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# Cloud-supported framework for patients in post-stroke disability rehabilitation

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ABSTRACT

Given the flexibility and potential of cloud technologies, cloud-based rehabilitation frameworks have shown encouraging results as assistive tools for post-stroke disability rehabilitation exercises and treatment. To treat post-stroke disability, cloud-based rehabilitation offers great advantages over conventional, clinic-based rehabilitation, providing ubiquitous flexible rehabilitation services and storage while offering therapeutic feedback from a therapist in real-time during patients' rehabilitative movements. With the development of sensory technologies, cloud computing technology integrated with Augmented Reality (AR) may make therapeutic exercises more enjoyable. To achieve these objectives, this paper proposes a framework for cloud-based rehabilitation services, which uses AR technology along with other sensory technologies. We have designed a prototype of the framework that uses the mechanism of sensor gloves to recognize gestures, detecting the real-time condition of a patient doing rehabilitative exercises. This prototype framework is tested on twelve patients not using sensor gloves and on four patients wearing sensor gloves over six weeks. We found statistically significant differences between the forces exerted by patients' fingers at week one compared to week six. Significant improvements in finger strength were found after six weeks of therapeutic rehabilitative exercises.

## 1. Introduction

Stroke is one of the most important reasons of long-term impairment in Saudi Arabia (Asirvatham and Marwan, 2014; Health Statistical, 2013; Al Khathaami et al., 2011; Al Jadid, 2011; Hamad et al., 2011; Al-Jadid and Robert, 2010) and around the world (Go et al., 2013; Heidenreich et al., 2011; HSF Canada, 2014; Hossain et al., 2016). Every year, many people suffer strokes, which lead to various disabilities on different parts of their bodies. To avoid and recover from disability, patients require rehabilitation services. The traditional stroke rehabilitation (Takeuchi and Izumi, 2013; Heart and Stroke Foundation of Canada, 2013) exercises are carried out in rehabilitation centers, located in special clinics or medical centers that may offer inadequate admission to patients living in the countryside. In this typical rehabilitation approach, a single patient can be provided therapy session by each therapist at a time. Patients might lose interest in doing repetitive tasks (Chen et al., 2008), such as moving their hands repeatedly. To address these challenges, rehabilitation systems may be based on Augmented Reality (AR), as have many recent rehabilitation systems (Alamri et al., 2008; Burke et al., 2010; Hu et al., 2016; Hossain et al., 2016), for seamless interaction with the combined real and virtual

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environment (Grealy and Nasser, 2012) so that patients' treatment and performance can be monitored and measured.

Although AR-based serious games (Burke et al., 2010; Hu et al., 2016; Hossain et al., 2016) have countless advantages for post-stroke rehabilitation, existing rehabilitation systems (Al Jadid, 2011; Al-Jadid and Robert, 2010; Takeuchi and Izumi, 2013; Hossain et al., 2016; Grealy and Nasser, 2012; Dobkin, 2005; Karime et al., 2012) still require perfections with regards to their effectiveness, patient inspiration, cost-effectiveness, interactivity, and applicability to a wide variety of real-life treatments. Recently, cloud-assisted rehabilitation systems have emerged so that patients can do real-time exercises, ubiquitously. To improve the accuracy of the systems' ability to recognize patients' conditions and track their improvements, advanced technologies (AR, gesture/touch, etc.) are used in cloud-based rehabilitation, which deploys ubiquitous rehabilitation services with flexible data processing and storage services. The promise of cloud computing is that the patient, the doctor, and the therapist can access and share real-time healthcare-related data remotely, from anywhere and at any time. Computationally intensive tasks are deployed in the cloud server, and while client devices render user interfaces.

