A BALANCE BOARD DEVICE FOR HOME CARE TELEREHABILITATION EXERGAMING

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Abstract: A prototype of a low-cost balance board for exergaming-based tele-rehabilitation systems is introduced. The objective is to extend at patient's home the interactive nature of the individualized rehabilitation therapies traditionally carried out at clinic. Preliminary results on posturographic tests showed encouraging performance.

Keywords: Tele-rehabilitation, Balance Board Device, Exergaming-based, Home Care;

1. INTRODUCTION

Tele-rehabilitation is an emerging research area with high integration between bioengineering, information technologies, and medical skills. Increasing elderly- and disable-oriented health services are determining a growing need for rehabilitative facilities. As an example, the need for appropriate and effective rehabilitative therapies has a rising importance in many neurological diseases. Each year, in Italy, approximately 196,000 cases of stroke occur, with about a 30 % of survived patients suffering of severe disabilities. The stroke is the third source of death in industrialized countries, after cardiovascular diseases and cancer, but the leading cause of disability with a significant impact on individual, family, and community health [1, 2].

Conventional physical therapy involves extensive one-on one interaction with a therapist in the clinic, often for hours at a time, several times a week. Numerous studies proved that duration, capacity, and intensity of exercise sessions are the most important factors for effective motor rehabilitation [3, 4].

From this situation, high costs related to hospital rehabilitation treatments arise for the Public Health Service. This and the advantages for the patients to stay at their home are progressively bringing to move medical protocols from the hospital to home care-based applications, retaining the effectiveness of cognitively challenging movement exercises.

In literature, recent research about tele-rehabilitation systems has led to interesting systems [5]. Moreover, these systems exploit major rehabilitation devices customized to individual practices, [6], showing low applicability to other rehabilitation practices. These twofold aspects make difficult their possible applicability and portability at home.

Other systems, inspired to game consoles on the market (Wii, Xbox [7]), have proposed a mixed rehabilitative and gaming use of these commercial devices, known as "Exergaming" [8]. Despite the undisputed advantage of these devices in term of low cost, usability, and attractive game environment, such attempts have presented limits in terms of both hardware and software flexibility, typical of closed property commercial systems.

Positive aspects of home automation devices, such as fitness devices and software for exergaming [9], and links between cognitive control, virtual reality, video games and physical activity [10] have led to the creation of neuromotor tele-rehabilitation.

In this paper, the project of a low-cost, wireless, and open architecture of a balance board for home care telerehabilitation exergaming applications is illustrated.

2. BALANCE BOARD FOR CARE AT HOME

In the following, (i) the basic ideas, (ii) the requirements, and (iii) the design of the Balance Board for Care at Home (BB for CrHome, BBC) are outlined.

A. Basic Ideas

BBC is inspired by the balance board game consoles introduced into the package for fitness Wii–Fit by Nintendo [11]. The design aim is to improve performance in order to have a device specific to tele-rehabilitation. Unlike this, BBC has some innovations substantial, especially from the point of view of flexibility and greater rehabilitative applicability, in addition to cheapness. The introduced flexibility is both at hardware and software levels. For the hardware, a wireless open communication system (ZigBee [12]) is used for connecting the BBC to a central hardware platform. The flexibility of software is a direct consequence: the BBC can be interfaced with whatever open-source software developed for Tele-rehabilitation. This rehabilitation software customization provides the BBC by a higher applicability to the Tele-rehabilitation, compared to the Wii Balance Board, using software primarily dedicated to fitness [9].

The inspiring philosophy is Exergaming, namely the approach of PC games introduced by the new generation of interactive consoles [8]. Specifically, the BBC project has the ambition to improve the post-stroke rehabilitation and to increase its effectiveness, especially in terms of motoric relearning.
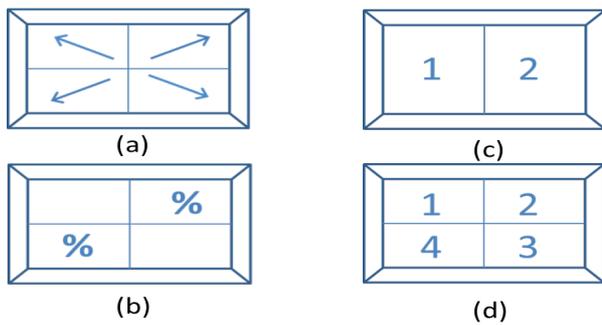
Figure 1. Functional features required to BBC: (a) Arrow and (b) Weight Mode; (c) Double and (d) Quadruple Definition.

The flexibility of the BBC allows the further possibility to customize the Exergames, allowing them to be developed according to the appropriate rehabilitation protocols.

B. Requirements

The Balance Board CrHome was conceived as a physical interface between the user (patient) and the specific application, or the Exergame. In particular, the associated Exergames has to provide two main topologies rehabilitation exercises of:

- recovery proprioceptive and manual dexterity, involving the use of the BBC with the hands,
- postural motor coordination and recovery of lower limb proprioception, involving the use with the trunk or feet, from sitting and in standing posture.

