Movement recognition and preference in home-based robot-assisted stroke rehabilitation

Angelo Basteris
University of Hertfordshire
College Lane
AL10 9AB Hatfield - UK
+44 1707 284630
angelobasteris@gmail.com

Farshid Amirabdollahian
University of Hertfordshire
College Lane
AL10 9AB Hatfield - UK
f.amirabdollahian2@herts.ac.uk

ABSTRACT
Robots can be effective tools for rehabilitation of subjects with stroke. Furthermore, home-based robotic rehabilitation could reduce the costs and improve the therapy outcome. We worked on such a context within the SCRIPT (Supervised Care and Rehabilitation Involving Personal Telerobotics) project. We designed a system composed of a wearable passive orthosis which assists and measures hand and wrist movements, a personal computer and motivational and interactive games. In this paper, we focused on the definition of the movements which are used to play the interactive games. We considered the results of testing our methods on 20 subjects with chronic stroke who completed a six weeks clinical trial and investigated their preference of certain movements. Our results show a tendency to train hand movements among subjects with lower impairment and wrist movements for more impaired participants.

General Terms
Performance, Experimentation,

Keywords
Robot, stroke, home, rehabilitation, interactive games

1. INTRODUCTION

1.1 Background
Majority of literature show that, after the event of a stroke, patients have at least 12 months during which their brains are highly susceptible to the benefits of neuro-rehabilitation [11]. On the other hand, due to the high costs of clinical neuro-rehabilitation, post-stroke treatments are limited in most countries to only a few weeks after the stroke event. Hence, any system aimed at prolonging neuro-rehabilitation out of the clinics, i.e. at patients' homes, and with low costs treatments, provides a chance to exploit potential recovery towards better life quality and a more independent individual thus addressing one of the major challenges of in the current health systems.

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1.2 Robot-assisted rehabilitation
The earlier studies on robot-assisted rehabilitation targeted training for reaching to targets, due to the inherent complexity of designing grasping tools. However, hand and wrist function have a more pronounced impact on individual's independence and performance in activities of daily living. In line with this, a smaller and more recent subset has targeted training of the hand and wrist. In most cases, focus was specifically on training of either wrist [5, 6, 9] or hand [7, 12], inherently from the design of the device. A smaller number of systems integrate training of arm, wrist and hand functions [4, 10]. However, it is still unclear whether focusing the training on arm, wrist or hand functions leads to benefits in therapy outcome.

1.3 About SCRIPT
One of the main objectives of SCRIPT project is the user-driven technology development for stroke rehabilitation at home. This includes designing a passive-actuated hand and wrist therapy device and also designing a motivating and engaging front end – i.e. interactive games for the user, with a particular focus on usability. An underlying component which connects the orthosis and the front-end makes the human-robot interaction therapeutic

Our approach for developing such component was that of defining a gesture recognition system which enabled subjects to control the games by moving their arm, wrist and fingers. This modular approach makes such interaction potentially expandable to other games and allows a more comprehensive training. Design and development was evaluated using formative assessment of the work with a triad of patients, their family members and their health care professionals. The system had then undergone summative evaluation with 20 patients. In this paper, we investigate how subjects focused on arm, wrist or hand training, based on their level of impairment.

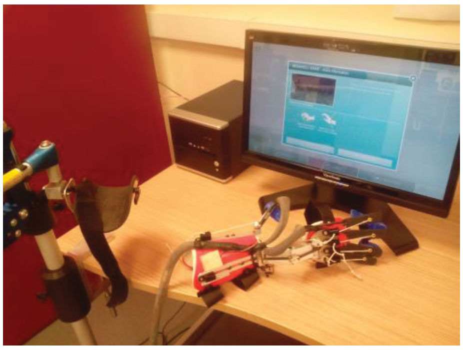

Figure 1 The SCRIPT system.Videos demonstrating the system can be found on the Youtube channel http://goo.gl/fpaZUD

2. METHODS

2.1 The SCRIPT passive orthosis

The SCRIPT passive orthosis [1] is an exoskeleton which assists subjects in finger and wrist extension by providing an offset torque by means of elastic elements. It also features several sensors. Each finger flexion is measured by a resistive sensor, a potentiometer measures the wrist angle and an inertial measurement unit which provides information about velocity and orientation of the hand.

2.2 Arm model

The data from the device are sampled at 30 Hz and used as input to a Python 21 DOF (four for each finger – three for the thumb, flexion/extension and lateral abduction/adduction of the wrist). We start with the hand in neutral position (flat, with no wrist flexion/extension). The first step consists of modifying the three values of flexion per finger, based on the flexion sensors readings, which results as the sum of metacarpal, proximal and distal inter-phalangeal joints flexion angles. We partition such value over the joints by multiplying it by a constant vector. Lateral abduction/adduction of fingers is not measured by the device, thus held constant in the model.

