). Furthermore, difficulties come also from the fact that ROMs present considerable variations among different persons, and factors such as age, sex, obesity, genetics can influence them. Last but not least, the patient can be asked to perform the ROM maneuver at home by him/her-self, without assistance from the examiner (these are the so called active ROM). This is because, enabling individuals to manage daily self-care is among the most important goals undertaken by the rehabilitation staff, since such tasks relate directly to the business of living and their performance signifies a return to participation in the routines of daily life. In this occurrence, comparisons can be possible between active ROM and the measurements performed by specialists (known as passive ROM), but only if the starting position, stabilization, goniometer's alignment, and type of goniometer are strictly the same.

In addition to all the previous considerations, the mapping of the body postures/kinematics and the measured values over a period of time can be of strategic importance, again not only for rehabilitation purposes, but even for evaluating the emotional reactions a patient can present to several events, and for realizing more ergonomic stuff necessary for the rehabilitation itself, or to furnish a complete database useful for programming future interventions.

So, it becomes mandatory to reserve to the measure of patient's motor residual functionalities much more consideration and devote them more efforts respect to what has been done till now. It is now evident the importance to have the possibility to count on an alternative system of measure with the characteristic of objectivity, precision, reliability, portability (home/clinical/other environment), economy, long term monitoring (minutes, hours till days) and ease of use even for non-specialists. The alternative system of measurements refers only to the latest years and, even if technologically enough mature, struggle to be adopted as standards. These new systems are mainly based on the latest developed sensors, and for them the electronic part plays the winning rule. Several further advantages of the new system of measure:

- The measurements can be directly presented as digit, so they can be easily read and understood;

- The measurement are expressed by electronic signals, so data can be easily directly processed and stored even in digital records specific for that particular patient;
- The measurement can be easily performed even over a long period, so data can be adopted to easily monitor the patient's long time trend;
- The measurements are not "strictly" dependent on the operator's skill.

So, we will have a look at the novel possibilities offered by the new technologies and, as a starting point, we purpose a scheme for their classification, so to offer a suggestion to be adopted as a profitable technical solution of measure for the specific patient. In addiction we will detail some solutions we developed in our laboratory.

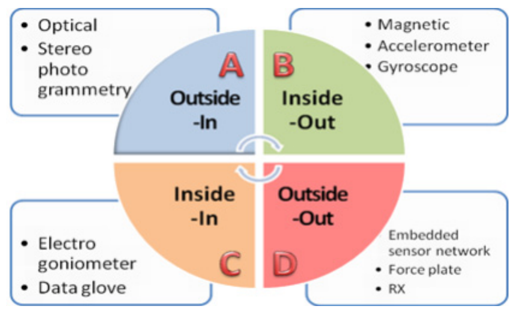
3. CLASSIFICATION OF SYSTEMS FOR STATIC AND DYNAMIC POSTURE MEASUREMENTS

The latest technologies offer different measurement systems, more or less sophisticated, more or less expensive. To determine which are the most feasible for the purpose of obtaining objective, accurate and time protracted measure for rehabilitation purposes and for specific patients, it is convenient to classify all the current systems.

An interesting classification is based on position of the sensors and the sources (Wang, 2005; Saggio and Sbernini, 2011). Specifically, as schematized in Figure 7:

- **Outside-In Systems:** The sensors are somewhere in the world, the sources are attached to the body.
- **Inside-Out Systems:** The sensors are positioned on the body, the sources are somewhere else in the world.

Figure 7. Schematization of body posture measurement systems



- **Inside-In Systems:** The sensors and sources are on the user's body.
- **Outside-Out Systems:** Both sensors and sources are not (directly) placed on the user's body.

The *Outside-In* Systems typically involve optical techniques with markers, which are the sources, strategically placed on the patient's body parts which are to be tracked. Cameras, which are the sensors, capture the patient's movement, and the motion of those markers can be tracked and analyzed. Examples come from the assessment of the amount and the consistency of natural motion at the trunk anatomical complex during locomotion and elementary oscillatory exercises (Benedetti, Biagi et al., 2011), biomechanical analysis in posture & gait (D'Amico et al., 2011), head-tracker device based on a light source placed on the patient's head and a CCD camera which capture the movements of the head (Lin et al., 2006), and so on.

The *Inside-Out* Systems deal with sensors attached to the body while sources are located somewhere else in the world. Examples are the systems based on accelerometers (Fiorentino et al., 2011; Mostarac et al., 2011; Silva et al., 2011), MEMS (Bifulco et al., 2011), strain gauges (Ming et al., 2009), ensemble of inertial sensors such as accelerometers, gyroscopes and magnetometers

(Benedetti, Manca et al., 2011), or IMUs which we applied to successfully measure movements of the human trunk (see Figure 8, Saggio & Sbernini, 2011).

Within this frame, same research groups and commercial companies have developed sensorized garments for all the parts of the body, over the past 10-15 years, obtaining interesting results (Post et al., 2000; Lorussi, Tognetti et al., 2005; Giorgino et al., 2009).

