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Interactive and Connected Rehabilitation Systems for E-Health

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Abstract

Functional rehabilitation aims at recovering the locomotion dysfunction of the human body by the physical therapy. The objective of this paper was to develop interactive and connected rehabilitation systems as a system of systems for monitoring the bio-feedbacks of the human musculoskeletal system during the rehabilitation exercises. Video-based non-contact system as Kinect sensor was used to get kinematics data of the human body. Generic and subject-specific avatar representations were integrated. Rehabilitation exercises will be designed as serious games to motivate the end users. Our first prototype was focused on the rehabilitation exercises of the lower limb. Software development and experimental aspects of our proposed solution were presented and discussed. Our system would be of great interest in the supervision of physical therapy exercises in clinical as well as in non-clinical environments (e.g. rehabilitation at home). As perspectives, multi-sensor fusion between Kinect sensor and other kinematics-based sensors like Shimmer ones will be investigated to get an accurate 3D joint motion. Electromyography (EMG) signals will be also used to monitor the muscle functions. Moreover, specific device will also be developed to facilitate the sensors set up and motion monitoring.

Keywords: Functional rehabilitation; Bio-feedback signals; System of systems; Multi-sensor fusion; Serious game; Musculoskeletal system; Real-time monitoring; Rehabilitation at home

1. Introduction

Functional rehabilitation aims at recovering the locomotion dysfunction of the human body by physical therapy exercises [1,2]. This involves performing controlled physical and occupational therapy interventions with or without assistance of physiotherapist to improve musculoskeletal strength and flexibility as well as range of motion. Functional rehabilitation is commonly realized in clinical environment under the supervision of physiotherapists [3]. However, the supervision and the evaluation of a rehabilitation motion pattern remain a medical and engineering challenge due to the lack of feedback information about the effect of the rehabilitation motion on the human biological tissues and structures. Recently, rehabilitation systems using immersive virtual reality technologies have been developed to provide useful reinforced feedbacks (e.g. functional measurements) during rehabilitation exercises such as motion velocity (speed), duration of motion pattern (time), ergonometric measurement, video data or joint patterns [4,5]. These quantitative feedbacks may be used to identify the musculoskeletal impairments and assess the quality of the rehabilitation motion as well as to assist the patient or the physiotherapist to correct the motion patterns. Virtual simplified avatar has been usually created to represent the patient body [4]. However, these systems provided only external information (e.g. kinematics) of the musculoskeletal system during rehabilitation motion. In fact, the acquisition of internal information inside the musculoskeletal system is still a challenging problem for such useful rehabilitation systems.

Kinematics of the musculoskeletal system is commonly acquired using traditional motion capture systems (e.g. VICON) or video-based systems like KINECT sensor [6–10]. The use of video-based system has the advantage of low cost and portable

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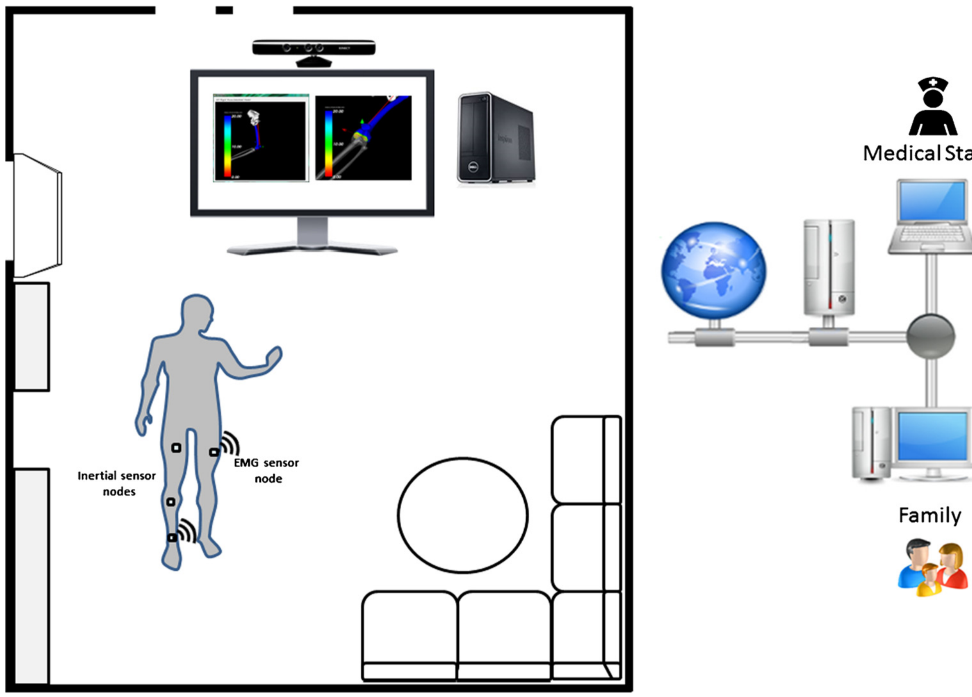