The model also includes a single parameter to measure the opening of the hand, *handOpening*. We considered the fingertips to be closer to each other with a closed hand than with an open hand. Let *Fn* be the three dimensional array representing the fingertips positions for the n-th finger. Then if F_X, F_Y and Fz are the arrays containing the x,y and z coordinates of all the five fingers, then $D=\|std(F_X)\ std(F_Z)\ std(F_Z)\|$, is proportional to the distance among the fingers and thus to hand opening. We normalized such value in a range obtained [0,1] with respect to the values measured when all fingers were flexed and extended, respectively.

Moreover, measured rotation from the IMU *handRoll* is applied to the hand. Finally, the wrist flexion angle *wristQ* is set in the model. The hand position is held constant, as the IMU measured its velocity, of which we considered components on the IMU plane *wristX'* and *wristY'* only . Such information is held out of the model, but is used for some gestures within the games.

2.3 Gestures definitions

Activities of daily living include eating with a knife and fork, drinking, holding objects, keyboard work, taking money from purse, buttoning a shirt, combing hair and door handle manipulation.

. All of these require several movements of hand and wrist. It is elemental that retraining of hand and wrist movements should include some of the basic components of these gestures. Thus, the device intervenes on flexion/extension movement of both wrist and fingers.

Table 1 Specifications of the gestures recognized. Different color shadings highlight movements of hand, wrist and arm.

Gesture related quantity	**Specification**
Hand open handOpening	Combined information from finger sensors is in a range (90-100%)
Hand close handOpening	Combined information from finger sensors is in a range(0-10%)
Grasping handOpening	Combined information from finger sensors is in a range (40-70% of maximum value)
Wrist flexed wristQ	Angle from wrist sensor is in a range around t its upper boundary (90-100%)
Wrist extended wristQ	Angle from wrist sensor is in a range around t its lower boundary (0-10%)
Hand prone handRoll	Hand roll angle is in a range (90-100%)
Hand supine handRoll	Hand roll angle is in a range (0-10%)
Hand Forward wristY'	Hand anteroposterior velocity is around its upper boundary (80-100%)
Hand Backward wristY'	Hand anteroposterior velocity is around t its lower boundary (0-20%)
Hand right wristX'	Hand horizontal velocity is in a range (80-100%)
Hand left wristX'	Hand lateral velocity has gone in a range (80-100%)

Thus, we first focused on identifying whether the subject had reached a full flexed or extended wrist position or his/her hand is being fully opened or fully closed, respectively. However, training should include movements similar to those performed during ADL. We hence identified a list of gestures, of which a subset is used in a specific game/category. Table 1 lists the gestures recognized by the training system and their specifications. If a gestures was performed, it was required that the condition which determined its recognition became false before this gesture could be recognized again. As a consequence of this, if for example one opened the hand and held it open only one "Hand Open"gesture would have been recognized no matter how long the hand was held open.

For each session, the reference values were measured for each of the required gestures by a calibration algorithm which we described in previous work [2, 3].

2.4 Games

These gestures are matched with actions within the games that are intended for providing motivating exercise. Three games were available: "Sea Shell", "Super Crocco" and "Labyrinth". In the Sea Shell game, the patient operates a shell using his/her hand in order to catch fishes. In the Super Crocco game, in addition to grasping, wrist flexion and extension are performed to avoid obstacles, and lateral movements of the hand to move the character on the screen. The Labyrinth game offers, in addition to this, training of forearm prone/supination and antero-posterior movements of the hand.

2.5 Experimental protocol

Twenty chronic stroke subjects from three countries (Netherlands, Italy and United Kingdom) completed six weeks of training as part of an ongoing clinical trial [8]. Subjects received arm and hand training at home using the SCRIPT system. All subjects trained independently, and were remotely supervised, off-line, by a healthcare professional (HCP). Subjects were recommended to train 180 minutes per week but they were free to choose their own preferred training time and exercise. During the first training week, the HCP visited each subject three times, in order to ensure competence with the SCRIPT system. During the other training weeks, the HCP visited each subject once per week to check on the subject's performance. Subjects were assessed by Fugl-Meyer (FM) in the week before the intervention.

2.6 Data analysis

We considered as indicator of the efficacy of gesture recognition the total number of movements recognized and its distribution among different gestures, for each subject. We investigated whether difference in gestures frequencies exist between subjects with different level of impairment by correlating the frequency of hand (sum of the frequency of Hand Open, Grasping and Hand Close), wrist (sum of Wrist Flexed and Extended movements) and arm(Hand Left, Right, Forward or Backward) with FM at inclusion.

