A System for Collecting Motion Data on Patients' Activities of Daily Living

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***Abstract*— Functionary recovery is administered to hemiplegic patients as rehabilitation. Some patients who recover their functions better in a rehabilitation facility cannot do any activities in their home. Therefore, recovering Activities of Daily Living (ADL) has become more significant than functionary recovery recently. Since existing ADL recovery level indices are based on questionnaires, recovery level judgments are easily affected by an evaluator's subject. In this paper, we describe a system we propose that collects and stores motion data on daily life activities to quantitatively evaluate ADL recovery levels.**

Keywords-rehabilitation; functionary recovery; activities in daily living; ADL; BLE beacon; Google Firebase.

I. INTRODUCTION

Most patients suffering from cerebrovascular disease have paralysis on one side of the body, and their bodies lean and twist to the paralyzed side. Also, because of unusual muscle strain, their hands and feet become stiff. In some cases, muscles of the upper body go into convulsions. Functionary recovery is administered to hemiplegic patients as rehabilitation. However, some patients are not always to live less inconveniently in their home. Some patients who recover hand and arm functionality better in a rehabilitation facility cannot eat meals better in their home. Therefore, recovering Activities of Daily Living (ADL) has recently become more significant than recovering functionaries.

The Barthel Index, which is based on questionnaires, is popularly used to quantitatively evaluate ADL recovery levels [1][2]. With questionnaires, however, recovery level judgments easily change in accordance with the evaluator's subject. Each recovery level is digitized to a few levels. For example, answers for feeding include "unable," "needs help cutting, spreading butter, etc., or requires modified diet" and "independent." Each answer is scored 0, 5, or 10. However, the recovery level for feeding with help ranges from "a patient eating food directly from dishes without using a spoon or fork" to "a patient eating a meal with a knife and fork in almost the same way as a healthy person." Also, it takes too much time to ask and observe whether a patient can do an activity independently without needing help.

Functional Independence Measure (FIM) [3] and Katz Index [4]-[6] scores are also used to evaluate ADL. FIM scores cover not only functional disease but also mental disease. Scores are broken down into seven levels for each activity, including feeding. Katz Index scores are usually applied to cure elder patients or those suffering from chronic disease.

The question formats for these evaluation methods are basically the same, and an evaluator needs much time to ask questions and observe a patient. We think that a quantitative evaluation system with a computer is needed to evaluate patients objectively without needing to ask them any questions and/or observe them.

Judging ADL recovery levels is based on whether patients can do tasks, such as eating, getting dressed, bathing, washing, and discharging bodily waste by themselves. Therefore, a system that collects motion data of patients in daily life needs to not only measure and collect the motions of body parts but also detect which activities are performed. However, it is very difficult to estimate these merely from changes in acceleration and/or gyro sensor data obtained from devices attached to body parts. Therefore, we estimate activities by using information about places, such as a dining table, bathroom, dressing room, or bedroom. We used the BLE beacon [7] to detect places in this system.

Most surgeons also think that postoperative patient functions assessed by ADL and quality of life have become especially important ways to measure surgical treatment outcomes for the elderly [8].

In this study, we developed a system to collect and store patients' motion data to quantitatively judge **the recovery level of activities in daily living**. A patient's name, measured location, sensor-attached body parts and time-stamps are described as the file names for each measured data file in this system. Since we wish to use this system not only to evaluate patients' ADL but also to develop algorithms for detecting whether patients can do designated activities, we designed the system so that it can store video data of recorded patients' motions.

The system only requires that recognized medical doctors or physiotherapists can access measured data to maintain security. To ensure this, we developed a data collecting system based on Google Firebase [9]. Since the Firebase application can be independently implemented for any organization, high level security can be maintained.

Evaluation algorithms are needed to judge recovery level from measured data. However, in this paper we describe a system to collect measured data rather than evaluation algorithms. We plan to introduce the latter in another paper.

After introducing related work in Section II, we describe the system's design concept and its implementation in Sections III and IV. Examples of measured data for a

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participant played a patient who has paralysis on one side are introduced in Section V. Section VI concludes with a summary of key points.