The *Inside-In* Systems are particularly used to track body part movements and/or relative movements between specific parts of the body, having no knowledge of the 3D world the user is in. Such systems are for sensors and sources which are for the most part realized within the same device and are placed directly on the body segment to be measured or even sewed inside the user's garment. The design and implementation of sensors that are minimally obtrusive, have low-power consumption, and that can be attached to the body or can be part of clothes, with the employ of wireless technology, allows to obtain data over an extended period of time and without significant discomfort. As an example, in the latest years innovative sensors have been the so called "bend sensors" which are mostly piezoelectric based devices, and are adopted placed directly on the human joint or trunk part under measure. Adopting them, our research group developed a version of a "data glove" (in Figure 9 three different versions), named *Hiteg glove* (*Health Involved Technical Engineering Group*, see paragraph 4.1.1, Saggio et al., 2009a), which is a glove provided with sensors, capable to measure all the degree of freedom of the human hand.

Figure 8. Measured trunk movements are replicated on a PC screen

The *Outside-Out* Systems refer both sensors and sources not directly placed on the user's body but in the surrounding world. Let's consider, for instance, the radiology apparatus. Nowadays it is practically used for trunk movement and posture analysis. It presents the great advantage of a very high measurement accuracy since it shows directly what happens to the joints. Obviously, on the other end, it can be hazardous, for repeated X-ray exposures and needs highly skilled operators and special dedicated environment. We cannot affirm that in the radiology, sensors and sources are placed on the user's body as, in the same way,

Figure 9. (a) First, (b) second, and (c) latest version of the Hiteg glove

(a) (b) (c)

appens for non-contact sensors as microphones can be, with audio processing (for instance to measure the hearth beat), or the new Wireless Embedded Sensor Networks which consist of sensors embedded in object such as an armchair. The sensors detect the human postures and, on the basis of the recorded measures, furnish information to modify the shape of the armchair to best fit the user body, even taking into account the environment changes. A derivation of this concept was applied for adjusting cushion pressure of a wheelchair to the sitting position of the patient (Tanimoto et al., 1998), or realizing sensing devices embedded within a manually powered wheelchair to measure biomedical signals (Pinheiro at al., 2011). Other systems of the same kind were based on wireless modules integrated on forearm crutches which measure the weight applied, the tilt and the hand position of the user (Merret et al., 2010), or the measure of the respiratory effort signals using pressure sensors placed below a mattress (Holtzman et al., 2011), till the adoption of an array of embedded fiber optic pressure sensors placed under a hospital bed mattress for the detection of bouncing during sit-to-stand transfers (Arcelus et al., 2011). Clearly, this systems, as well as the others, can find applications not strictly related to measure patient's motion or postures. In fact, as a particular and curios applications, Outside-Out System was adopted to utilize the motion tracking of the hand of a surgeon as a pointing device in a surgery room (Colombo et al., 2003).

3.1. Methods

After the proposed classification, we tried to understand which is/are the system/systems among the four, that can be more interesting in order to measures of motor capability of the patients. To this aim, we conducted a survey to understand which are the most important and/or appealing requirements a measuring system must satisfy, to discover which possible new scenarios will be opened in the next future (Saggio and Sbernini, 2011). A detailed form was submitted to 24 participants actually or potentially involved with the utilization of human measurement for motor analysis systems. In particular we interviewed 4 groups of people divided into 6 clinicians (3 spine surgeons and 3 orthopaedics), 8 bioengineers, 4 orthopaedic technicians, 6 patients with light/heavy trunk's injuries. The form is divided into four sections: the first "overall" concerns general considerations (12 questions), the second "data" (5 questions) and the third "measure" (11 questions) are devoted to acquisition and analysis of data, the last "patients" (8 questions) mostly concerns the user's point of view. Each row of the form reports a question beginning with the sentence "the importance to have …?" to which each of the 16 people are asked to reply with a weight from zero (no importance at all) to 5 (extreme importance). Table 3 reports the results, where the last four columns before the total summarize the average values obtained from each of the 4 groups of people.

To give a meaning to the form, we added each row values obtaining (12+5+11+8 questions =) 36 numeric results, and empirically (only based on our experience) we assigned a positive result only to the row sum greater than 16 (being 20 the maximum rate).

Summarizing, the most relevant parameters for the electronic measurement systems resulted to be: high portability, lightness, robustness, short calibration time, accuracy, no influence and independence from environment, no mechanical constrains, non-intrusiveness, for normal day activities, unhazardous/non-invasive and subject's acceptance.

Crossing all the results, as a conclusion we can say that the type "A" *Outside-In* Systems have a low consideration, the type "B" *Inside-Out* Systems have been positively considered with except the magnetic based solution, the type "C"

Table 3. Form submitted to 24 people involved in trunk posture measurements

	OVERALL	Clinic.	Bioeng.	Orthop.	Patients	TOT
O1	Low cost	4	3.5	3.25	2.33	13.08
O2	High portability	4.5	4.25	4.5	4.67	**17.92**
O3	Lightness	3.83	3.88	4.75	4.33	**16.79**
O4	Short time to assess the measurement	3.67	4.13	4	3.83	15.63
O5	Easy to use	3.5	4	4.25	3.83	15.58
O6	Skilled operators, dedicated environ.	4.33	3.13	4	3.5	14.96
O7	Systems robustness	4.33	4.63	4.75	4	**17.71**
O8	Short calibration time	3.5	4	4.5	4	**16.00**
O9	Low power consumption	3.83	2.88	2.75	2.33	11.79
O10	Consolidated technology	3.83	3.25	3.25	2.5	12.83
O11	Self consistency	2.67	2.25	2	1	7.92
O12	Indoor/outdoor usage	3.83	4.63	3.5	3.5	15.46
	DATA	**Clinic.**	**Bioeng.**	**Orthop.**	**Patients**	**TOT**
D1	Low data analysis complexity/ Processing time	2.67	1.88	2.5	1.33	8.38
D2	Low number of key measurement points	3.33	3.75	2.75	3.67	13.5
D3	Real time/ Negligible transient time	3.83	4.63	3.5	2.33	14.29
D4	High frequency sample	3.67	3.38	3	2.17	12.22
D5	No ambiguity	4	4.88	4.25	1.83	14.96

