Novel Field Oriented Patient Monitoring Platform for Healthcare Facilities

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***Abstract*— Several kinds of patient monitoring systems have been provided to healthcare facilities such as hospitals in recent years. Most of these systems lack interoperability and are designed for sensors to be connectable within the same medical manufacturer. In these systems, monitoring devices and terminals are connected to a network, and operations are performed on a central console. This means that an operator is needed to do the job, which is not suitable for realistic healthcare fields. To address these problems, we have developed and propose a novel patient monitoring platform for healthcare facilities. This platform consists of a notification system for event monitoring applications and a data collecting system for data measuring applications. In the notification system, pairing between a patient monitoring device and a mobile terminal carried by a medical person can be completed merely by reading a Quick Response Code on the display of a monitoring terminal at a patient's bedside. When the monitoring device detects that a patient is having trouble, it sends event messages to the mobile terminal. In the data collecting system, medical data files measured by sensor devices are automatically uploaded to a cloud server and downloaded from the server to an authorized medical professional.**

Keywords-hospital; patient monitoring system; remote measuring system; patient-nurse hotline; QR-code; healthcare facility.

I. INTRODUCTION

We are developing patient monitoring systems [1]. Several kinds of communication systems have been provided to medical or healthcare facilities in recent years. They are roughly classified into call systems and patient monitoring systems. The latter are roughly classified into event monitoring systems and data measuring systems, which are sometimes integrated as a comprehensive network system.

In event monitoring applications, notifications that a patient is having problems are usually sent to a nurse station or management office rather than to a specified medical person in Japan. Therefore, the nurse station or office is likely to be very busy quite frequently. An example of the types of systems used in Japan is the patient-nurse hotline system provided by Carecom Inc. [2]. In this system, several kinds of sensor devices are connected to the hotline. One such device is a mat sensor to detect a patient leaving his/her bed [3]. The mat is beside the bed, and if a patient steps on it, an alert is sent to a nurse station.

Honeywell provides a tracking and localization system integrated with a patient communication system and a call system [4]. General Electric Company (GE) provides many kinds of patient monitoring equipment [5]. They are connected to a central computer server through a hospital intranet. This makes it possible for medical professionals to monitor measured data.

Most of these systems lack interoperability and are designed for sensors to be connectable within the same medical manufacturer. In these systems, monitoring devices and terminals are connected to a network, and operations are performed on a central console. This means that an operator is needed to do the job, which is not suitable for realistic healthcare fields.

To address the problems of the lack of interoperability, necessary of an operator and busy nurse stations or offices, we developed a patient monitoring platform designed for healthcare fields. This platform consists of a notification system for event monitoring applications and a data collecting system for data measuring applications.

We first proposed the notification system at eTELEMED 2018 [1]. In this system, the monitoring device by the patient's bedside is connected to a mobile terminal such as a smartphone carried by a medical worker. The mobile terminal reads a Quick Response Code (QR-code) [6] on the monitoring device to pair them. This operation can be done at the bedside of a patient. We assume that it would be done by a medical worker such as a nurse who establishes a monitoring device for the patient. When the monitoring device detects the patient is having trouble, it sends a notification message to the mobile terminal. The medical worker who receives the message immediately goes to the monitored patient. The sensor relay unit and the mobile terminal were developed with an Android smartphone. The sensor relay unit is a part of the monitoring device to which sensors are connected. This makes it possible to hand the patient monitoring operation to another worker merely by having the latter read the QR-code on their smartphone. This operation is the same as reading the original QR-code.

In addition to the notification system, we also developed a novel data collecting system for measuring applications. In this system, measured data are transferred to a cloud server and stored on it. Authorized persons such as medical professionals can access the server to download and analyze the stored data. A supervisor can freely change the relationship established among patients, medical workers who provide measuring terminals and medical professionals who have access to servers.

We developed two event monitoring applications that use the proposed notification system and one data measuring application that uses the data collecting system. The first one monitors cases when intravenous feeding devices are removed from a patient, the second one monitors cases when the patient leaves the bed, and the third one continuously measures changes in the angle of the arm and the lumbar region of the body.