Considerable research efforts have been related to cloud-based (Hoda et al., 2015; Fardoun et al., 2013; Woodman et al., 2015) and remote-home-based rehabilitation (Karime et al., 2015, 2014; Atashzar et al., 2017) for the improvement of motor function at different aspects or levels. Hoda et al. (2015) proposed a cloud-based framework for the recovery of affected arms from stroke, where a therapist, based on feedback, can interact with patients to see the improvements in their upper limbs. Fardoun et al. (2013) presented CRehab, a cloud-oriented framework to provide virtual environments for rehabilitation exercises; a child was considered for this exercise, but no simulated or experimental results were presented. Woodman et al. (2015) illustrated an architecture for the cloud-based deployment of a therapy for upper-limb rehabilitation, with therapeutic data used to see the deployment of games. Game data are used in clinical settings only for user management, processing and storage. Atashzar et al. (2017) reported a tele-robotic rehabilitation architecture for analyzing stability, mentioning the possibility of deploying augmented-reality therapeutic capabilities. Recently, sensory technologies (Lange et al., 2011) have been used to capture human motion and gestures for rehabilitative purposes. These technologies open great opportunities for monitoring patients and tracking their progress. Much of the reported work provides some sort of rehabilitative exercise using the potential of cloud technology. However, the integration of AR-based serious games and cloud computing presents several challenges that have not yet been enough explored by the research community. Some of these challenges are the seamless transmission of patients' real-time data to the cloud, effective analysis and correlation, processing of related data with regard to tracking patients' progress, and finally integrating therapist feedback.

In this paper, we attempt to investigate these challenges to enable the design and development of a cloud-based framework for rehabilitation services that uses AR and other sensory technologies. We have designed cloud-supported, AR-based serious games in which a patient holds and moves a cup during a rehabilitation session. We also designed sensory gloves equipped with a gesture-recognition mechanism that detects patients' real-time progress during their rehabilitation exercises. The sensory data from the gloves are delivered to the cloud server for later processing.

With the use of serious games and visual feedback in the rehabilitation process of the upper limb, objective measurements showed significant improvement in motor function and in patients' control of the fingers during the study period. To track patient improvement from rehabilitation exercises, sensory gloves were used in the prototype, which was tested by two patients for six weeks; the patients demonstrated signification improvements in week six compared to week one. The contributions of this paper are as follows: (a) a framework that uses the combined potential of AR and cloud-based technologies to track patients' progress through colorful visual cues for the affected hand movements while holding cups in post-stroke rehabilitative exercises and (b) a prototype upper-limb, post-stroke rehabilitative exercise using sensor gloves that capture real patients' kinematics. Significant improvement in finger strength was observed after six weeks.

The rest of this article proceeds as follows. In Section 2, we presents some of the related works conducted in the cloud-supported post-stroke rehabilitation. Then, we briefly describe the proposed cloud-supported framework for disability rehabilitation in Section 3. Section 4 reports an early experimental evaluation of AR-based serious games without the use of sensory gloves, followed by the reported effects of sensory gloves on the rehabilitation process. Finally, Section 4 concludes.

## 2. Related study

Recently, cloud-oriented or tele-rehabilitation has gained tremendous insights with the evolutions of Augmented Reality (AR)–based video and/or serious games and smart sensors (e.g., Microsoft Kinect). Augmented Reality (AR)–based video and/or serious games can provide enjoyable environment for post-stroke disability rehabilitation exercises remotely by considering a Physical Therapist's (PT) supervision or guidance. Here, we report some of the notable related works (Chen et al., 2008; Burke et al., 2010; Hossain et al., 2016; Hoda et al., 2015; Karime et al., 2015; Hossain, 2017; Jack et al., 2001; Connelly et al., 2010; Rahman, 2017; Gauthier et al., 2017; Chatzitofis et al., 2015; Hossain, 2016). Some of them are summarized in Table 1, based on some features.

Rahman (2017) investigates a novel cloud-based physical therapy monitoring and guidance system. The patient can train himself by following the physical therapist avatar and getting real-time guidance from this guideline system. A Physical Therapist (PT) can record a multimedia training session as "model therapy" and after that stream to a patient who can be mobile and using a motion sensor such as Microsoft Kinect follows the avatar in real-time. The user session data can subsequently be transmitted to the cloud for measuring the accuracy of the user session in comparison to the PT avatar. The system has been tested with real subjects under the guidance of a licensed Physical Therapist.

Chatzitofis et al. (2015) presents a cloud-oriented rehabilitation exercise coupled with serious game facility for post-stroke cardiac patients. Along with bio sensors, Kinect v2 is used to record the exact movement of patients/user in real-time to have enjoyable