



A low-cost force sensor-based posturographic plate for home care telerehabilitation exergaming



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ARTICLE INFO

Article history:

Available online 30 January 2014

Keywords:

Telemedicine
Patient rehabilitation
Force sensors

ABSTRACT

A wireless architecture of posturographic plate, conceived as a physical interface between the patient at home and a semi-immersive virtual environment of telerehabilitation exergaming, is proposed. The design is aimed at maximizing cost reduction as well as hardware and software flexibility, for integrating third-party rehabilitation applications with the exergaming-oriented approach in a telemedicine open development platform. Apart general-purpose bodyweight exercises, rehabilitation protocols based on twofold exergaming tasks for recovering (i) proprioceptive and manual dexterity, using the board by hands for postural motor coordination, and (ii) lower limb proprioception, using by trunk or feet (from sitting and standing posture) to control static and dynamic balance, are provided. The plate was validated experimentally at functional level by means of posturographic and exergame tests, emulating the shots on goal for soccer penalties. Moreover, results of clinical tests in comparison with a force measuring plate of a high-cost professional state-of-the-art system for posturographic analysis, both in normal and in pathological subjects, with open and closed eyes, highlighted encouraging performance and fostered industrial transfer.

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1. Introduction

Increasing elderly- and disable-oriented health services are determining a growing need for rehabilitative facilities. As an example of the European trend, in Italy, each year about 196,000 cases of stroke, with about a 30% of survived patients suffering severe disabilities, arise. The stroke is the third leading cause of death in industrialized countries, after cardiovascular diseases and cancer, and the first source of disability, with a significant impact on individual, family, and community health [1,2]. Numerous studies proved that duration, capacity, and intensity of exercise sessions are the most important factors for effective

rehabilitation [3–5]. Conventional therapy involves extensive one-to-one interaction with a therapist in the clinic, often for numerous sessions by week, by several hours at time. The resulting high cost for the Public Health Service, and on the other hand, the advantages for patients to stay at home, are progressively moving medical protocols from hospital- to home care-based applications. In [6,7], network-based tele-rehabilitation systems introduce the idea of mobility and continuity of rehabilitation at home. However, recent research about tele-rehabilitation systems has led to expensive [8] and invasive robotic systems [9], with demanding applicability and portability at home. Major rehabilitation devices are customized to individual practices [10], showing low applicability in other rehabilitation practices. Moreover, clinical studies indicate that only 31% of patients actually follow home exercise regimen, such as prescribed by therapists [11].

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For these reasons, recently home rehabilitative protocols are addressing a game context, by retaining simultaneously the effectiveness of cognitively challenging movement exercises. This approach allows the therapy effectiveness to be enhanced by a strong motivational playful component, avoiding the monotony of the simple movements' repetition. For these applications, video games providing a form of exercise, called "exergaming", based on body movement detection as a feedback for the game system, are a challenging new field. In particular, some research projects have directly explored the potential of existing commercial games for rehabilitation. Console games with motion-based input devices, such as Playstation [12,13], and Wii Sports [14], have been used in clinical studies, showing main drawbacks related to a design aimed at normal subjects use. Further systems [15,16], inspired by the game console on the market (Wii, Xbox), have proposed a mixed rehabilitative and gaming use of these commercial devices. Among these, very few studies are devoted to develop exergaming devices customized for rehabilitation [17–22], not all suitable for home care settings, and none of them can be integrated as telerehabilitation devices in telemedicine systems.

In this paper, a low-cost, wireless open architecture of balance board for home care telerehabilitation exergaming applications is presented: Posturographic Plate Care at Home, PoPCrHome. Beyond an open development platform as well as cost reduction, PoPCrHome flexibility allows different third-party tele-rehabilitation applications to be integrated with the exergaming approach in a telemedicine framework. In particular, after highlighting design details in Section 2, the main realization aspects of measurement and exergame are illustrated in Section 3. Then, in Section 4, functional tests at measurement, rehabilitative, and exergaming levels are reported. Finally, in Section 4, clinical tests in comparison with a professional force measuring plate carried out at the Bioengineering Department of the Rehabilitation Institute of S. Maugeri Foundation in Telese Terme (Italy), are described.

2. Design

In the following, (i) the *requirements*, (ii) the *concept design*, (iii) the *architecture*, (iv) the *balance algorithm*, and (v) the *telerehabilitation operations* of PoPCrHome are described.

2.1. Requirements

Main requirements of the project PoPCrHome are:

- (i) *Low cost*, by integrating off-the-shelf components, to allow PoPCrHome to be bought by the patient himself, if necessary, for a daily practice also beyond the official therapy prescription.
- (ii) *Home care use*, in order to limit the patient's stay in care centers, by decreasing his hospitalization stress, and to improve the continuity and the care efficiency of chronic diseases, without reducing the patient monitoring by physician or caregiver.

- (iii) *Exergaming-oriented rehabilitation*, inspired by the new-generation interactive consoles [23], for exploiting the attractive game environment and the usability of the game console for performing the standard motor functions of rehabilitative practices without boredom.
- (iv) *Flexibility*, at hardware level, by a wireless and open communication system (ZigBee) [24], allowing the plate to be interfaced easily to a PC-based exergame, as well as at software level, for hosting any specific rehabilitation application, with the further possibility to customize the exergames according to appropriate rehabilitation protocols.
- (v) *Rehabilitative flexibility*, for both postural and manual exercises, using the board by trunk or feet, for static and dynamic postural balance, or by hands, for motor coordination.
- (vi) *Tele-medicine integration* (Rehabilitation Software Customization), for allowing software of a remote Rehabilitation Center to be interfaced by Internet and/or mobile network.
- (vii) *Open architecture*, to improve the interoperability between medical centers, and the interconnection among physical therapist, caregivers and doctors, by allowing data exchange and shared access to the central database.

2.2. Concept design

According to the above requirements, PoPCrHome is conceived as a physical interface between the patient and a PC-based exergame. In particular, PoPCrHome is aimed at improving the post-stroke rehabilitation and, specifically, its effectiveness in terms of motoric relearning (Fig. 1).

Exergaming adds a greater emotional involvement of the patient (the game challenge) and completeness of the cognitive-motor exercises. For this semi-immersive virtual environment, three main classes of rehabilitation protocols are provided:

- (i) Exergaming tasks for recovering proprioceptive and manual dexterity using the board by hands.
- (ii) Exergaming tasks for postural motor coordination and recovering lower limb proprioception using board by trunk or feet (from sitting and standing posture) to control static and dynamic balance.
- (iii) General-purpose bodyweight exercises: diaphragmatic breathing movements, low muscular effort trainings for upper and lower limbs, and yoga-like practice.

At this aim, PoPCrHome provides four different modes of operation:

- *Arrow Mode* (Fig. 2a), emulating a joypad, i.e. directional functions suitable for exercises with the hands and feet according to exergaming concepts.
- *Weight Mode* (Fig. 2b), emulating a balance board, allowing weight distribution on the plate to be assessed for customized rehabilitative aspects of cognitive relearning.

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