II. Related work

To develop a quantitative evaluation system for the recovery level of activities in daily living of hemiplegic patients, we have to know how to evaluate ADL quantitatively, existing life log systems and healthcare information cloud service.

A. Evaluation index for function level in daily living

Three indexes to evaluate function level in daily living are widely used: the Barthel Index, the Functional Independence Measure (FIM) and the Katz Index. They are basically questionnaires for daily life activities, such as feeding. The Barthel Index and FIM are popularly applied to evaluate function levels for rehabilitation patients, such as those afflicted with cerebrovascular disease. There are ten question items in the Barthel Index: Feeding, Moving from wheelchair to bed and return, Personal toilet (washing face, combing hair, shaving, cleaning teeth), Getting on and off the toilet (handling clothes, wiping, flushing), Bathing self, Walking on level surfaces, Ascending and descending stairs, Dressing (includes tying shoes, fastening fasteners), Controlling bowels and Controlling bladder [1] [2]. A score of independently doing an activity is usually 10 points, doing it with help is usually 5 points, and not doing it is 0 points.

FIM evaluates not only physical functions but also social abilities, such as communication or social recognition [3]. The number of questions covers 18 issues; 13 for physical functions and five for social abilities. Questions about physical functions are more segmentized. For example, the dressing function is divided into dressing the upper body and the lower body, moving activities are divided into the moving between a wheelchair and a bed/chair, and sitting on a toilet seat and moving to a bathtub. Scores are given on a seven-point system. Independently doing an activity gets seven points, doing it with full help gets one point, and doing it with partial help gets scores ranging from two to six points.

The Katz Index is usually applied to elder patients or those suffering from chronic disease in a variety of care settings [4 - 6]. The index ranks adequacy of performance in six activities: bathing, dressing, toileting, transferring, continence, and feeding. Clients are scored yes/no for independence in each of the six functions.

Every three indexes evaluate whether a patient can do activities in daily living. Therefore, our proposed system must know what kinds of activities a patient tries to do.

B. Life log system

Over the years, many researchers have tried to estimate daily life human activities, such as walking and sitting up and down from acceleration and/or gyro sensor data obtained from wearable devices and/or smartphones. In this paper, we refer to the research done respectively by Khan et al. and Wang et al. [10] [11]. Only a few motions were given in this research; distinctions among activities were not recognized. In contrast, Debraj et al. tried to recognize 19 daily living activities [12]. They collected environment information, such as that for temperature and location in addition to activity information. They used GPS and BLE beacons to identify places. However, they did not consider the Barthel Index or other indices and consequently their target activities did not correspond to activities in the index of function recovery levels.

C. Healthcare cloud serveice

Zhang al. developed a cyber-physical system for patient-centric healthcare applications and services. They called it Health-CPS. It was built on cloud and big data analytics technologies [13]. It consisted of a data collection layer, a data management layer and an application service layer to collect and follow up on many kinds of big data. It used a security tag to maintain security.

Doukas et al. proposed a mobile system that enables electronic healthcare data storage, update and retrieval using cloud computing [14]. A mobile application was developed using Google's Android OS and Amazon's S3 to provide management of patient health records and medical images.

We developed a cloud service whose collecting function for medical data is basically the same as that for the above systems. However, our system is specialized so that it can collect activity and place information to functionally evaluate recovery levels that correspond to existing evaluation methods, such as the Barthel Index. In this paper, we show how we implemented the system with SONY Smart Watch 3 [15] as the sensor node, as well as Android smartphone, BLE beacon, and Google Firebase.

III. System design concept

We designed the proposed system so that it could not only evaluate ADL for a patient, but also develop algorithms for detecting whether a patient can do a designated activity. The system collects and stores sensor data and video data synchronously and allows appropriate persons to access stored data. We designed the system while taking the following issues into consideration:

1) Suppressing battery consumption for wearable sensor devices and smartphones
2) Suppressing recorded data and collecting necessary data
3) Maintaining security.

Google Firebase service provides many functions, including authentication and real-time database functions, to enable systems to be managed effectively, such as through the means of allowing access to authorized persons. Since any organization can independently implement Firebase applications, it becomes possible to maintain high level security. This is why we implemented our data collecting system on Google Firebase.