After introducing related work in Section II, we describe the notification system and its example applications in Section III. The data collecting system and example applications for it are detailed in Section IV. Section V concludes with a summary of key points.

II. Related Work

Remote monitoring applications for patients are roughly classified into event monitoring applications and measuring applications. In this section, both of them are introduced.

A. *Event monitoring applications*

These applications have been put to use ever since communication systems for sending messages from monitoring devices to hospital personnel first started to be used.

One example is the "Risho Catch" system Paramount Bed Inc. has developed [7]. "Risho" means getting out of a bed in Japanese. This system detects when a patient sits up in bed, sits on the side of the bed, or leaves the bed. When this happens, it sends a message to a nurse station through a patient-nurse hotline system. The system structure is shown in Fig. 1. A load sensor unit in the bed is connected to the patient-nurse hotline system through a relay unit located at the patient's bedside. The nurse station has a monitor and console terminal. It is possible to send messages to a mobile terminal. However, wireless tablets and smartphones are not commonly used for sending messages to nurse stations in Japan. Therefore, nurse stations and offices are likely to often become very busy.

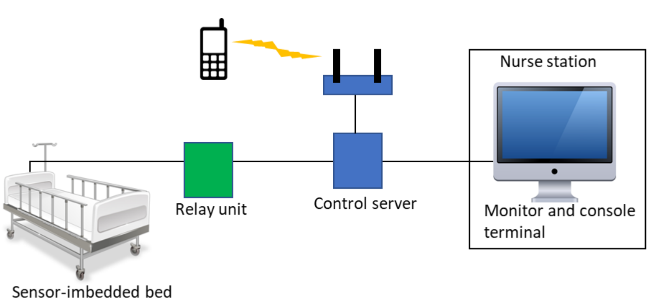


Figure 1. System and network structure of "Risho Catch."

Balaguera et al. evaluated decreasing the number of falls from bed using the SensableCare System [8]. Its architecture is shown in Fig. 2. The sensor pad in the system sends data through a cable to the control box located at the patient's bedside. The control box wirelessly transmits this data to a Bluetooth access point located throughout the ward. This information then travels through the hospital WiFi network to the dashboard and docking server where the data is analyzed. When an alert is sent to the nurse via an application on his/her mobile terminal, it is wirelessly transmitted through the hospital WiFi network. The patient's condition is monitored on the dashboard terminal.

In both systems, the console terminal in the nurse station or office must connect sensor units with a mobile terminal. This makes it a little hard to change relationship between a mobile terminal and monitoring patients.

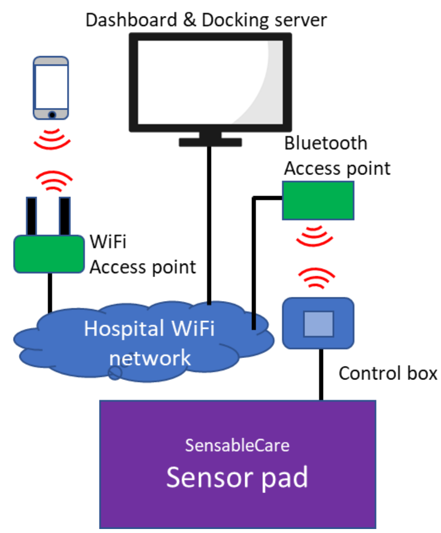


Figure 2. Architecture of the SensableCare System.

B. *Measuring applications*

In the early 2000s, there were several remote measuring systems for patients that used the General Packet Radio Service/Wireless Local Area Network (GPRS/WLAN) as the wireless network and the Personal Digital Assistance (PDA) as the mobile device [9-12]. In these systems, sensor devices were connected to a monitoring terminal or server through a wireless network. Since they were experimental systems, they had no fixed destination address.

In recent years, several companies have been providing not only patient remote monitoring devices but also cloud services. GE provides a "GE Health Cloud" system along with many kinds of sensor devices and monitor devices [13]. The cloud manages the connecting of sensor devices to the hospital network and operates them on the console terminal.