To achieve this, the BBC must have twofold features:

- directional such as in commercial joysticks and/or Game Pads,
- to provide information on the distribution of weight (or force);
- and other useful information represented by the occurrence and location of user actions on the platform.

For these reasons, two modes and two definitions of operation have been identified (Fig. 1):

- In Arrow Mode, the functionality of a Joypad dealing only with executive functions is emulated. This mode is a direct consequence of Exergaming philosophy, leading the project, lending itself particularly in the ways of the exercises on the hands and feet.
- In Weight Mode, information on the distribution of weights and measures on the interfacing board are given.

The BBC has to be also equipped with two modes of definition, Double and Quadruple Definitions, referring to the amount of quadrants divided the plane interface of the BBC (2 and 4, respectively, in Fig. 1).

C. Design

In this Section, the hardware design of the BBC is presented.

In particular, in Fig. 2, the architecture meeting the abovementioned general requirements and functional features, is shown.
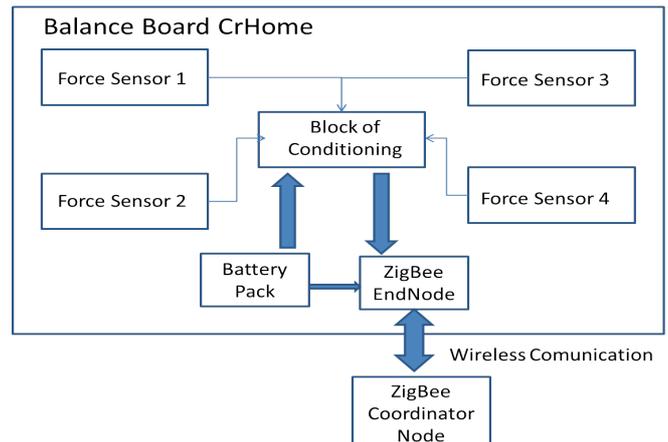
Figure 2. Architecture of the Balance Board CrHome.

Force sensors are placed in the zones where most of the human weight falls. In the case of posturographic test (standing), the higher weight points are under the heel and the metatarsal. For this reason, four force sensors [13] were necessary, followed by an appropriate conditioning circuit.

The conditioning circuit filters and linearizes the sensor's analog output signal. A module ZigBee (End Node ZigBee in Fig. 2), appropriately programmed, allows the conversion to digital data, and their wireless transmission to a second node, Router Node, acting as receiver inside the PC.

3. REALIZATION

In the following, the implementation of the BBC prototype (Fig.3) is described. In particular, (i) the *sensor's setup and conditioning*, and (ii) the *wireless communication* are detailed.

A. Sensor's Setup and Conditioning

A balance board prototype exploiting the characteristics of the force sensor FlexiForce [13] was developed (Fig.3). The sensing area of the force sensor is treated as a single point of contact.

Figure 3. Prototype of Balance Board for Care at Home.
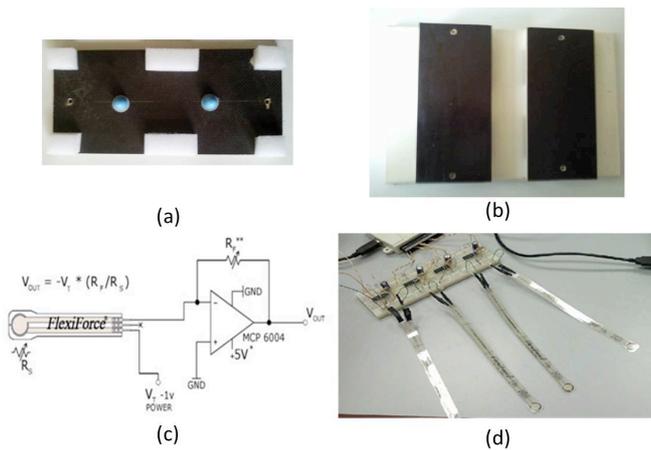
Figure 4. Force sensors and contact setup: (a) hot-spot pins, (b) rigid flats, (c) conditioning circuit, and (d) connection scheme.

A pin was used to make pressure on the force sensors exactly at the hot spot, hard but rounded to not damage the sensors (Fig. 4a). As points of contact, semi-ellipsoidal plastic, filled with silicone were used. The sensors work in pairs and are located in two flats, rigid and almost immobile (Fig. 4b).