3. RESULTS

3.1 Overall number of gestures

Overall, subjects performed 587 sessions, for a total of 542373 gestures recognized.

Figure 1 shows the frequency of each gesture, by showing the mean value among all subjects. Generally, participants showed the tendency to train hand movements (in green), rather than wrist ones (in blue). The lower recurrence of gross arm movements is reflective of the requirements of the games, which focused mainly on either wrist or hand movements and eventually included also arm movements.

3.2 Differences among subjects in number of gestures

Despite this overall tendency, we observed remarkable differences among subjects in the distribution of hand, wrist and arm movements.

Table 2 shows characteristics and results (frequency of different gestures and therapeutic outcome) for each subject.

It is noteworthy that, given the opportunity to choose training times and intensity and duration on their own, subjects exhibit a very high variability in amount of training, with number of gestures detected by the system ranging from 4173 to 91493 between subjects.

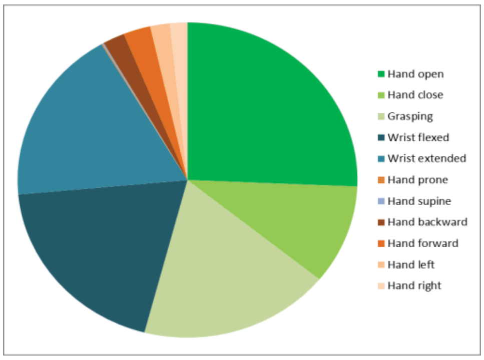

Figure 1 Mean frequency of each of the 11 gestures, all subjects. Movements of the hand were preferred over wrist and arm movements. Green shades represent hand movements, blue shades represent wrist movements and orange shades represent arm movements.

Table 2 Subjects characteristics and baseline scores, number of movements performed and gains in clinical scores. Subjects are presented in order of increasing FM score before therapy.

Id	Gender	Age	FM at inclusion	Number of gestures	Hand %	Wrist %	Arm %
nl0	F	61	9	36320	1	98	1
nl0	M	43	11	70925	12	87	0
nl0	M	62	12	7324	34	61	5
en1	F	79	16	9687	9	75	16
it02	M	62	16	25052	89	10	1
nl0	M	52	17	6320	60	38	1
it08	F	56	31	16255	73	18	9
it12	M	80	31	46580	61	31	8
it04	F	73	34	27231	58	35	7
it05	F	65	37	5744	86	14	0
it11	F	62	38	5846	66	21	13
en0	F	43	42	38334	80	13	7
nl0	M	58	44	4173	53	41	6
en1	F	63	45	83170	46	49	5
it06	F	66	46	12151	21	32	46
nl0	F	68	46	2377	59	38	3
nl0	M	69	49	19061	54	41	5
it10	M	35	50	23187	65	21	14
nl1	M	58	53	91493	94	5	1
nl0	M	34	56	11143	61	24	15

Table 3 shows the correlation between frequencies of hand and wrist movements with FM scores at inclusion. The positive correlation coefficients of frequency of the movement of the hand - and negative for movements of the wrist – indicates that more impaired subjects tended to focus on wrist movements, while subjects with milder impairment trained on hand movement.

Table 3 Correlation between frequency of hand and wrist movements with Fugl-Meyer at inclusion

		FM at inclusion
HAND	Pearson Correlation	.481*
	Sig. (2-tailed)	.032
WRIST	Pearson Correlation	-.629**
	Sig. (2-tailed)	.003
ARM	Pearson Correlation	.339
	Sig. (2-tailed)	.144

4. CONCLUSIONS AND FUTURE WORK

We designed a system able to detect movements of arm, wrist and hand, and allow subjects with stroke to control interactive games. The system was evaluated for feasibility for home-use by stroke patients, over a period of 6 weeks. Our results indicate that subjects differed in training, with subjects with higher level of impairment focusing on wrist movements while subjects with milder impairment were more keen on training hand functions.

A natural follow-up question is whether these repetitive trainings resulted in any significant clinical changes as reflected by the FM test. This is the subject of our ongoing investigation in the project.

Future work comprehends the enhancement of gross arm movements detection by means of optical tracking and the recognition of new, more functional types of hand postures incorporated into 6 new games. This will allow identifying whether the clustering effect observed here was due to the small number of games available or whether this is indeed a preference effect resulting from patient's level of impairment. Furthermore, we will consider cases where significant clinical changes were identified and observe whether these comply with the preference, or whether when patients try games that are not preferred, a more significant clinical change can be achieved.

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