continued on following page

Table 3. Continued

	MEASURE	Clinic.	Bioeng.	Orthop.	Patients	TOT
M1	Repeatability/reversibility	4.83	4.13	3.75	3	15.71
M2	Accuracy	4.83	4.38	3.75	3.5	**16.46**
M3	Long term	4	4	3.75	3	14.75
M4	No sensitivity to shock	4	4	4	2.5	14.50
M5	No influence from environment	4.17	4.63	4.25	3.33	**16.38**
M6	Autonomy	3.33	3.25	4.5	3.83	14.91
M7	Immunity to noise/disturb/drift/shifts	4.67	4.25	2.75	2.5	14.17
M8	Indirect measure	3.17	2.5	2	1.5	9.17
M9	Independence from the environment	4.33	4.63	4.5	4.17	**17.63**
M10	No occlusion problems	3.67	3.75	3.5	2.17	13.09
M11	Limited to 2D or for 3D measures	4.5	4.25	3	1.33	13.08
	PATIENTS	**Clinic.**	**Bioeng.**	**Orthop.**	**Patients**	**TOT**
P1	No mechanical constrains	4.67	4.38	3.75	4.17	**16.96**
P2	Non intrusiveness	4.67	4	3.75	4.5	**16.92**
P3	For normal day activities	4.67	4.63	3.75	4.33	**17.38**
P4	Unhazardous/non-invasive	4.83	5	5	4.83	**19.66**
P5	Low weight/bulkiness	3.83	3.63	4	4.33	15.79
P6	Large space for movements	4.83	3.5	3.5	4	15.83
P7	Subject's acceptance	4.67	4.13	4.25	4.67	**17.72**
P8	Self-adoption	3.5	3.38	3.25	4.17	14.30

Inside-In Systems have a good consideration and finally the type “D” *Outside-Out* Systems have a great consideration if we leave out the radiology application.

So the results of our test indicates that the systems to which people look generally with more attention are hybrid, collecting the most interesting features mainly of the type “D”, followed by the types “C” and finally “B” Systems. The type “A” has its importance, but restricted for applications which needs robustness and without any kind of mechanical constrains.

3.2 Technological and Economic Feasibility

It is interesting to notice that, with respect to the submitted form, for all the questioned figures in rehabilitation (clinicians, bioengineers, orthopedic technicians, patients), the “low cost” is not one of the major issue. But, as we know pretty well, it can be the first consideration, also according to our purposes here, for the realization of any kind of electronic measures. So, here we propose and discuss systems which take into account the results already discussed, but technological aspects and economic feasibility. These electronic systems must be capable to measure the human static postures, kinematics, alignments, symmetry, but we will focus especially on Range of Motions (ROMs), since these can be the most meaningful measures for the *functional assessment* step in the rehabilitation course.

Generally speaking the ROM should be checked in flexion, extension, rotation, and lateral or side bending. Going into details of the human parts, the normal ROM for shoulder are approximately 180° flexion, 45° extension, 180° abduction, 45° adduction, 55° internal rotation, 45° external rotation; ROM of the knee should be approximately 135° of flexion and 0° degrees of extension, while both internal and external rotation should be approximately 10°; when testing ROM for the ankle, there should be at least 10° of dorsiflexion with 45° of plantar flexion; the subtalar joint (also known as the talocalcaneal joint which is a joint of the foot) should measure around 20° of inversion and 10° of eversion ROM. Regard the upper limb, the most interesting measures can be the forearm pronation and supination, the wrist flexion and extension, the wrist radial/ulnar deviation, the first, second, third, and fourth metacarpophalangeal flexion, the first, second, third, and fourth interphalangeal flexion. All the body ROM’s averages are reported in an American Academy of Orthopaedic Surgeons (AAOS, 1988).

3.2.1. Hiteg Glove

Among all, initially we focused on an automatic system capable to measure movements of the hands. This is because the hands are our primary tools for interacting with the environment. Even the most significant function of the shoulder, elbow, and wrist is somewhat to position the hand in space to allow it to proceed with its functional task.

The measuring system is required to acquire data related to the ROMs of a patient’s hands in a fraction of the time required by a skilled therapist, and with more repeatable results. As a comparison a skilled therapist with a mechanical goniometer can take up to two hours to perform a complete measure of the two hand’s ROMs and, if the same expert with the same mechanical goniometer later re-performs the same measurements, the results are only repeatable to within five degrees in angle. The automatic system is also required to be easily usable by less skilled expert or, even, by the patient alone, without a supervision.

