This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/JIOT.2017.2776150, IEEE Internet of Things Journal

m-Therapy: A Multi-sensor Framework for in-home Therapy Management: A Social Therapy of Things Perspective

Md. Abdur Rahman, Member, *IEEE* and M. Shamim Hossain, Senior Member, *IEEE*

Abstract— Social Internet of Things (SIoT) is assumed to provide health services by incorporating social networks and the internet of things (IoT). Although much development in therapy monitoring has been observed recently, few advancements have been achieved in the domain of in-home therapy. Existing industrial and medical solutions require complex and expensive hardware and software that are impractical for home use. Another challenge for in-home therapy is that therapists cannot confirm whether patients are conducting the therapy correctly and for the prescribed number of times. To address these challenges, we propose the m-Therapy framework, in which multiple gesture-tracking sensors and environmental sensors are used to collect therapy and ambient data. The m-Therapy framework compresses the collected data and uploads to a big data server. The framework uses a model of the therapy to guide a patient performing therapy exercises outside medical institutions and even at home. Ambient IoT sensors can help maintain an appropriate ambient environment, which is generally maintained at the medical institutions. We have developed analytics that can provide live or statistical kinematic data, including rotational and angular range of motion of the joints of interest, and ambient environmental data, which can be shared with therapists and caregivers. We present our findings, which shows that the proposed m-Therapy monitoring system can be deployed in real-life scenarios.

Index Terms— smart living, gesture recognition sensors, therapy, range of motion, SIoT-based mobile therapy.

I. Introduction

ARRANGING proper therapy for disabled people or people recovering from injuries has always been a great challenge. Gradual increases in the numbers of disabled people and a lack of required number of therapists have contributed to this challenging situation. To maintain gains, therapists suggest optimal methods and numbers of repetitions. Practicing prescribed therapies can also be boring and tiresome, making it hard for the disabled to maintain the prescribed exercises. Hence, in-home therapy is gaining popularity [1, 2, 3, 4, and 5] because it allows patients to perform more frequent repetitions of therapy exercises with the assistance of caregiver family members. Therapists cannot take personal care of a large number of patients; therefore, monitoring of in-home therapy allows a therapist to remotely obtain therapeutic data from multiple patients [26].This increases the number of patients that a therapist can care for, even outside a medical institution. There have been several recent advances in gesture-tracking technologies such as Microsoft Kinect v2 [6], Microsoft Digits [7], Vicon camera [8] Leap Motion [9], and Myo [11]. All these technologies can be used to monitor and facilitate therapy by acting as an IoT sensor as well [28]-[37]. Although they can track certain joints of the human body, none supports full-body joint analysis by recognizing both angular and rotational motions. For example, Kinect v2 cannot track minute hand joint range of motion. Leap and Myo sensors can only detect hand gestures, although they differ in their technology, field of view and range of gesture recognition.

A shortcoming of both Leap and Kinect v2 is that they require a direct line of sight within their field of view. In contrast, Myo is a wearable device that uses Electromyography (EMG) to track motion, and communicates using Bluetooth low energy (BLE) to allow for longer-range monitoring. Although each sensor mentioned above has strengths and weaknesses, together they form a strong, whole-body, gesture recognition framework [16] [17] [18] [22] [23] [24] [25]. Hence, we propose a framework that can combine multiple multimedia gesture-tracking sensors to allow monitoring of therapy at home. A therapist can create any therapeutic exercises consisting of any number of primitive joint-motions and can assign these exercises to a patient. The patient can then perform these exercises at home or at any disability center. The framework allows the exercise session to be captured and remotely stored and analyzed for various improvement factors [20] [21]. Fig. 1 shows a high-level framework where multiple sensors can be integrated to support monitoring of therapy at home.

In the present study, we propose a multi-sensor, IoT-based full-body therapy management framework, which can detect 35 joints and their movements, both rotational and angular. The framework is able to detect whether any predefined high-level gesture has occurred. The framework collects various types of kinematic measurement data, even at home. Additional sensors can be added to the framework to collect other information such as noise level, dust level, gas level, air quality, ambient temperature, luminance and humidity. These data can be used to ensure that an appropriate therapeutic environment is being maintained at home, similar to that maintained at medical

M. A Rahman is with the Department of Forensic Computing and Cyber Security, College of Computer Science and Information Technology, University of Prince Mugrin, Madinah Al Munawwarah, Saudi Arabia. Email: m.arahman@upm.edu.sa
M. A Rahman is with Advanced Media Lab and Smart City Research Lab of University of Prince Mugrin, Madinah, Saudi Arabia.