This scheme maintains a high security level but lacks flexibility and interoperability. This makes it difficult for medical workers to install and pair sensor devices at the patient's bedside, especially other company's devices.

III. Notification System

In this section, we describe the novel notification system for event monitoring applications.

A. Design concept

We designed the system so that:

(1) Medical personnel can install monitoring devices.

(2) Medical personnel can easily pair the monitoring devices with their own mobile terminals at the patient's bedside.

(3) When the monitoring device detects a patient is having problems, it sends notification messages to the mobile terminals of the medical personnel, not a nurse station.

(4) Pairing situations can be monitored from a console terminal.

(5) Event messages are monitored from a console terminal.

(6) Mobile terminals belonging to other organizations must be excluded.

Therefore, no operations are performed with the console terminal and monitoring devices can be easily installed at the patient's bedside. The other side, the supervisor such as a medical doctor in charge, can monitor pairing situations and event messages to maintain security and safety. The system configuration is shown in Fig. 3. In this figure, Worker A monitors a patient Mr. P at first and hands off the monitoring job to Worker B later. There is no alarms in a nurse station.

The system consists of three programs; one works on the sensor relay unit to which sensor units are connected, the second one works on mobile terminals to receive event messages and present them, and the third one works on the cloud server to relay event messages from the sensor relay unit to the mobile terminals.

Prior to monitoring a patient, each terminal must register with the cloud server and get an ID from it. Here, we call the ID for the sensor relay unit "SR-ID", that for Worker A's mobile terminal "MA-ID", and that for Worker B's mobile terminal "MB-ID." When one of the two mobile terminals establishes pairing with the sensor relay unit, it must send SR-ID together with its own ID (MA-ID or MB-ID). A QR-code is generated on the sensor relay unit from SR-ID and presented on its display. Since the QR-code encodes text data to codes and encodes code to text data, using the QR-code enables a worker to enter SR-ID easily. If Worker A pairs his/her mobile terminal with the sensor relay unit, he/she merely reads the QR-code on the sensor relay unit's display with his/her mobile terminal to input SR-ID.

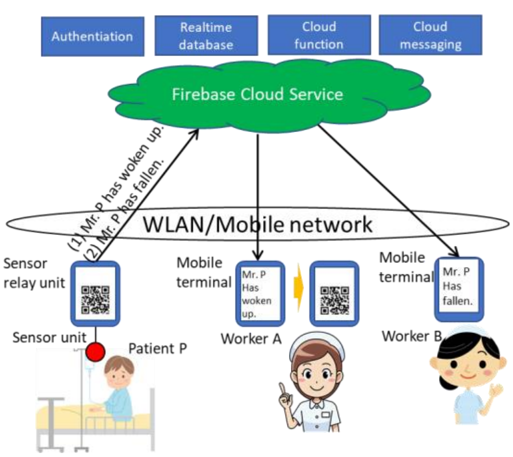


Figure 3. Configuration of the notification system.

The mobile terminal sends its own ID (MA-ID) and the read ID (SR-ID) to the cloud server. The cloud server uses SR-ID and MA-ID to pair the sensor relay unit and Worker A's mobile terminal.

In the case shown in Fig. 3, the sensor unit detects the event "waking up in bed" and the sensor relay unit sends the message "Mr. P has woken up" to Worker A's mobile terminal via the cloud server.

This system using a QR-code is useful for handing monitoring work over to another worker. The handing over operation is done by a worker (Worker B in Fig. 3) reading a QR-code on his/her mobile terminal. This QR-code is created from the SR-ID read from the sensor relay unit. In this situation, event messages can be sent to both mobile terminals. However, no messages will be sent to Worker A's mobile terminal if Worker A sends the signal to release his/her pairing with the cloud server. In the case shown in Fig. 3, the second message "Mr. P has fallen." was sent to Worker B.