We satisfied the requests with the already mentioned *Hiteg glove* (www.hiteg.uniroma2.it), which summarizes the interesting properties of type “B” (*Outside-In*) and type “C” (*Inside-In*) Systems.

It is essentially a lightweight, tight-fitting, stretchable, unobtrusively, no loose-fitting glove, containing sensors capable to measure all the hand's degree of freedom. Particularly the finger joints measured are the metacarpophalangeal (MP or inner) joints, the proximal interphalangeal (PIP or middle) joints, the distal interphalangeal (DIP or outer) joints, their relative abdu-adduction movements (see Figure 10), while the other measures regard the palm, the wrist and the forearm movements and positions in space. Positioning, orientation, movements (roll, jaw, jitter) data, comes from of an ensemble of sensors, i.e. accelerometers, gyroscopes and magnetoresistances, since data recorded from one of them are correlated to the others so to compensate and reduce the measurement errors.

The analog recorded signals from the sensors are electronically conditioned, digitally converted and multiplexed to data-acquisition hardware which interfaces to a personal computer. Sensitivity of the *hiteg glove* was demonstrated to allow errors less than four degrees in angles (Saggio at al., 2009b), so a bit better than the ones produced by skilled expert of measure.

In addition to the anatomical measures obtained by the ROMs data, the *hiteg glove* can be capable to functional test measurements, i.e. to establish the times the patient needs to perform common unilateral tasks like stacking checkers, turning over cards, putting objects in a can, etc., but this aspect was not considered at this time since the rehabilitation common protocols are usually limited to ROM and motion profiles and do not address the precision of motion (Becker and Thakor, 1988; Chao et al., 1989). In any case, in a next future, this other aspect will be covered too. In fact, the data glove was also demonstrated to be effective for functional hand assessment (Williams et al., 2000; Simone et al., 2007).

3.2.2. Trunk Measures

Another step we performed was the development of a non-invasive, light and wearable system capable to measure the human trunk movements. It is based on three-axial accelerometers and Inertial Measurement Units (IMUs), which integrate a combination of accelerometers, gyroscopes and magnetoresistances. We used a combination of sensors, because they, even if fairly diffused, suffer from drift and off-set problems. So, we implemented home-made correction algorithms capable to overcome the problems, taking into account cross-measures among the sensors.

To be confident with the realized system, we built a dummy which replicates the real human trunk movements (see Figure 11a), and a set-up to realize automatic measurements and to verify the performances of the sensors in terms of accuracy and sensitivity (see Figure 11b).

In addition we designed and realized the electronic conditioning circuitry and implemented a virtual representation of the measured movements too (see Figure 12).

Figure 10. (a) Evidence of the finger's joints, (b) flex-extension, and (c) abdu-adduction movements

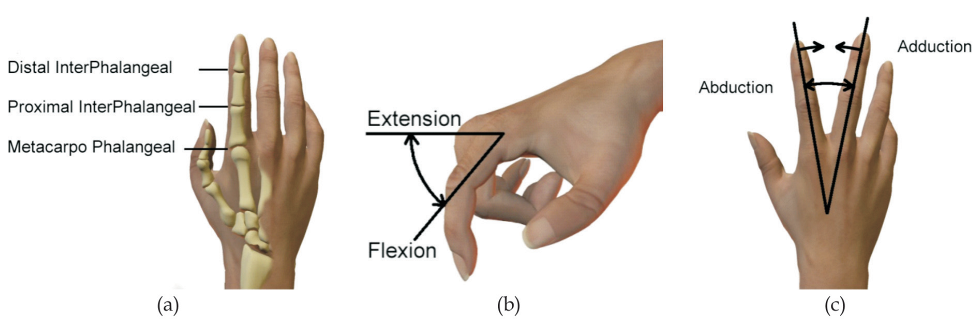
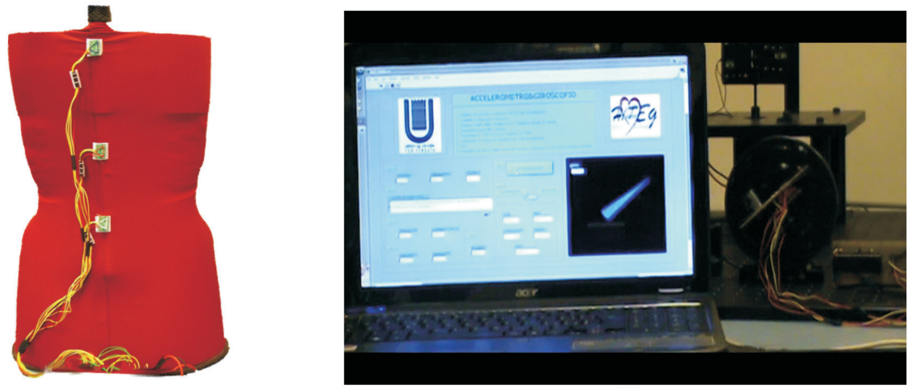


Figure 11. (a) The dummy and (b) the set-up for the automatic measurements



(a) (b)

Figure 12. (a) Lateral and (b) front measured trunk movements are replicated on a pc screen

