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A remote quantitative Fugl-Meyer assessment framework for stroke patients based on wearable sensor networks

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ABSTRACT

To extend the use of wearable sensor networks for stroke patients training and assessment in non-clinical settings, this paper proposes a novel remote quantitative Fugl-Meyer assessment (FMA) framework, in which two accelerometer and seven flex sensors were used to monitoring the movement function of upper limb, wrist and fingers. The extreme learning machine based ensemble regression model was established to map the sensor data to clinical FMA scores while the RRelief algorithm was applied to find the optimal features subset. Considering the FMA scale is time-consuming and complicated, seven training exercises were designed to replace the upper limb related 33 items in FMA scale. 24 stroke inpatients participated in the experiments in clinical settings and 5 of them were involved in the experiments in home settings after they left the hospital. Both the experimental results in clinical and home settings showed that the proposed quantitative FMA model can precisely predict the FMA scores based on wearable sensor data, the coefficient of determination can reach as high as 0.917. It also indicated that the proposed framework can provide a potential approach to the remote quantitative rehabilitation training and evaluation.

1. Introduction

A stroke is one of top three causes of mortality and the leading cause of adult disability worldwide [1]. Between 70% and 85% of first-ever strokes are accompanied by hemiplegia [2]. According to epidemiological statistics [3], the annual stroke mortality rate is around 1.6 million, approximately 157 per 100,000 in China. Strokes have put enormous mental pressure and economic burden on our society and families.

Due to the limited resources in rehabilitation centers, home-based rehabilitation is getting more and more attention. According to researchers [4–6], in comparison with inpatient care, home-based rehabilitation shows no difference in the effect on any of the outcomes. Moreover, there are fewer constraints on time and space in the home settings, so patients can practice more frequently, for longer periods of time and according to their own schedule. Unfortunately, patients undergoing rehabilitation at home are not able to assess their own functional state without a physician around. Thus,

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personalized interventions that will maximize the improvements in subjects' motor recovery cannot be reached, which has become the bottleneck of home-based rehabilitation. Additionally, the commonly used assessment scales have the following two drawbacks: (1) they are susceptible to subjective factors, the assessment results may different between physicians; (2) they only have several rating levels and are influenced by a ceiling effect [7], making it impossible to exactly detect the improvement in the movement.

Nowadays, wearable sensor network systems (WSNs) technology – particularly inertial sensors that contain accelerometers, gyroscopes, and magnetometers – can assess the type, intensity, duration, frequency, and quality of various mobility-related functional activities [8–15]. Additionally, some researches combined the inertial measure sensors with physiological sensors, like ECG [16], sEMG [17], etc. These sensing systems can introduce new possibilities for continuous, unsupervised, objective monitoring of mobility and functional activities in clinical and non-clinical settings. From the aspects of application scenarios, it can be divided into the following four categories: falling detection [18,19], physical activity monitoring [20–22], movement recognition [23–25] and quantitative assessment [26–31]. Particularly in the area of quantitative assessment for stroke patients, there are many valuable research results have been published. Uswatte et al. [32] have shown that accelerometer data can provide clinically-relevant information about upper extremity motor status via research on 169 stroke survivors. Patel et al. [28,33] proposed a Random Forests based algorithm to monitor rehabilitation outcomes in stroke patients using accelerometers attached to the hand, arm and trunk. The authors selected eight tasks from the Wolf Motor Function Test (WMFT) to estimate the total Functional Ability Scale (FAS) score via analysis of accelerometer data. Our pilot work has shown that automatic Brunnstrom stage classification can be achieved with an accuracy of 92.1% by analyzing the accelerometer data [34]. Zhang et al. [35–37] proposed a novel single-index based assessment approach for quantitative upper limb mobility evaluation, the experiments collected 145 motion samples from 21 stroke patients and 8 healthy participants. The results suggested that the proposed assessment index can not only differentiate the levels of limb function impairment clearly but also strongly correlate with the Brunnstrom stages of recovery.

However, the above researches are all implemented in clinical settings. In other words, to the best of our knowledge, there is no existing system can remotely assess the motor function of stroke patients in home settings. Hence in order to help the stroke patients can do rehabilitation training after they leave the hospital, this paper proposes a novel remote quantitative Fugl-Meyer assessment system based on wearable sensor networks.

The rest of the paper is organized as follows. In Section 2, the full view of the proposed framework and modeling method will be presented. The experimental configurations will be introduced in Section 3. The experimental results and discussions will be described in Section 4. Finally, the work and contributes will be concluded in Section 5.

2. Methods

2.1. Overview of system framework

The overview of proposed remote quantitative Fugl-Meyer assessment framework is shown in Fig. 1. The whole system consists of three parts: the patient client, physician client, and web server. At the patient client side, patients will wear the accelerometer and flex sensors first and then finish the individualized rehabilitation prescriptions which were made by the physicians. During their training process, the wearable sensors will record the movement information in real time and wirelessly transmit to the computer through ZigBee protocol and finally upload to the web server database through Internet. In our studies, the microcontroller Unit of wearable sensor is CC2530, which contains an embedded ZigBee module uses 2.4 G band. The whole wearable sensor is powered with a Lithium-ion battery, whose capacity is 300 mAh. When the battery is full charged, the wearable sensor can continue work about 10 h. Besides the storage function, another important function of web server is to analyze the movement data and give an accurate prediction of Fugl-Meyer score (the detailed modeling method will be introduced in Section 2.3). At the physician client side, physicians can view the patients' training record and Fugl-Meyer score via website and APP (Android or iOS). Meanwhile, physicians can adjust the individualized rehabilitation prescriptions according to the patients' condition.

2.2. Simplified upper limb training exercises

As seen in Fig. 1, the core of proposed system is the quantitative Fugl-Meyer assessment (FMA) model, which mapping the

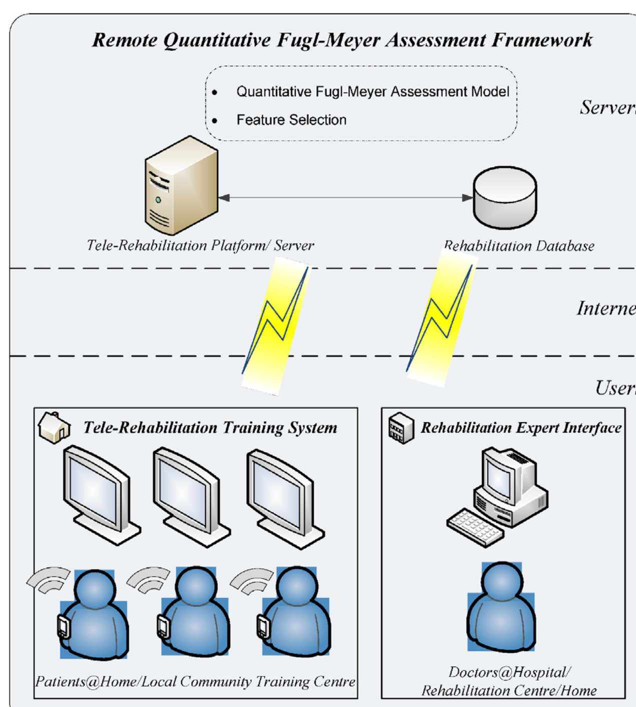

Fig. 1 – Overview of system framework.