A Mobile Cloud based IoMT Framework for Automated Health Assessment and Management

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Abstract— **In recent years, there has been growing interest in the use of mobile cloud and Internet of Medical Things (IoMT) in automated diagnosis and health monitoring. These applications play a significant role in providing smart medical services in modern healthcare systems. In this paper, we deploy a mobile cloud-based IoMT scheme to monitor the progression of a neurological disorder using a test of motor coordination. The computing and storage capabilities of cloud server is employed to facilitate the estimation of the severity levels given by an established quantitative assessment. An Android application is used for data acquisition and communication with the cloud. Further, we integrate the proposed system with a data sharing framework in a blockchain network as an innovative solution that allows reliable data exchange among healthcare users. The experimental results show the feasibility of implementing the proposed system in a wide range of healthcare applications.**

I. INTRODUCTION

The manifestation of neurological disorders, such as Parkinson's disease (PD) and cerebellar ataxia (CA), commonly leads to problems in walking, control of extremities and balance, issues which are major impediments to everyday living. More than 10,000 adults in the UK suffer from CA [1] and currently there is no cure for the disease. It is due to the nature of these conditions that continuous care and monitoring of disease progression and medicine consumption require great attention. However, as the load of hospitalisation increases over time, such healthcare services can become inefficient, expensive and difficult to manage [2].

With the emergence of Mobile Cloud Computing (MCC) and Internet of Medical Things (IoMT) technologies, the healthcare industry has experienced a paradigm shift in clinical assessment and healthcare management in recent years [3-6]. The mobile cloud based IoMT system can capture subtle changes from the patient's physical signs and provide better access to the clinical health records. Specifically, a more objective assessment can be obtained and medical data can be accessed by multiple healthcare parties in a more convenient and rapid manner with appropriate authorization. Additionally, in this context, both clinician and patient can keep track of the disease progression and the medication efficacy is also evaluated accordingly.

A number of methods have been proposed to improve movement disorder assessment on different mobile cloud IoMT environments [7-10]. The authors in [7] proposed a wearable solution to provide an activity monitoring service on elderly people using Bluetooth smart beacon sensors with a cloud based mobile app. The system was capable of recognizing different drinking and restroom activities with high accuracy, which could be helpful to caregivers in monitoring old patients. To support upper limb rehabilitation on stroke survivors, a smart system which used a sensing network of motion, electromyogram (EMG) and temperature sensors with cloud computing service was introduced on an Android platform [8]. The work [9] presented a prototype on the mobile cloud-based mHealth app that was used to monitor and assess movement disorders in home-based settings. The outcome of the assessment was estimated and stored by cloud computing services using the data from the smartphone's acceleration. In [10], an automatic prediction system for scoring Parkinsonian tremor using a wrist-watch-type wearable device and machine learning was designed. The performance evaluation showed that assessment results from automatic scoring of Parkinsonian tremors highly correlated with severity scales measured by neurologists.

Motivated by such developments, this paper presents an automated assessment system for grading the severity of CA in the Romberg test. The proposed system is enabled by the combination of MCC and IoMT technologies on a mobile-cloud platform. From the network perspective, a data sharing scheme is designed and integrated to give different healthcare entities the ability to access the medical records in a secure environment. More specifically, we develop a blockchain network that allows data sharing in a trustworthy and efficient manner. All computing processes take place on a cloud server to address issues of resource constraints on mobile devices and therefore increase the usability of our system.

The paper is organized as follows. The system architecture and implementation are introduced the next section. Section III shows the experimental results and evaluates the performance of the overall system. Section IV presents the integrated scheme for data sharing using blockchain, and discussions of the proposed approach are presented in Section V. Finally, Section VI draws conclusions of the paper.

II. SYSTEM OVERVIEW

A. System Architecture

The proposed system uses a wearable sensor to collect motion data, and exploit computing and storage capability of cloud service for data analysis and severity estimation. The model includes three main parts: wearable sensor device, mobile gateway and cloud server as shown in Fig.1. In the cloud server, a data sharing scheme is implemented as a