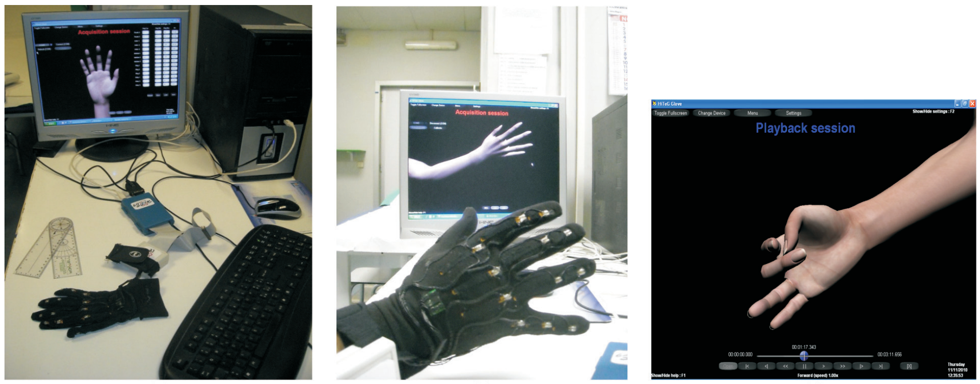
(a) (b)

4. APPLICATIONS AT HOME

Applications at home of the previously described measurement systems can be fundamental from an economic point of view, for less time-consuming procedures, for the effectiveness of the treatment. In fact, in this manner, the number of persons and locations involved can be meaningfully reduced, there is no necessity of prepare a measurement set-up in advance, and the patient performs measurements during his/her daily common activities without bearing stressful medical sessions at the hospital. The implementation of sensors that are minimally obtrusive, have low-power consumption, and that can be attached to the body or can be part of clothes, with the employ of wireless technology, allows to obtain data over an extended period of time and without significant discomfort. Furthermore, this advantages permit to redirect clinical assessment from the dedicated laboratory to a more real-life setting such as the home.

Again, as an example of application we will refer to the hand, since it is our first shield as a protection to fall and other kinds of mishaps, and it is one of the main part of the body to be potentially damaged by accidents. Then the motor rehabilitation highly involves the human hand, and for this aspect among the sensorized garments a fundamental rule is played by the “data glove”, which is easy to don, quite comfortable since it can be made of light tissue, and does not obstruct common movements. In Figure 13 is represented the overall data acquisition system for measurements recorded by our *hiteg glove*. The glove communicates the patient’s hand movements to a personal computer and an avatar replays the same recorded static and dynamic postures, so to give a visual feedback to the user.

Figure 13. (a) Set-up for data acquisition of hand movements, (b) movements are replicated in real-time on a PC screen, (c) movements can be off-line replayed



(a) (b) (c)

4.1. Virtual and Augmented Reality

The motivation of the patient can be significantly improved thanks to systems which integrates a Virtual (Holden, 2005; Saggio, Latessa et al., 2009; Saggio & Pinto, 2010) or Augmented Reality (Luo et al., 2005) scenario. The patient can visualize the movements he/she does observing a specimen avatar on a computer screen replaying his/her movements, so having non-intimidating and unambiguous suggestions. The patient can replay those movements as in a play rule, so being more motivated (Maclean et al., 2000) according to the Kemp model (Kemp, 1998). He/she can be supported by a pc-based software which records all his/her movements and classifies them so allowing a self-evaluation of the rehabilitation progresses (Saggio, Ferrari, Mugavero, patent no. PCT/IB2011/000077).

In particular a pre-imposed routine visualize qualitatively and quantitatively static and/or dynamic postures, which the user is asked to perform (for instance according to a pre-defined workload). The visualization can be realized by an ad-hoc detailed avatar on a computer screen. The quantitative information can be furnished, for instance, by simple numerical values and/or by scale indicators. The user is asked to don a wearable sensorized system useful to quantify his/her movements, of a reduced part of the body (only one hand, the knees, the neck, …) or of the total body. Sensors and transducers, electronic circuitry, wired and/or wireless system, furnish measured data to a computer (laptop, desktop, netbook, palmtop, handheld device,..). Data values can be conditioned, stored, digitalized, etc. so algorithms or analysers or classifiers (Neural Network, Support Vector Machine, Fuzzy logic etc. based) recognize and classify the postures assumed by the user. The system can provide qualitative and quantitative (numerical) values to the user to evaluate his/her motor performances, and can be capable to furnish suggestions how to improve the user's performance.

From recorded data can be possible to:

- Reproduce the real time situation.
- Analyse user's postures (static and/or dynamic) in modality: play, pause, fast forward, rewind, frame-by-frame.
- Reproduce the real situation by an avatar which can be rotated and zoomed in every possible directions.

In addiction one (or more) avatar can visually reproduce/proposes the pre-imposed routine of the static/dynamic postures the user is asked to perform, and (even superimposed) a second (or more) avatar can reproduce the real postures of the user, so he/her can easily evaluate himself/herself if his/her movements correspond to the pre-imposed ones. The pre-recorded maneuvers the patient is asked to perform are given according to a protocol furnished by the case specialist or in according to known tests e.g., Larson test, Lachman test, pivot-shift test, etc. (D'Ambrosia, 1986).

An eventual supervision of qualified personnel can be remotely furnished since all recorded data can be sent via web.