Fig. 1. Schematic illustration of an in-house rehabilitation scenario.

capacities. However, this provides only accurate planar kinematics for slow motion [10]. Moreover, serious game has been intensively developed to improve the user motivation during rehabilitation exercises [11,12]. Some commercial applications were also proposed like REHABILITATION FOR LOWER LIMB[1] or SEE ME[2] or JINTRONIX.[3]

Conventional/traditional rehabilitation provides a wide variety of therapy exercises with complex functional rehabilitation motions (e.g. extension/flexion, axial rotations, bending or a combination of these elementary motions). However, this deals with the limited time and non-controlled nature of the rehabilitation training for a patient due to high medical treatment cost and human resources (e.g. experimented clinicians and therapists) as well as the lack of objective and visual feedback of the rehabilitation effect. It is well known that the intensive and well-controlled use of rehabilitation program/training leads to significant improvement of musculoskeletal dysfunctions. Thus, a rehabilitation system providing an immersive virtual reality environment in which visual and quantitative feedback about the effect of rehabilitation motion on the musculoskeletal tissues and structures could be of great clinical interest. In particular, this assistive technology could be a valuable assistant to the patient to perform more precisely and accurately the exercises/motions of interest. Moreover, the system could allow the patient to perform his rehabilitation exercises at home in an intensive manner leading to motivate the practice and maximize the benefit of the rehabilitation program (Fig. 1).

1 http://applications.3d4medical.com/rehabilitation_lowerlimbs.
2 http://www.virtual-realityrehabilitation.com/products/seeme.
3 http://www.jintronix.com/.

The objective of this work was to develop interactive and connected rehabilitation systems as a system of systems for monitoring the bio-feedback signals of the musculoskeletal system during rehabilitation exercises in clinical as well as in non-clinical environment (e.g. home-based rehabilitation). Our proposed system of systems needs to satisfy the following challenges: 1) accurate joint kinematics by using the multi-sensor data fusion; 2) user motivation enhance using serious game technologies; 3) biomechanical modeling to provide useful bio-feedback signals; 4) innovative engineering design to facilitate the system set up; 5) system architecture development to integrate heterogeneous systems.

2. Material and methods

The flow chart of the proposed interactive and connected rehabilitation systems is shown in Fig. 2. It consists of a data acquisition and management system, a musculoskeletal simulator system and a graphical user interface (GUI) system.

2.1. Data acquisition and management system

A Kinect camera was used to acquire the kinematic data of the musculoskeletal system in real-time conditions. This marker-less motion capture system has a RGB (red, green, and blue) camera and a pair of depth sensors including an infrared laser projector and a monochrome CMOS (complementary metal–oxide–semiconductor) sensor. The Kinect system may capture the 3D geometrical data and 2D planar kinematics in ambient light conditions. The non-commercial Kinect software development kit (SDK) v1.7.0 for Windows and Visual C# (Microsoft®, USA) were used as programming languages to access into Kinect capabilities (e.g. raw sensor streams, skele-