B. System configuration

Authentication and messaging functions are needed to meet the requirements listed at the beginning of subsection A. Hence, we decided to use the Google Firebase Cloud Service (GFB) [14] to implement the notification system. The GFB has many functions; the ones we use are an authentication function to exclude non-registered terminals, a real-time database to manage and monitor the status of pairings and event messages, and a push messaging function to send notifications. As mentioned above, our system consists of three programs. These programs we developed are "PatientApp", which works on the sensor relay unit, "NurseApp", which works on the mobile terminals, and "MessageManager", which works on the GFB. We use an Android smartphone for the sensor relay unit and the mobile terminals. We designed PatientApp and NurseApp from a simple application and a corresponding library program so that a practical event monitoring system that adopts kinds of sensors could be developed easily

The MessageManager program works with the Authentication, Realtime Database, Cloud Function, and Cloud Messaging tools in Firebase. These tools can be summarized as follows:

- Authentication: This provides backend libraries to authenticate users for developing applications. It supports authentication by using passwords, phone numbers, and popular federated identity providers such as Google, Facebook, and Twitter.
- Realtime Database: This is a cloud-hosted database. It stores data in JSON format and synchronizes it in real time to every connected client.
- Cloud Function: This automatically runs backend codes in response to events triggered by Firebase features and HTTPS requests. It stores backend codes in Google's cloud and runs in a managed environment.
- Cloud Messaging: This is a cross-platform messaging solution that delivers messages reliably. It can send notification messages to drive user re-engagement and retention.

We introduce sequence flows between these tools when building and registering a PatientApp or NurseApp program, pairing between PatientApp and NurseApp, and sending notifications. We use the Open Source QR Code Library [15] to create a QR code in the sensor relay unit and the mobile terminals. In the following sequence flows, the program is described as "QR maker."

1) Building PatientApp and NurseApp (Fig.4)

Before developing a Firebase application, a developer accesses Firebase to download a configuration file. Firebase sends back a configuration file that includes the project code and software development kit as a Google-Service.json file to a development PC.

After building an application, an Android application package file (Apk File) is made as a building application. Each application connects to Firebase with a Project ID and Application ID. These IDs are included in the Google-Service.json file in the building process.

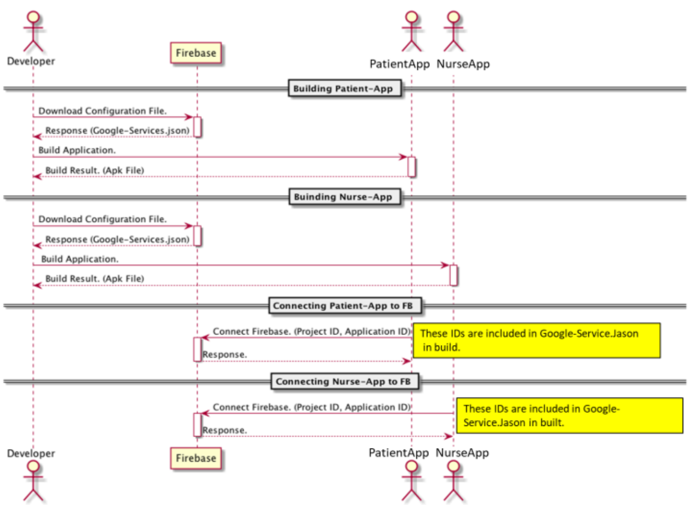


Figure 4. Sequence flow to build applications.

2) Registering PatientApp and NurseApp (Fig. 5, 6)

Since mobile terminals are commonly used by multiple medical workers, a proper login procedure is needed to identify the current worker. We currently use the Google account certification for the NurseApp program to register a medical worker with Firebase. It is possible to change from the Google ID to another identification code. The NurseApp program works with the MessageManager program, which assigns the authentication procedure to the Authentication in Firebase. Then, an account (Nurse UID) is created and managed in the Realtime Database as shown in Fig. 5. The Nurse UID corresponds to the MA-ID or MB-ID given in subsection A.

