Smart objects in rehabilitation

Walter Baccinelli, Franco Molteni, and Maria Bulgheroni

***Abstract*—Stroke is a leading cause of disability worldwide, and home-based solutions at low costs are required to provide effective rehabilitation to patients and decrease the economic burden. The interactive objects are one of the components of the RETRAINER system, and we exploited them to produce a stand-alone home rehabilitation tool. Patients own objects are equipped with RF sensitive tags and an antenna connected to a RF reader is placed on patient's hand. Using the relation between the distance of RF sources and the RSSI the contact with the object is detected and the task completion is identified. A backend system autonomously guides the execution of the exercises designed by therapists and record the data about the performance of the execution. Preliminary results demonstrate the feasibility of the approach and show a good degree of acceptability by patients and clinicians.**

I. Introduction

STROKE represents the major cause of disability worldwide [1], and motor impairment of the contralateral arm affects 80% of the stroke survivors [2]. This leads to a high burden for providing rehabilitation therapies.

To cope with these needs, research is highly investing in ICT supported aids for rehabilitation aimed at increasing the effectiveness of the therapy as well as to reduce the personnel costs. However, between the patients' needs and the current technological offer there is still a huge gap in devices' costs, ready availability and easiness of use. Rehabilitation needs extensiveness to reach patients at local premises or directly at home. This asks for low cost devices, high ease of use, proved reliability and efficacy, with the potential to move the rehabilitation provision from hospitals to homes.

One of the components developed for the RETRAINER systems consist of the interactive objects, that are used, in the context of RETRAINER, to automatically recognize the completion of a task and guide the execution of the exercise. In this paper it will be shown how this concept has been translated to produce an effective and low-cost stand-alone tool for home rehabilitation of the upper limb.

II. Working Principle

A. Overview

High-intensity, repetitive and task-oriented practice is a key element for an effective rehabilitation programme. Upper extremity impairments are a significant cause of disability in terms of both incidence and impact on the performance of Activities of Daily Living (ADLs) and working engagement. Physical and occupational therapy plays a specific role in reducing such an impact and facilitating return to ADLs and job-related tasks performing [3]. Home-based rehabilitation may gain advance by the repetition of occupational tasks in the user's own environment thanks to the "specificity of learning" concept stating that the learning or relearning of a skill is empowered by practice conditions matching real life tasks. Task-specific training, i.e. practicing movement within a complete action, is gaining evidence as an effective tool in neurological rehabilitation of the upper limb [4].

The system described in this paper implements a home-based physical therapy aimed at motor recovery, by providing a rehabilitation program based on user's habits and ADLs. The exercises composing the rehabilitation session are designed by the therapist, who set a sequence of reaching and grasping tasks involving patient's own objects, and a number of repetitions to be completed during the session. To perform the rehabilitation session, the patient wears an RF reader, placing its antenna in correspondence of the his/her hand, and sits in front of the objects selected for the session. By starting the session, the system, running on a PC, suggests the first action to be completed (i.e. reach an object or a position in space); the task completion is automatically detected, the user is acknowledged of the correct execution and the next task to be performed is prompted. The iterations go on until the completion of all the tasks in the exercise, and the exercise is repeated a number of times decided by the therapist.

B. System components

The proposed system is built around three main components: smart objects, UHF RF reader and backend system, as shown in Fig. 1.

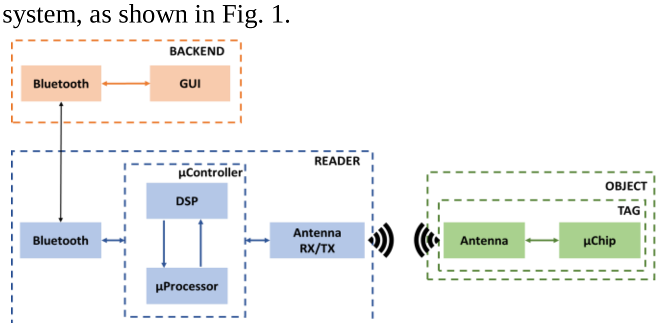

Fig. 1. System components. In green the objects and the tag mounted on it. In blue the RF reader with the Bluetooth module. In orange the backend system.