The force sensor is connected to the conditioning circuit (Fig. 4c) consisting of the operational amplifier in inverting configuration MCP6004, connected as shown in Fig. 4d. The value of the reference resistance is 22 kΩ. Moreover, owing to the inverting amplifier, the output signal is always positive. The amplifier was fed to +5 V DC, and a 100 nF capacitor was finally inserted, in parallel with each reference resistance RF of 20 kΩ). The capacitor acts as low-pass filter in order to eliminate high-frequency components and avoid aliasing. The sensor driving voltage was chosen equal to -2.0 V to ensure a positive output and between zero and three volts. This is a design key feature because Zigbee transmitters accept analog inputs with a value between 0.0 and 3.0 V.

B. Wireless Communication

ZigBee was selected because is based on the IEEE 802.15.4 physical radio specification: a packet-based radio protocol intended for low-cost, battery-operated devices [14-15].

The modules Texas Instruments eZ430-RF240 were used for implementing the ZigBee network [16]. They consist of (i) a transceiver CC2480 with embedded ZigBee stack protocol [17], and (ii) a 16-bit MSP430F2274 microcontroller, provided by multi-channel ADC for sensor's acquiring.

The realized wireless network is composed by: (i) an End device/Router Node (Fig. 5a) for sensor's data acquisition, to transmit to coordinator; and (ii) a Coordinator Node (Fig. 5b), receiving the measures from the End Device nodes and passing them to the local unit through serial communication [18]. The acquired data are packed in BCD codes and sent to coordinator to be forwarded to the local PC for processing.

Figure 5. ZigBee Nodes: (a) End Node and (b) Coordinator Node.

The microcontroller Texas Instruments MSP430F2274 includes all the hardware and software capabilities required to (i) acquire the sensor's output by the 10-bit ADC with a selectable sampling frequency up to 20 S/s per channel; and (ii) develop an entire wireless communication protocol.

4. EXPERIMENTAL RESULTS

In the following, (i) the *functional tests* and (ii) the *cost analysis* of the BBC prototype are highlighted.

A. Functional Tests

The functional test have been carried out for basic and straightforward posturographic experiments. In extreme synthesis, the test protocol consists in computing the weighted average of the force components of the four sensors. This allows information about the posture of the person standing on the balance to be provided.

At this aim, a procedure was implemented in LabView for analysing and displaying the data (Fig. 6). In particular, the centre of the balance board prototype is assumed as the origin of a Cartesian coordinate system. The weight is computed as concentrated at the coordinates of the 4 sensors, placed at the points x and y equal to ± 12 and ± 6.5 cm, respectively.

In addition to the coordinates of the barycentre, the two left and right hemi centres are also calculated and plotted, in order to have a feedback, analogously as in commercial instrumentation used for clinical posturographic tests [19].

B. Cost Analysis

The focal idea underlying the BBC is to create low-cost tele-rehabilitation home device, easily applicable to different rehabilitation protocols, and flexible, both in terms of hardware and software.
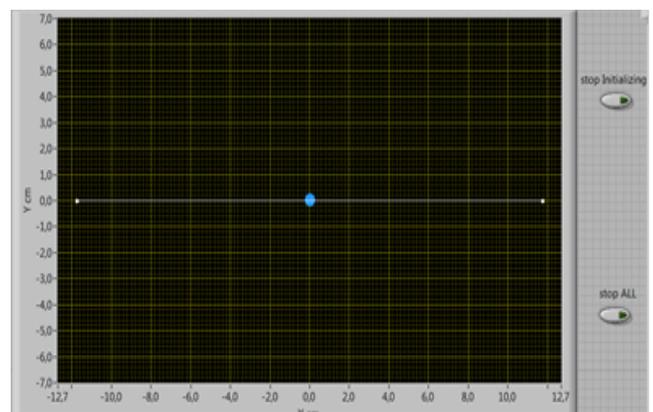
Figure 6. Labview interface for posturographic test.

TABLE I – EXISTING PLATFORMS / COSTS

Brand	Model	Price / Cost
	Proposed BBC	< 500€
VERTIGO	VSP400P	> 5000€
CHINESPORT	PODATA	> 7000€

The intrinsic low cost of proposed device has to make it accessible to medical centers and private patients.

In fact, the basic components of the proposed device have an estimated cost of about 500 €, much lower than the commercial posturographic platforms on the market (Tab. I).

5. CONCLUSIONS

In this paper, a low-cost Balance Board for Care at Home (BB CrHome, BBC) is proposed for exergaming-based tele-rehabilitation. The objective has been to develop architecture and algorithms for a low-cost tele-rehabilitation tool to extend the interactive nature of the traditional individualized rehabilitation therapies at home the patient. .

The BBC was experimentally validated on posturographic tests. Preliminary tests, reported here, show encouraging performance. The validation tests carried out in comparison with a high-cost clinical tele-rehabilitation system are currently on going.

The increased applicability allows the doctor to use the same device for different rehabilitation protocols. The hardware and software flexibility makes BBC open and easy to interface with the Internet, personal computers and software of any kind, for example Exer-games. Therefore, the proposed balance board will be easily interfaced with games for the PC, properly developed and customized to specific rehabilitation protocols.

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