Since the sensor relay unit itself is registered with MessageManager, we use the Anonymous certification in this case. An account for the PatientApp (Patient UID) is automatically created and managed in the Realtime Database as shown in Fig. 6. The Patient UID corresponds to the SR-ID given in subsection A.

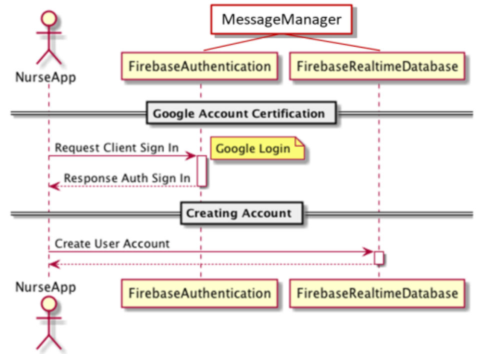


Figure 5. Sequence flow to register a mobile terminal.

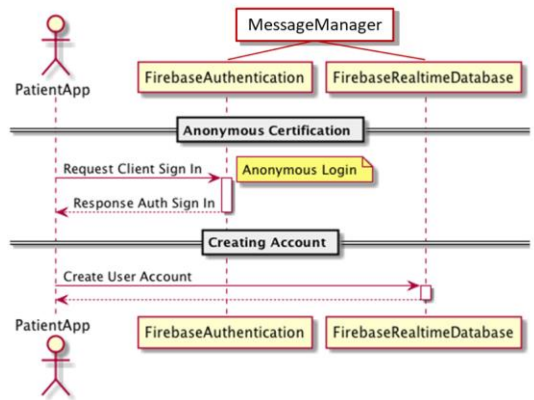


Figure 6. Sequence flow to register a sensor relay unit.

3) Pairing between PatientApp and NurseApp (Fig. 7)

The PatientApp accesses the Authentication to get its own current user (Patient UID, token) and the QR maker makes a QR-code from a Patient UID. NurseApp gets a Patient UID to read the QR code, accesses the Authentication to get its own current user (Nurse UID, token), and accesses the Realtime Database to write the pairing information (token, Patient UID, Nurse UID).

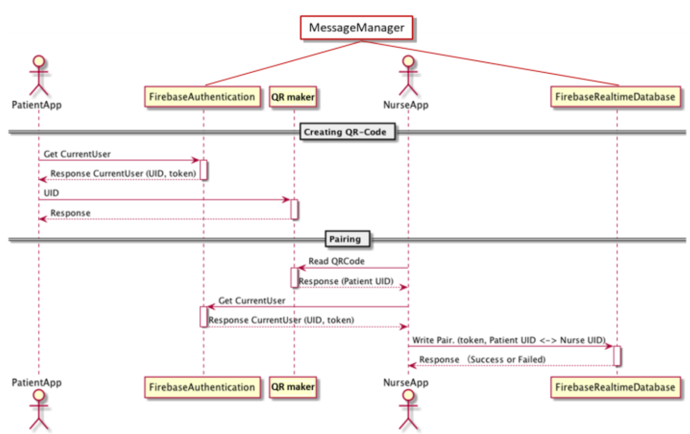


Figure.7 Sequence flow to pair between PatientApp and NurseApp.

4) Sending notifications (Fig. 8)

When a PatientApp in the sensor relay unit detects an event, it accesses the Authentication to get its own current user (Patient UID, token) and the Realtime Database to change its own state.

The Realtime Database collaborates with the Cloud Function to request the Cloud Messaging to push a notification (Nurse push token). The Cloud Messaging sends a signal (Notify Patient State Change) to a NurseApp as shown in Fig. 8.