Thanks to this system, we experimented an improvement of patient's participation to the treatment, by means of actions aimed at recovering his/her best physical, cognitive, psychological and functional levels.

The great importance that sensorized garments can have for remote postural and motor rehabilitation stands for the fact that the movements are suggested without ambiguity by a "guide"-avatar (no teaching motor therapists are necessary); the patient replays the movements in a domestic environment (no room in hospitals and clinics is necessary); the sensorized garments measure the movements and reproduce them with a "ghost"-avatar superimposed to the "guide"-avatar (no physiotherapists are necessary) (see Figure 14); a pc-running software, led by classification algorithms, eventually suggests to the patients which movements must be corrected (no medical staff in necessary and a synthesized voice can motivate the patient); all the recorded movements are remotely sent via tele-health services, as useful information to the qualified staff, who will evaluate the performances of the patient.

The example furnished by the data glove, relative to the hands, can be easily adopted for other parts of the body, or even for a full body treatment with a complete sensorized suite (see Figure 15).

The system is completed by a virtual representation of an already mentioned avatar, by a GUI (Graphic User Interface) to deal with the software, and by a database to store all the recorded data (Figure 16).

5. IMPACT FOR HOSPITAL USE

The recorded measures obtained by the previously described system can be easily provided from the house of the patient to the doctors at the hospital, thanks to a tele-medicine support, which can transmit data via internet, or via a protected connections to avoid interception of patient's sensible data. The doctors can see all the movements performed by the patient via a representation software capable

Figure 14. Training session: the movements performed by the user are visualized as "ghost" and superimposed on the avatar-teacher

(a) (b)

Figure 15. A complete system for a full body measurements

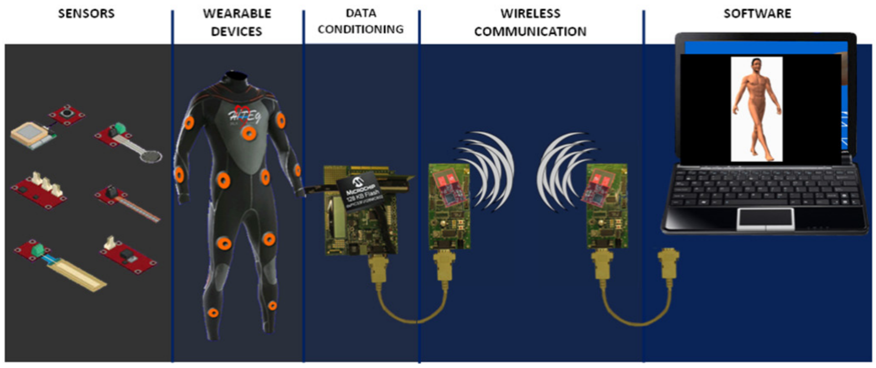
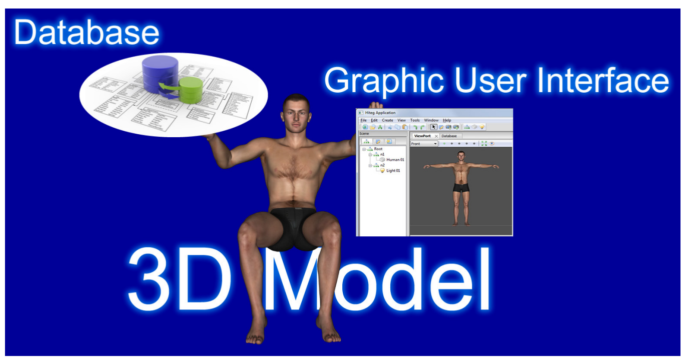


Figure 16. System completed by a 3D model, a GUI and a database



to show the avatar of the patient (see Figure 17 as an example).