The image of a data collecting system that collects data about the motions that a patient performs daily is shown in Figure 1. The system we propose consists of sensor devices, a sensor relay unit (smartphone), BLE beacons and Google Firebase. A smartphone is used as the sensor relay unit that controls sensor devices and temporally stores and forwards measured data to the Firebase.

BLE beacons are placed in various locations: under a dining table, on top of a toilet, in a bathroom, in a bedroom, in a closet. When the smartphone receives a BLE beacon signal level that exceeds the threshold level, it sends a message to sensor devices to start measuring data. And when the smartphone receives a receiving signal level lower than the threshold level, it sends a message to sensor devices telling them to stop measuring data. Sensor devices and smartphones are managed by the Realtime Database. Security is maintained by enabling only authorized persons using the system, including patient, readers, such as medical doctor and installation personnel, such as nurse are also managed by the Realtime Database is used to maintain security. In this system, measured data are downloaded for pre-registered persons from the web server.

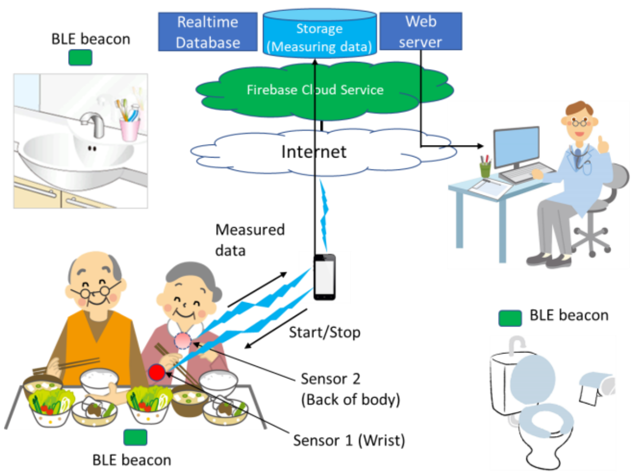

Figure 1. Image of the data collecting system for patient's daily life motions.

IV. SYSTEM IMPLEMENTATION

We developed a PatientApp program that works on the sensor relay unit and a DataCollectionServer program that works on Firebase. The PatientApp manages sensor devices, gets measured data from sensor devices and uploads the data file to the DataCollectionServer.

A. *PatientApp*

This time, we developed a PatientApp program based on the Android Framework. With this program, a developer must first access the Firebase and download a configuration file. An Android application package file (Apk File) is then made as a building application and is connected to Firebase. This makes it possible to securely download the Apk File for each organization.

Before starting to measure sensor data and/or video data, it is necessary to enter a patient's name, bind a sensor with a body part, bind a BLE beacon with a place of activity and select a video recording on/off function. Therefore, we designed a transition diagram of UI pages as shown in Figure 2. There were three alternatives for a user name at the login; the patient's name, the medical worker's name with measuring devices set up, and the medical professional's name with measured data analyzed. For the latter two cases, a patient's name must be entered after the login. Therefore, we decided on the first one, login with a patient's name.

After login, a "List of setting up" page is presented. An example of this page is shown in Figure 3. With it, a user can confirm a state of setting. When the "Change" button is clicked, the page will change to the "Sensor" page to bind a sensor with a body part. When the "Next" button is clicked, the page will change to the "Beacon" page to bind a BLE beacon with a place in activity. When the "Next" button is clicked, the page will change to the "Video" page to select video ON/OFF. When the "Next" button is clicked, the page will change to the "List of setting up" page. When the "Next" button is clicked in the "List of setting up" page, the page will change to the "Measuring" page. When the "Start" button on this page is clicked, the PatientApp sends a message to the sensor messages to start measuring, and the "Start" button changes to the "Stop" button. When the "Stop" button is clicked, the PatientApp sends a message to the sensor messages to stop measuring, and the "Stop" button changes to the "Start" button. When the "End" button is clicked, the PatientApp finishes.