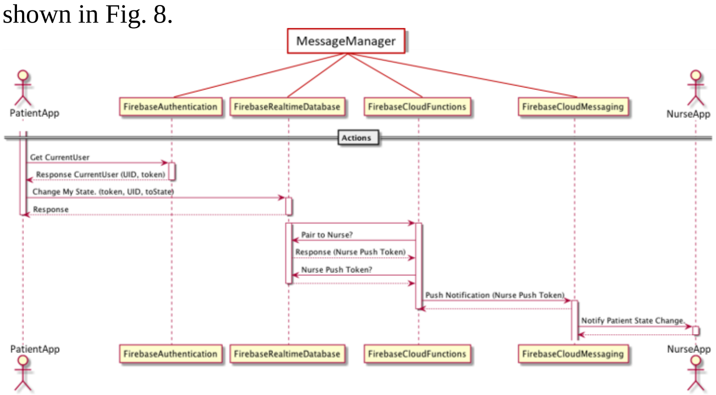


Figure 8. Sequence flow to send an event message.

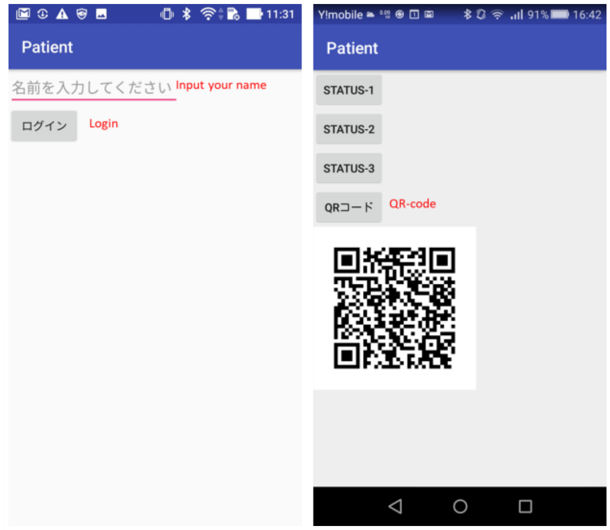
C. *Test application and management display*

We developed a very simple PatientApp and NurseApp to test the proposed notification function. We call them PatientTest and NurseTest. Since these application programs were developed for Japanese, each item on UI pages was written in Japanese. Hence, we provided an English translation for each item.

After logging in with the Anonymous certification of PatientTest, the four buttons "STATUS-1", "STATUS-2," "STATUS-3," and "QR-code" are presented as shown in Fig. 9. The first three buttons are used to change the status in a sensor device. Clicking the "QR-code" button creates a QR-code from a Patient UID and shows it on the display (Fig. 9 (b)).

After the Gmail address and password are input to the NurseTest login page (Fig. 10 (a)) and the PatientTest QR-code (Fig. 9 (b)) is read, the list page of patients (Fig. 10 (b)) is presented. In the case shown in Fig. 10 (b), the nurse has established two sensor relay units and is monitoring two patients. Patient "Murata test" is having trouble. Clicking the "Messages" button, a list of received messages is presented as shown in Fig. 10 (c). When the "Handing" button is clicked, the same QR-code as that shown in Fig. 9 (b) is presented. Messages and the relationship between sensor devices and monitoring nurses are managed in the Realtime Database. Supervisors are able to monitor them by accessing Firebase.

When Firebase is accessed, and the Realtime Database is clicked, the display appears as shown in Fig. 11. Information is classified into "notifications," "nurses" and "patients."



(a) Login page (b) Change status page

Figure 9. PatientTest display..

(a) Login page (b) List page of patients

(c) List page of messages

Figure 10. NurseTest display.

In Fig. 11 (a), the notifications are classified into those for two nurses whose encrypted Nurse UIDs are "4ANVMkv1kDarruVlt8l1opmAYj13" and "IQBt78Xrg4c-60auc195lhkG8nJl2."

When the + former of a Nurse UID is clicked, the + changes to – and notification message IDs are listed as shown the upper part of Fig. 11 (b). When the + former of a notification message ID such as "L8WQVLzi3Vc989MUK-fs" is clicked, the + changes to – and the contents of the notification are listed. The line "created_at" shows the coordinated universal time in Java that the notification has been sent, "instance_id" is the encrypted Patient UID, "message" is a practical message for which the meaning is "Drip system for Murata has left," and "title" is the patient's name. The "message" and "title" lines are changed for each application.