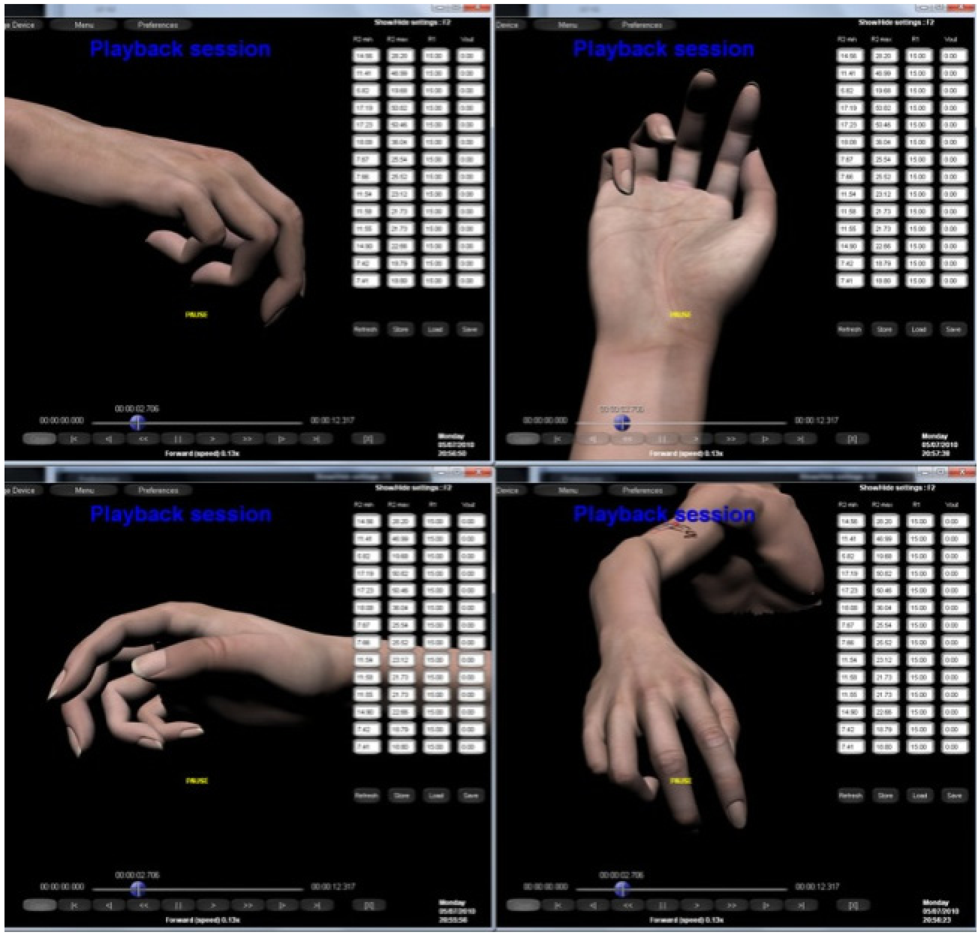
The avatar can be in/out zoomed, clock-anti-clockwise rotated, translated, and parts can be even deleted, so to focus the attention to only some aspects. As an example, if the doctor is interested only on the thumb's capabilities, he/she can remove all the other fingers from the view.

All of these have a great impact for the hospital use. In fact less personnel, from medical and paramedical staff, can be involved with respect to current procedures, less hospital structures can be necessary and less time can be devoted to a unique patient. But, at the same time, results of the rehabilitation treatment can be even improved in the sense of obtaining better results with the same devoted efforts.

A pair of our hiteg gloves were adopted both for the follow-up procedures after hand's surgery so to verify the progresses of the patient, and for the rehabilitation treatments of the same patients. The procedures were adopted at the "Bel Colle" hospital in Viterbo (Italy), under the expertise medical supervision of doctors Antonio Castagnaro and Anna De Leo. The validity of the overall system and the obtained results are reported elsewhere (Castagnaro et al., 2010).

Others researchers report analogous procedures too, utilizing data gloves with more or less similar performances, in terms of sensitivity and accuracy, but sometimes adopting sensors, embedded in the glove, differing from the functioning principle with respect from ours. Also these other researchers found interesting improvement in the rehabilitation course adopting a data glove

Figure 17. Avatar representation of the patient's hand movements



(Bonato, 2005; Lorussi, Scilingo et al., 2005; Pyk et al., 2008), and integrating it with ad-hoc created virtual reality environments (Szekely and Satava, 1999).

Of course, this is not intended to be the perfect solution to the problem of rehabilitation course and critical aspects still remain opened. In particular we refer the fact that even if the glove (or other sensorized clothes) is really comfortable to don and does not obstruct the main movements of the hand, in any case it remains an extraneous staff for the hand and it can become uncomfortable after some time. In addiction not all persons can be easily trained to this technology, as it can happen with elderly people, or not everyone can be in the condition to use a common glove, as it can happen for people with hand's malformations. Nevertheless we consider the proposed system to be valid for the really near future.

6. OPEN SCENARIOS

Relating to our experiences, it makes sense that the measuring system has not to limit its capabilities to furnish to the operator "only" reliable measurements. We suggest that it must be completed with "added values". As a starting point it would be important to define a standardization for the measurement protocols. Nowadays each system has got its own procedure for the measure of the human hand, trunk, leg and, generally, all the parts of the human body. All teams involved in body tracking adopt procedure strictly related to proprietary protocols for commercial systems or proceed on the basis of their particular experience for self-realized systems or modified ones. So it can be hard for different research groups to share their experiences and ideas. Even the obtained measure can be difficult to compare and, over all, to validate among research groups if the results are reported on the basis of different protocols. We encountered the same problem for the Brain Computer Interface Systems, which is another of our research fields and for which we suggested to adopt the UML (Unified Modelling Language) as universal language which allows to define a protocol for method and timetable (Quitadamo et al., 2008).

Another key element we want to underline is the data "usability". Once data have been acquired it becomes fundamental to count on both a correct analytical tool and a proper representation. For a surgeon, for instance, it can make the difference to literally "see" each movement of the patient in re-play mode from any possible point of view. So we are thinking to overcome the present possibilities as the Arena graphic tool by OptiTrack or the Vicon (www.vicon.com) or the IGS-190 Technology (www.metamotion.com) applications offer, but looking for a possible future scenario of a hologram or stereogram that can report patient's motion via avatar in a real 3D space. This is what already happen in other fields as, for instance, the edutainment one (see Figure 18), in which we were involved for a project with a specialized Company (PFM Multimedia).