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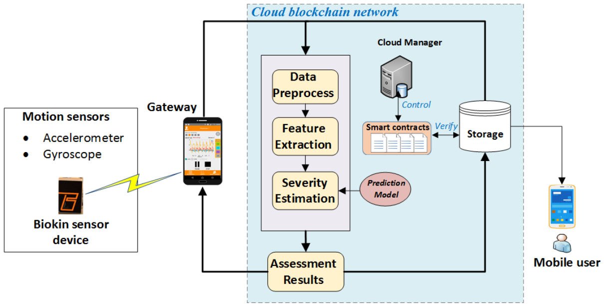
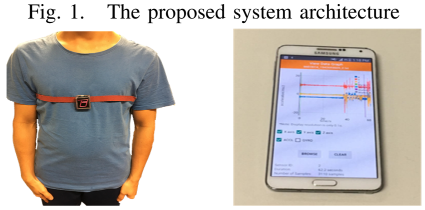


Fig. 1. The proposed system architecture



(a) (b)

Fig. 2. Biokin Sensor and Mobile Gateway

control mechanism for the data transaction between network users. Their details are presented as below.

- Wearable sensor device: In our system, the Biokin sensor network developed by Networked Sensing and Control Lab, Deakin University, is mounted on the human body (Fig. 2a) and is used to measure activity data. BioKin is a system of wireless motion capture devices designed to capture complex movements of human body [13]. A Biokin sensor network consists of low-cost wearable wireless motion capture sensors with a tri-axial accelerometer and a tri-axial gyroscope for motion data collection. In our test, the sampling rate of the accelerometer is set to 50 Hz.

- Mobile gateway: We use an Android phone as a mobile gateway where a mobile application is integrated to collect 3D acceleration data from wearable sensors via a wireless network (Fig. 2b). Data captured by the sensors are stored temporarily on the gateway before transmitting to the cloud for analysis. A real-time visualization is also provided to keep track of the historic medical records.

- Cloud server: The proposed system adopts Amazon Web Services (AWS) as the main cloud computing platform. The AWS cloud service has demonstrated its potential applications in the healthcare domain [12]. In our model, we employ several cloud services on AWS, including Amazon Elastic Compute Cloud (Amazon EC2), AWS Lambda, AWS IoT and AWS Simple Storage Service (AWS S3). All motion data and analysis results are kept in a cloud database which is used to track patient health history. Data processing consists of three components: data pre-processing, feature extraction and severity estimation. Details of these steps will be described in the next subsection.

B. *Implementation*

We examine the performance of proposed model through a Romberg test which was studied in our previous work [14]. One sensor unit was positioned on the sternum (front-chest) to collect movement data during the test. The aim of Romberg test is to investigate postural imbalance during

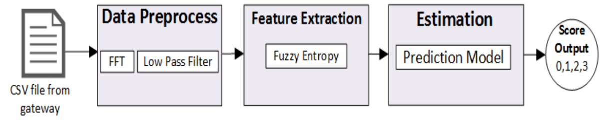


Fig. 3. The flowchart of cloud data processing

quiet standing for patients diagnosed with CA. Based on our research, fuzzy entropy measurement from acceleration data is evaluated as an effective method to evaluate human postural balance and stability of gait ataxia. Further, fuzzy entropy values calculated from acceleration data highly correlates with severity scores that was used to estimate the degree of patient severity.

The details of our experiment are described as below.

- Dataset preparation: We employed thirty-four patients and twenty-two age matched healthy subjects to perform the Romberg test. This project was approved by the Human Research and Ethics Committee, Royal Victorian Eye and Ear Hospital, East Melbourne, Australia [15]. In the trial, we analysed a sample of entropy data with corresponding clinical scores, all of which will be used as training data for building a support vector regression model.

- Data processing: Acceleration time series data was collected by a wearable sensor and stored in a CSV file. In the *data preprocess module*, time series data was down sampled to 5Hz before being filtered by a low pass filter. In the next step, acceleration data was analysed in the *feature extraction module* to extract the motion feature with entropy value which contains meaningful information of the motion disorder of patients. Based on analysis result in our previous research [15], fuzzy entropy is considered and calculated for showing severity levels. The extracted feature was then fed into the *estimation module* to estimate the severity score using a nonlinear support vector regression model. All data processing modules were designed and written by Python language and deployed on AWS Lamda computing service of the Amazon cloud platform.

C. *Data sharing scheme*

A data sharing scheme is necessary to control the exchange of clinical records among authorized healthcare entities in the network. For instance, the outcomes of patients' assessment should be accessible for their healthcare providers such as doctors and treating physicians so that they can provide appropriate medical supports. Mobile users without access rights should not be given access.

In this work, we use a blockchain network to create a secure and reliable environment for the sharing of such private data. The blockchain technology has emerged as a promising solution thanks to its decentralized and trustworthy nature to revolutionize e-health services such as data sharing of electric medical records (EMRs) [16-18]. However, the use of blockchain in mobile cloud for data sharing is still an open research problem.