When the + changes to – and former of a nurse UID is clicked, the + changes to – and the patient UIDs and tokens are listed as shown in the middle part of Fig. 11 (a). This tells us which sensor device each nurse has established.

When the + former of a patient UID is clicked, the + changes to – and the lines "name", "nurses" and "state" appear as shown in the lower part of Fig. 11 (a). The "name" line shows the patient's name in this application. The line "nurses" shows the nurses who have read the QR-code with their mobile terminal. In this case, two nurses whose encrypted UIDs are "4ANVMkv1kDarru-Vlt8l1opmAYj13" and "IQBt78Xrg4c60auc195lhkG-8nJl2" monitor two sets of sensor devices "csYUUM90CF0" and "dhwYz4dyGLw."

(a)

(b)

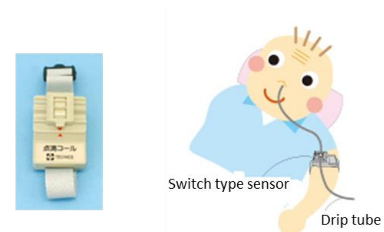
Figure 11. Examples of monitoring display.

D. *Example application*

We developed two monitoring applications that adopt the proposed notification system. One is an intravenous drip monitoring application; the other is a fall monitoring application. We describe their details in this section.

1) *Intravenous drip monitoring*

Some cognitive impairment patients sometimes remove an intravenous drip set by themselves. One existing intravenous drip monitoring system "Tenteki call" uses a switch type sensor that fastens a drip tube to detect when a drip set is removed as shown in Fig. 12 [16]. In case of a "Tenteki call", if a patient removes the switch type sensor together with the drip set, the sensor cannot detect the removal.



(a) Switch type sensor. (b) Example of use.

Figure 12. "Tenteki" call (Japanese), Technos Japan Co., Ltd.

We use a magnetic patch and a wireless magnetic sensor to detect removing a drip set, as shown in Fig. 13. The magnet is fastened to the body with an adhesive film in a place such as an arm. An intravenous drip tube is also fastened to the wireless magnetic sensor and the sensor is fastened to a magnetic patch with a medical fixing film. When a patient removes an intravenous drip set, the sensor is also removed from the body part. However, since the magnetic patch is fastened to the body part with an adhesive film, it must remain on the body part.

We developed the prototype system shown in Fig. 14. We used the STEVAL-WESU1 [17] developed by STMicroelectronics as the wireless magnetic sensor (see Fig. 14 (a)), and an Android smartphone as the wireless relay unit and mobile terminal. The muscle stiffness obtained by equipment manufactured by PIP Co., Ltd. [18] was used as the magnetic patch (see Fig. 14(b)). In this prototype system, the program for detecting removal is integrated with the wireless relay program.

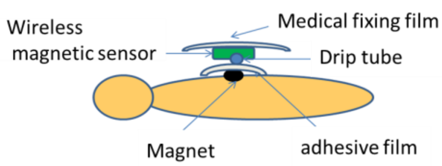


Figure 13. Structure of the magnetic intravenous drip monitoring

(a) Magnetic sensor and attached tube.

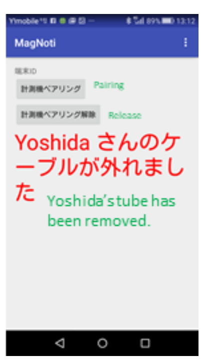
(b) Magnetic patch on an arm.

(c) Magnetic sensor on a magnetic patch.

(d) A removed drip set.

(e) W. R. display :monitoring

(f) W. R. display : detecting a tube removed



(g) M. T. display : receiving a message

Figure 14. Drip monitoring system prototype.

While a magnetic sensor is on a magnetic patch (see Fig. 14 (c)), the measured magnetic strength is bigger than the decision level (see Fig. 14 (e)). When the magnetic sensor is removed (see Fig. 14 (d)), the measured magnetic strength is less than the decision level; the detecting program has determined that an intravenous drip set has been removed (see Fig. 14 (f)). The wireless relay program sends a message "Yoshida's tube has been removed." That message is displayed on the mobile terminal (see Fig. 14 (g)).