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The smart objects are everyday objects equipped with RFID UHF passive tags, that are thus able to provide information about their characteristics and space location. When the RF reader scans the environment, all the tags and thus the objects, will respond providing their Unique Identifier (UID) and, for each identified tag, the Received Signal Strength Indicator (RSSI) is retrieved. The RSSI is defined as:

$$RSSI = \left(\frac{\lambda}{4\pi d}\right)^4 \chi G_r(\vartheta)^2 G_t(\vartheta)^2 |1 + \sum_i H_i|^4 \qquad (1)$$

Where d is the distance between tag and antenna, λ is the wavelength, χ is the reader-tag polarization mismatch, $G_r(\vartheta)$ is the reader's antenna gain, $G_t(\vartheta)$ is the tag's antenna gain ϑ is the main path incidence angle and H_i is the contribution of the *i*th multipath.

It is clear from equations (1) that the RSSI value is inversely proportional to the distance between the antenna and the tag. The lower the distance, the higher the RSSI.

By positioning the antenna on the patient's hand and exploiting the above concept, the contact between the hand and the object is detected, and the next task is triggered.

Because of non-idealities such as multipath effect and damping effect of the body, affecting the relations previously described, it is not possible to exploit a complete deterministic relation between distance and RSSI. To cope with these issues, an online pre-processing of the signal is performed. A first stage of the processing is performed to take into account the directionality of the movement. Indeed, the direction from which the object is reached by the patient's hand can vary from repetition to repetition and the radiation pattern of both the tags and the antenna is not omnidirectional. To overcome this limitation, multiple tags have been placed on the objects' surface, and a weighted mean of the RSSI values obtained from the object's tags is computed. The weights are computed as ratio of the RSSI of each detected tag to the sum of all the RSSI values. The weights are then inversely assigned to the RSSI values (the higher the RSSI, the lower the weight). The second processing stage is aimed at the stabilization of the signal over time. To remove the high frequency signal variations related to noise, a moving average is applied using a five samples window.

Non-idealities also imply the impossibility to compute *a priori* a value of the RSSI corresponding to the contact. A calibration phase is then required to estimate the threshold values before the execution of the exercise, during which the patient performs a walkthrough of the exercise and the RSSI value obtained in correspondence to the contact of the hand with the object is saved for each object involved. The walkthrough also acts as training of the patient.

The backend system consists of a PC or a tablet that communicates via Bluetooth with the reader, manages the processing and the storage of the signal, the sequence of the tasks in the exercise, the database to associate the UIDs and the objects, and the management of the users. During the execution, data describing the performance are stored (e.g. RSSI values, task completed, task skipped, etc.) and, at the end of the rehabilitation session, an overview of the execution performance is provided to the patient to increase his/her awareness.

III. RESULTS

From the technical point of view the system stability and reliability have been demonstrated. The application of the described configuration and processing algorithm resulted in a sensitivity of antenna-tag distance measurement of 5cm, while a sensitivity of 15cm has been obtained from raw RSSI consideration. The contact between hand and object, detected using the calibration and processing methodology previously described, is reported at a mean hand-object distance of 2.05±2.00 cm.

Interviews have been conducted with therapists after showing them the system and its application. The outcomes revealed that the system is perceived as useful and shown the interest of the clinicians in introducing the system in their daily practice.

5 hemiplegic patients have been asked to use the system and to score its usability through the System Usability Scale. A mean score of 95.5±4.8 % has been obtained, showing a very high usability of the proposed system in real clinical conditions.

IV. CONCLUSION

In this paper we have described how the smart objects concept implemented in the RETRAINER system are successfully deployed to implement a new stand-alone system for home rehabilitation.

The field tests and the interviews confirmed the expected interest in the adoption of the system, starting the path to the commercialization of the system.

Refinements are still needed to fully address the clinical requirements, as highlighted by the therapists, but it is evident that the proposed solution well fits with the current requests of the rehabilitation market and trends, providing a reliable, flexible and low-cost system for home-based therapy.

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