We employed Ethereum blockchain platform [19] to create the blockchain network and design smart contracts (predefined coding scripts on blockchain) to control user access on cloud. The proposed prototype is illustrated in Fig. 5. To

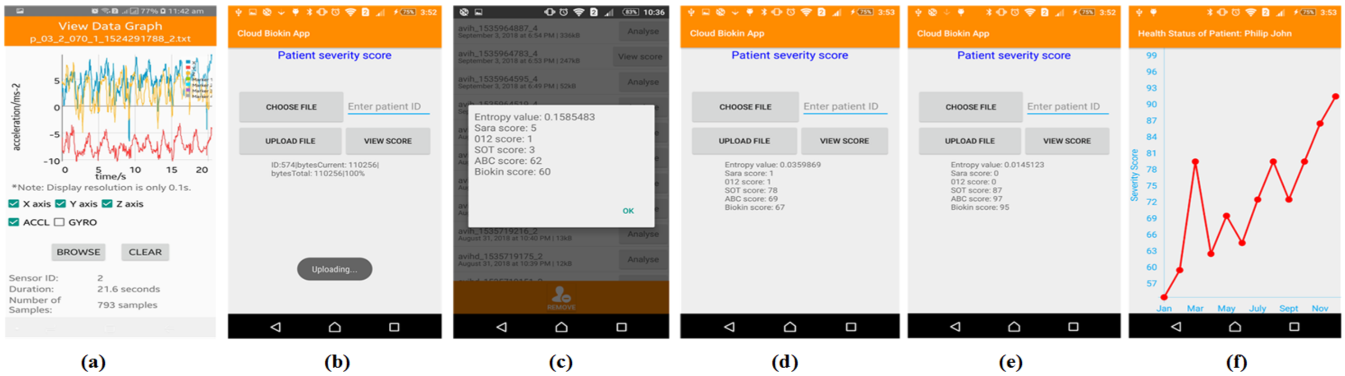


Fig. 4. Results of disorder scoring estimation on mobile app: a) visualization of motion data, b) uploading procedure of recorded data to cloud, c) online predicted severity scores, d) severity scores for a patient, e) severity scores for a normal subject, f) historic data trend of a patient.

join in the blockchain network, a mobile user first creates a blockchain account that includes a private key to sign transaction and a public key for user identification. In order to access cloud database, the user needs to send a data request as a transaction that is signed by their private key. The cloud storage will validate the access of the requestor by using smart contract protocol. The smart contract will verify whether the user is predefined in the policy list. If the access is authorized, the data storage will return the request data. A cloud manager is designed and responsible to manage all transaction operations on blockchain and update policies in smart contracts. Smart contracts are written in Solidity [20] and communication cloud software is developed in Python.

III. Results and Performance Evaluations

A. Assessment using cloud computing

In this section, we present results of the automated estimation system on a Sony mobile phone running on an Android OS version 8.0 platform. It is worth noting that evaluations on accuracy and correlation of prediction scores with clinical scales are not in the scope of this paper and their details can be found in our previous work [15].

The results of our implementation are presented through the following functionalities.

- ***Record data:*** Sensor data collected from the patient is visualized on the phone (see Fig. 4(a)). The physician can select data types (including 3-D acceleration and gyroscope data) with display options. This design feature allows users to track motion disabilities during the test.

- ***Process data:*** Recorded data is uploaded to cloud for data processing and physicians can acquire severity scores (see Fig. 4(b), 4(c)). We convert the fuzzy entropy to different score domains. Five different score types are selected to display for further reference. The Scale for the Assessment and Rating of Ataxia (SARA) is from 0 to 6 as the increasing level of severity according to a practice guideline, whereas 012 score limits the categorical decision to normal-mild-severe to eliminate the unnecessary linear assumption that exists in SARA. Similarly, we extract the Activities-specific Balance Confidence (ABC), Sensory Organization Test (SOT) and our BioKin scales ranging from 0 to 100 for the most noticeable impairment. Our algorithm can predict