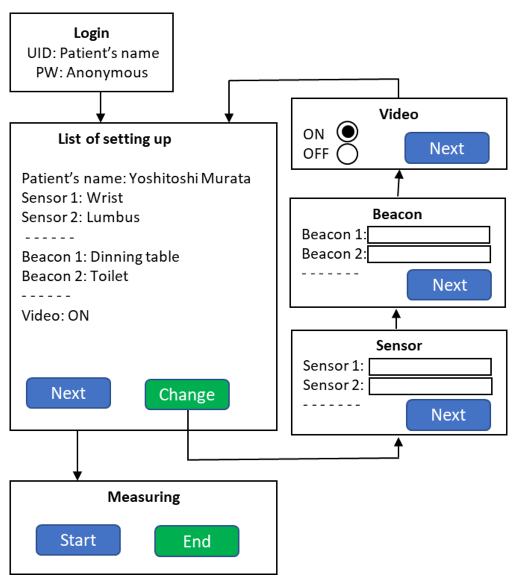

Figure 2. Transitions of UI pages in the PatientApp.

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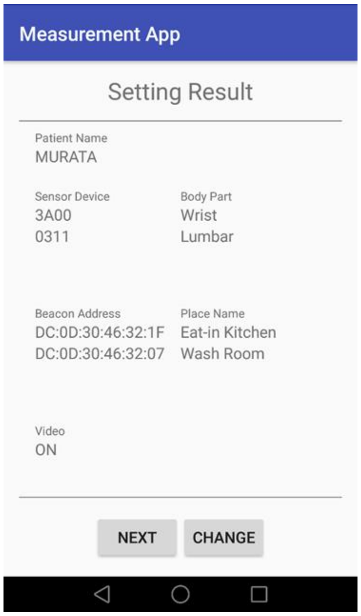

Figure 3. Example of setting up page list.

When a sensor receives a BLE beacon signal, it starts measuring, and, when a sensor loses a BLE beacon signal, it stops measuring. After clicking the "Stop" button, measured data are changed to a measured data file. Its file name is "Patient name_place_body part_timestamp" to recognize its properties. The file is uploaded to the storage in Firebase.

We developed the following six packages of classes to achieve the above proceedings:

- Beacon: receiving beacon signals and handing their information to other classes.
- Mobile2wear: controlling a sensor device and receiving measured data.
- Camera: managing a video camera.
- Firebase: converting measured data and transferring the data to the Firebase storage.
- View: managing transition of pages
- Viewmodel: listening events on buttons or input boxes and handing, such information to other classes.

B. *DataCollectionServer*

The DataCollectionServer has the following functions:

- Data upload function: The sensor relay unit temporally stores measured data and forwards them to the server.
- Data download function: Authorized persons, such as medical doctors can access the DataCollectionServer and download measured data files securely.

It consists of the Storage and WebSite. The WebSite collaborates with the Storage and provides a file download function to a medical professional through the Web browser.

In this subsection, we mainly introduce how to upload and download measured data file.

1) Data upload function (Figure 4)

After a measured file has been made, the PatientApp uploads the file to the storage server in Firebase as shown in Figure 4. The storage server generates the file download URL, which is managed in the Realtime Database.

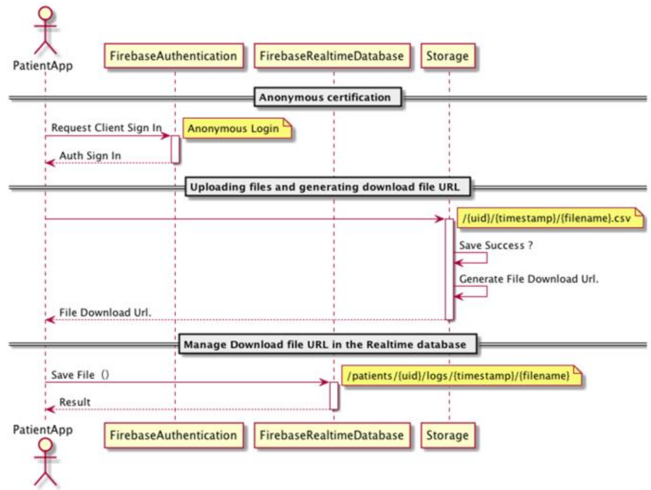

Figure 4. Sequence flow to upload measured files.