M. S. Hossain is the Department of Software Engineering, College of Computer and Information Sciences, King Saud University, Riyadh 11543, Saudi Arabia. E-mail: mshossain@ksu.edu.sa
M. S. Hossain is also with Research Chair of Pervasive and Mobile Computing, King Saud University, Riyadh 11543, Saudi Arabia

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/JIOT.2017.2776150, IEEE Internet of Things Journal

centers. These data can also be used for further analysis, to help therapists better analyze the current progress achieved by a patient.

Fig. 1: SIoT nodes to support in-home therapy management

Another key challenge of allowing a patient to perform therapy exercises at home is the possibility of human error. Generally, each exercise has to be precisely guided by an expert therapist to gain the most from a therapy session. Therefore, a guiding mechanism is required to attain confidence on the captured therapeutic data. A virtual therapist acting as a model to follow, or a real therapist through tele-collaboration, can model techniques and guide the patient through the therapy session.

Therapy session data consist of multimedia such as audio, video and text data, gesture and motion data, and model therapy information that serves as the ideal guide for any particular exercise. Because audio, video and gesture data from different sensors have different characteristics, it is challenging to synchronize them into a single session. The session data are compressed and uploaded to a big data repository. This therapy data repository stores the media files and skeletal motion data, and the synchronization metadata that is necessary for later playback. Finally, the session data are analyzed to deduce improvement metrics.

The rest of this paper is organized as follows. Section II describes the framework design. Section III details the implementation of the framework. Section IV presents the test results and Section V concludes the paper and presents our vision for future research.

II. Therapy Monitoring Framework Design

A. *Therapy Environment*

Our proposed framework (hereinafter referred to as 'm-Therapy') supports IoT devices, and other sensors, including Kinect v2, Leap, and Myo, to take advantage of the respective strengths of each type of sensor. Fig. 1 shows the operational environment. The Myo IoT device can detect omnidirectional motion, and can operate at an approximate range of 80 m from the connected computer or smartphone. In contrast, Leap and Kinect v2 must be connected directly to a computer through a wire. The sensor range of Leap is approximately 60 cm above the controller and 60 cm to each side. Kinect v2 has wider sensor range, between 0.5 m and 4.5 m horizontally and 1.8 m vertically. Because all the sensors use different gesture recognition technology, they do not interfere with one another and can be used by the m-Therapy framework to track different joints simultaneously.

After a patient completes a prescribed therapy session at home, the m-Therapy framework allows the collected data to be uploaded to our m-Therapy big data server. The server employs a big data analytics engine to use different gesture recognition algorithms to extract kinematic data from collected therapeutic session data. Timestamped session data include type of therapy, joints that were tracked, model therapy, start and stop time of each repetition, range of motion values, and highest and lowest angular and rotational kinematic data. These data are synchronized with gesture or event data and annotated with video and audio.

Once a therapy session has been submitted to the m-Therapy server, the therapist receives a notification. The therapist can review the therapy session data, and annotate the multimedia at any timestamp. These comments are uploaded to the m-Therapy server. Upon receiving therapist comments as multimedia annotation, patients or caregiver family members can playback the annotated comments and apply this feedback in subsequent therapy sessions. The therapist can monitor the data to see improvement statistics and the effectiveness of particular therapy exercises for each patient. The caregiver can also access the analyzed data and observe different metrics that evaluate the improvement of the patient and the quality of the therapeutic services.

B. High-Level Architecture

Fig. 2 depicts the high-level architecture of our proposed m-Therapy system, which can accommodate patients, caregivers, and therapists. We assume the patient has access to a number of *multimedia, gesture tracking and IoT sensors* that are used to support in-home therapy. When the patient starts a therapy session, multimedia, gesture and IoT data are recorded by the client *User Interface* components. At the *Stream Layer*, gesture, multimedia and IoT data are synchronized at the *Data Processing Layer*. Gesture and IoT parsers encapsulate the relevant processing libraries that are available to a client computer. For example, the Gesture Parser used in this research incorporates the libraries we have designed for Microsoft Kinect v2 sensor, Leap motion sensor and Myo sensor data streams. Different data streams have different media characteristics; thus, the *Synchronization Processor* plays a crucial role in preserving the spatial and temporal positions of each stream with respect to the overall therapy session. In addition, appropriate annotations and metadata are stored