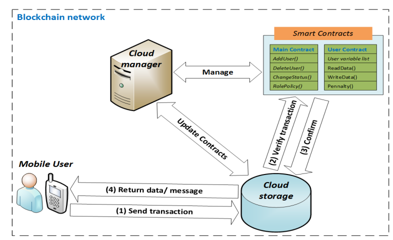


Fig. 5. The data sharing scheme on mobile cloud blockchain

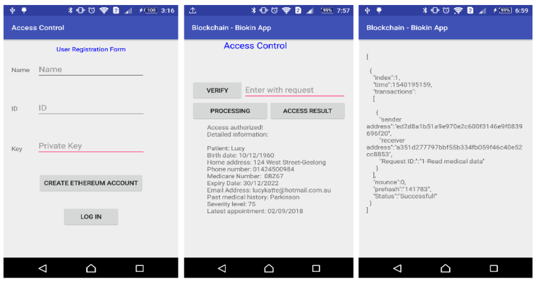
severity levels of ataxia that is able to identify patients and normal subjects (see Fig. 4(d), 4(e)). Note that our mobile application can allow users to obtain assessment results after the test (online usage-Fig. 4(c)) and retrieve past results for later use (offline usage-Fig. 4(d), 4(e)). This helps physicians to follow their patients' progression anytime.

- ***View historical data:*** In addition, our mobile application can allow users to view and manage historical records (Fig. 4(f)). This assists physicians in the process of monitoring disease progression and treatment scheduling with the availability of test results and statistics. Physicians can track the health status of their patients by sending a request to access the cloud storage. Also, patients can access to their medical records for a comprehensive view of their healthy condition.

B. Data sharing performance

Fig. 6 shows a successful deployment of the Etherem blockchain network on Amazon cloud. The blockchain web interface allows transaction status and user access to be monitored. To investigate the feasibility of the data sharing scheme, we design a mobile app integrated on an Android phone of a third party. This Android phone connects directly to the Amazon cloud via the blockchain network for data access. As shown in Fig.7(a), the mobile user needs to create an Ethereum account to start accessing cloud data. In order to retrieve data on cloud, the user needs to declare the request ID of their interest. Note that in our test, each request ID represents patient information such as medical data and disease history. Once receiving the request, the cloud storage will verify by the smart contract (by mapping user public key and predefined user list) and send back the results to the requester (Fig.7(b)). The transaction record of a successful data request is illustrated in Fig. 7(c).

Fig. 6. The running Ethereum blockchain on Amazon cloud



(a) (b) (c)

Fig. 7. Illustrations of data sharing results on blockchain mobile app: a) User registration form with Ethereum account, b) EMRs access results of an authorized user, c) Transaction record of authorized EMRs access.

IV. Discussions

The objective of the proposed architecture will be directed towards automatic assessment and real time severity estimation of neurological disorders on a mobile cloud platform. The integration of advanced cloud service provides a highly accessible and objective solution to improve healthcare quality. Furthermore, the proposed system also integrates with a data sharing scheme based on blockchain which enables reliable and efficient data sharing in a healthcare system. Overall, the designed framework brings several important features that can increase the usability of the application.

Flexibility: Any service users or providers with a smartphone can work on our system with multiple multimedia data sources (time series, video, and image data). Our framework can also adapt with various mobile platforms, including Android and iOS versions, and this flexible feature can facilitate design in various healthcare applications in both hospital and home-based settings.

Availability: Our system allows authorized users to access e-healthcare records for retrieving data anytime and anywhere with the mobile application. Another important feature of our design is to allow physicians to analyse patient data on cloud in both online and offline manners, which are essential to e-healthcare systems.

Low cost service: Conventionally, mobile e-healthcare applications mainly rely on mobile devices or local servers with expensive services for storage and computing demands [7-8]. By bringing cloud into e-healthcare frameworks, our proposed solution can help overcome such limitations by exploiting low cost services on cloud with unlimited data storage and computation capabilities.

Reliability: Most of current works focus on developing applications while neglecting reliability feature of the system [7-10]. In our proposed model, we exploit blockchain with its high trustworthiness features to fulfil the requirements of a full prototype on mobile clouds. By using our blockchain network, service users can exchange data without data privacy and trust concerns.

V. Conclusions

This paper introduces a new automated clinical assessment system based on mobile cloud and IoMT technologies. This research makes a contribution to the advance of intelligent clinical assessment systems for health monitoring on smartphones. Also, the mobile application incorporates a novel data sharing solution using a blockchain network which can achieve reliable data exchange among mobile users on mobile clouds. This also allows to connect patients, physicians and other healthcare providers in a more trustworthy and efficient manner. With the interesting design characteristics, the proposed system can support early diagnosis of neurological conditions and improve the healthcare management.

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