2) Measured data download function (Figure 5)

Supervisors input the access account of medical professionals from the management page in Firebase. The sequence flow with which medical professionals download their patients' files is shown in Figure 5. When medical professionals access the Website, they log in with their assigned ID and password on the page of Figure 6 (a).

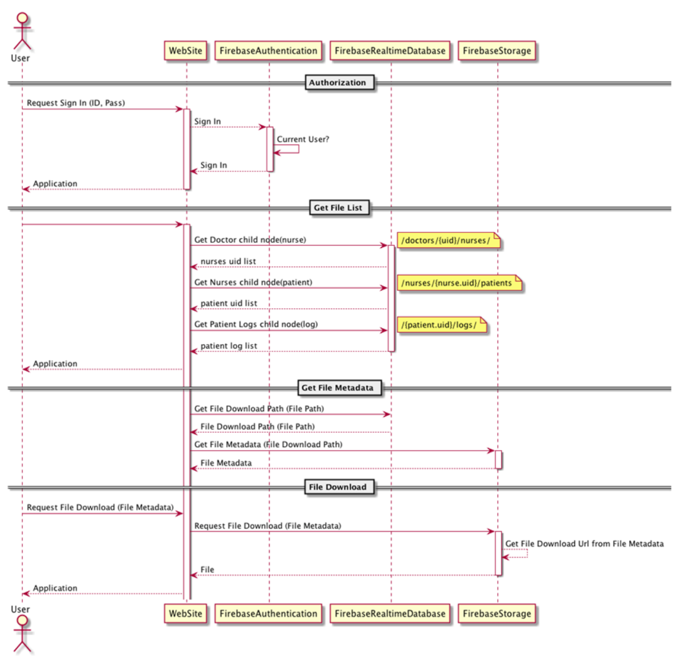

Figure 5. Sequence flow to download measured files.

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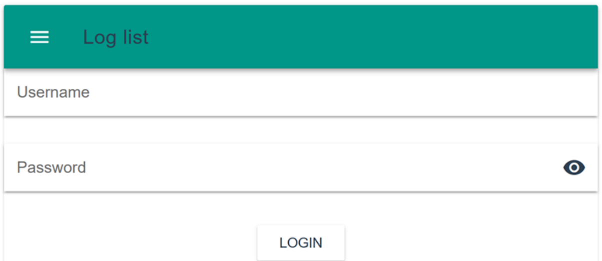
After login, the Website application accesses the Realtime Database to get information related to nurses and patients. The Website application also gets meta-data such as an access path to a stored file. When a medical professional clicks a file on the page of Figure 6 (b), the Website application accesses the indicated file on the Storage through the access path. Finally, the indicated file is downloaded.



(a) Login page

(2) File list page

Figure 6. WebSite user interface.

V. EXAMPLES OF MEASURED DATA IN DAILY LIVING

We measured motions of eating lunch and brushing teeth to text whether the developed system can measure well. A “normal” participant usually performed these actions first, followed by a person who was paralyzed in the right hand. In this experiment, wrist and lumbar region motions were measured with a 3D-gyro sensor. We used two SONY Smart Watch 3 units as the 3-D gyro sensor [15]. One was attached to the wrist with a wrist band and the other was attached to the lumbar region with a lumbago band as shown in Figure 7.

Figure 8 shows a picture and measured data for eating a curry rice dish with a spoon. In this figure, (a) is a picture of a participant eating freely and (b) shows a participant fixing and twisting his arm. The (c) and (d) depictions are graphs of the measured angle data for (a) and (b). When the participant played the role of a patient, his upper body always leaned forward and while eating he moved his arm less than when he usually did while eating. Such differences are presented in red square frames in (c) and (d). These data show that a participant eats food by himself. However, from these data it is impossible to judge whether a participant is able to eat food by himself without help. On the other hand, the data shows how their joints move.

Figure 9 shows angle data measured during the tooth-brushing activity. The right arm was fixed and twisted, and a wearable device was fixed on the right wrist. Since the participant brushed his teeth with his left hand, his right arm did not move except when he was sticking toothpaste on the brush and putting the toothpaste on a wash stand. These data show that a participant brushes his teeth by himself, but do not show whether the participant brushes his teeth without help from others.