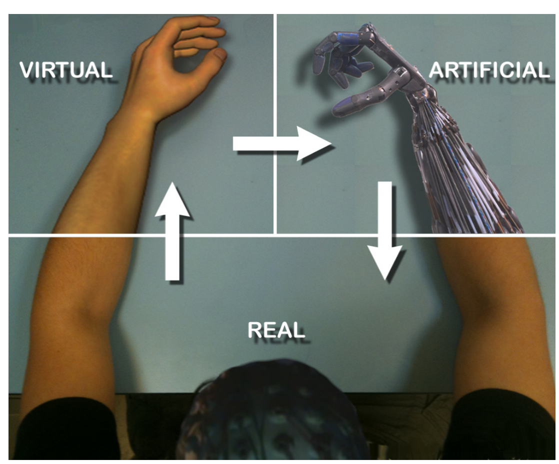
We suggest also that the measurement system can overcome the usual laboratory as the ones in a hospital (for rehabilitation purposes) can be. We believe that the treated systems can be usefully adopted, for instance, in psychology e psychiatry

Figure 18. Users donning special glasses see holograms of "floating planets" in the room (courtesy by PFM Multimedia Company)

ambulatories since the body kinematic can furnish an important evaluation key for the emotional reaction a patient can present to several events. But these novel systems can be used not only to re-habilitate an existing part of the body, but also for guidance to habilitate artificially replaced parts with mechanical artifacts (see Figure 19).

A further application based on body posture measure evaluations can furnish a body mapping giving to designers a tool for realizing more er-

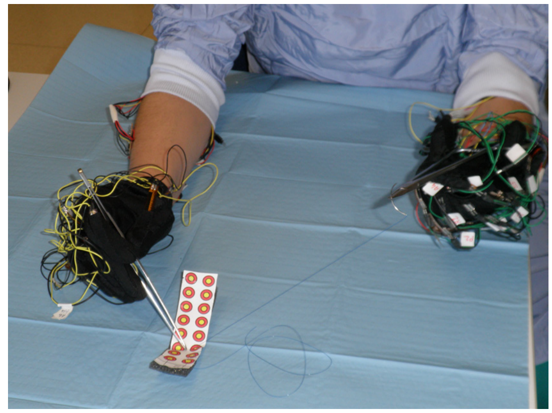
Figure 19. The patient can be leaned to move his/her mechanical upper limb with the aim of the proposed systems



gonomic rehabilitation stuff, but also for giving information to be conveniently adopted in fields like furnishings or automotives.

But, surprisingly, it can be important to measure the postures not only of patients, but of doctors as well! In fact, our *hiteg glove* has been adopted to verify the skill of the trainee in surgery, measuring their ability to manually perform some pre-imposed tasks (see Figure 20 - Saggio, Santuosuosso et al., 2011).

Figure 20. A typical surgical gesture measured by the system



Another circumstance for which the measure of the hand of surgeons can be mandatory, regards the realization of tele-surgery in a next future: the exact movements of a surgeon remotely located, can accurately drive the full potential of the hands of a robot to perform complex surgical tasks, as well as if the doctor was in the same location of the patient (see Figure 21).

CONCLUSION

Every day, all around the world, millions of people request postural and/or motor rehabilitation. This can be for really many reasons, i.e. for traumatic or connective or degenerative musculoskeletal disorders, after traumatic events such as strokes, severe cardiac disease, prolonged rest in bed, functional losses after treatment, etc. The rehabilitation process, also known as Tertiary Prevention, intends to be a sort of therapy to restore functionality and self-sufficiency of the patient. The postural and/or motor training can be necessary even to support cognitive and neurological rehabilitation request, for instance, after Traumatic Brain Injuries (TBI) due to car crashes, falls, gunshot wounds, sports. Only in the U.S., for instance, TBI affects from 500,000 to 1,900,000 persons (Rizzo et al., 1998).

The rehabilitation process regards not only millions of patients daily, but involves also a huge number of professionals in medical staffs, i.e.

Figure 21. The sensorized glove can be adopted to measure human gesture so to replicate them in a remote location to accurately drive a robot's arm

specialists, nurses, physiotherapists and therapists, social workers, psychologists, physiatrists, etc.

For the incredible number of patients, the medical staff and facilities necessary to support the appropriate postural and motor training, the monetary costs of rehabilitation is so huge to be even really difficult to estimate, but some data were given in the introduction paragraph.

Every effort towards a simplification of the rehabilitation route is really desirable and welcome. To this aim, our best efforts must have the purposes to reduce the cost, time, employees and facilities but, at the same time, increase the effectiveness of the rehabilitation. We can obtain these aims, *primum* motivating the patient (Maclean et al, 2000) according to the Kemp model (Kemp, 1988) taking into deep consideration the psychological aspects of rehabilitation (Rohe, 2005), *deinde* providing non-intimidating guides to the movements/actions suggested to perform in a domestic environment, post supplying a system which allows an self-evaluation of the rehabilitation progresses, and only as a final step remotely checking for feedback to the patient given by qualified personnel, all of these were detailed in this chapter.

Human movement analysis is not really a new science. Let's think that Giovanni Borelli is credited as being the first to make dynamic calculations of human movement even in the Renaissance period. But this science is necessarily based on systems capable to reveal human body kinematics. In this chapter a rapid overview of these systems was detailed. A classification scheme was proposed, the advantages/disadvantages of measuring systems were analysed. Finally we suggested the need of a standardization, of an universal language for protocols including time scheduling, furnished a look forward to future possibilities and novel applications of human body kinematic measure.

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