A medical doctor and physiotherapists plan to measure motions for real patients, and introduce their results.

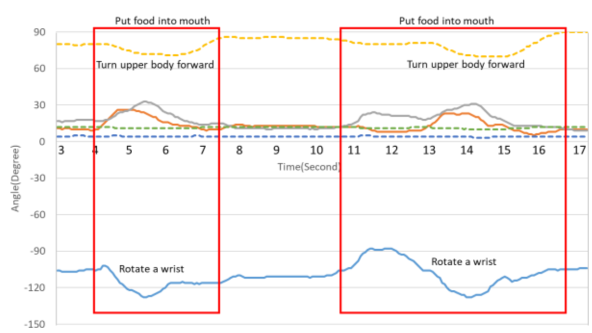
We believe that the obtained results enable us to determine whether with the proposed system we can judge whether a patient can do activities on the basis of Barthel Index or Katz Index judgments. However, it is impossible to judge whether a patient can do activities with or without help. On the other hand, they make it possible to ascertain how affected joints move remotely.

We believe that the results we have obtained will make it possible for us to make a new method to evaluate ADL on the basis of measured angle data rather than on Barthel Index FIM and Katz Index results.

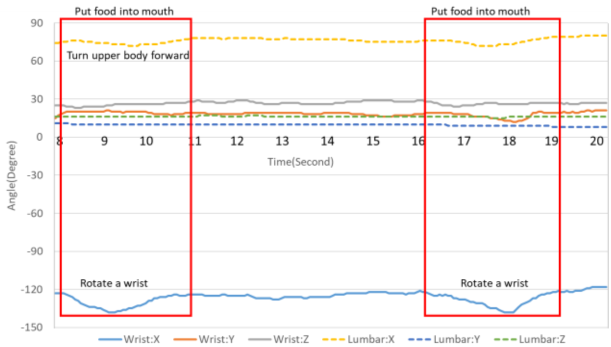
Figure 7. Participant wearing two SONY Smart Watch 3 sets.

(a) Eating with free arm.

(b) Eating with fixed and twisted arm.



(c) Angle of wrist and lumbar for free arm.



(d) Angle of wrist and lumbar for fixed and twisted arm.

Figure 8. Measured data for the wrist and lumbar region in eating a curry rice dish with a spoon.

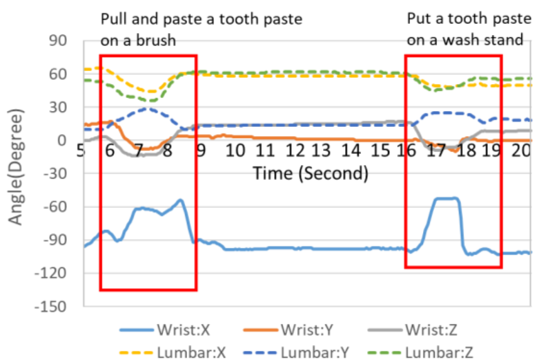


Figure 9. Measured data for the wrist and lumbar region in tooth-brushing.

VI. CONCLUSION AND FUTURE WORK

Existing evaluation indexes for activities in daily living (ADL) recovery levels such as the Barthel index are based on questionnaires. Therefore, the judging of recovery levels can be easily affected by an evaluator's subject. We proposed a system that is able to collect and store motion data about daily life activities to quantitatively evaluate ADL recovery levels. The system was developed on the basis of the Google Firebase. We used information about places such as a dining table, a bathroom to estimate activities. The BLE beacon was adopted for detecting places in this system. Measurement results obtained for a simulated patient demonstrated that it is possible to judge which ADL a patient can or cannot do. However, it is difficult to estimate whether a patient can do them with or without help.

A medical doctor and physiotherapists plan to measure motions of real patients using this system, and introduce their results.

The system we have developed does not correspond to GPS. The next version we plan to develop will correspond to it to measure motion during walking or running.

Our goal is to develop a new index for evaluating ADL recovery levels on the basis of motion data measured for persons performing ADL.

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