1) Fall monitoring

Elderly people, especially cognitive impairment patients, have an increased risk of falling and consequently injuring themselves. They need to be prevented from falling to maintain their health because injuries from falling are a major reason for them to prolong their staying in a hospital.

Therefore, many kinds of fall prevention systems have been developed. Most of them are classified into three schemes. The first type uses a mat type sensor like the systems described in Section II, the second one uses load sensors that are mounted in the legs of a bed, and the third one uses a camera. We developed a fall prevention system in which MS-KINECT was used. This is one of the third types. M. J. Rantz developed a fall detection system that uses MS-KINECT [19]. A medical worker monitors and judges whether a patient falls through the depth image of a patient on a monitor display.

On the other hand, our developed system detects whether a patient in a bed wakes up, sits up, stands up, or falls on the floor with a skeleton image of the patient. The detecting algorithms are as follows;

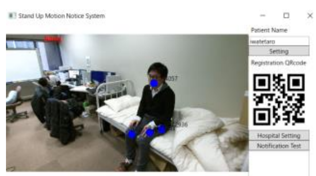
(1) Waking up: detecting that the head's height position is higher than the judging height 1.
(2) Sitting up: detecting both shoulders and a spine base angle of 25 or more degrees.
(3) Standing up: detecting the head, both shoulders and both hips, and a head is higher than the judging height 2.
(4) Falling down: detecting that the head's height position is lower than the judging height 3.

We experimentally tested whether the developed system can detect the four conditions given above. The MS KINECT was positioned diagonally in front of the bed so that the front of the patient could be observed as shown in Fig. 15. Experimental results are shown in Fig. 16. Since MS-KINECT works on a PC, the sensor device program that detects patient conditions with MS-KINECT and the wireless relay unit program are combined on a PC. Monitoring images of participants as patients and the QR-code for pairing are shown on the PC display.

The developed system can detect four conditions for a patient. With it, a mobile terminal receives a "standing up" message sent from a wireless relay unit. However, the system sometimes fails to detect conditions or does not detect them correctly. Accordingly, we plan to improve our algorithms so that detection accuracy will be increased. We should also mention that a patient using this experimental system is presented with color images. We plan to change these color images to depth images to maintain a patient's privacy.

Figure 15. Experimental image.

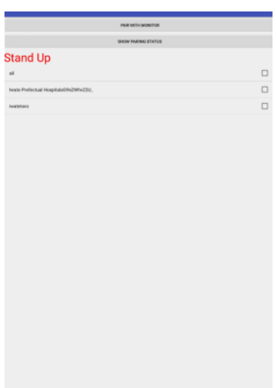
(1) Waking up



(2) Sitting up

(3) Standing up

(4) Falling down



(5) Screenshot of a mobile terminal that detects a "standing up" message

Figure 16. Experimental results for patient monitoring.

IV. DATA COLLECTING SYSTEM

In this section, we describe the data collecting system for data measuring applications.

A. *Design concept*

We designed the system so that:

(1) A medical person could easily install a measuring device at a bedside.
(2) Measured data were stored for each patient and the corresponding medical professional in the cloud server.
(3) A medical professional can access only authorized data.
(4) A supervisor can easily change the relationship among patients, nurses who install measuring devices and medical professionals who analyze data through remote terminals.

Therefore, no operations are performed with the console terminal and measuring devices can be easily installed at the patient's bedside. The other side, the medical professional such as a medical doctor in charge, can download measured data files to keep security and safety.

The system configuration is shown in Fig. 17. Before starting to use the system, the supervisor inputs login data that comprises the UID and password for a medical professional. Measured data are stored as files in the sensor relay unit at first. The files are classified for each patient on the accessed web page. When medical professionals access the given URL and login data with their recorded UID and password, a specified page for each medical professional is presented. The medical professional clicks the file and analyzes it.

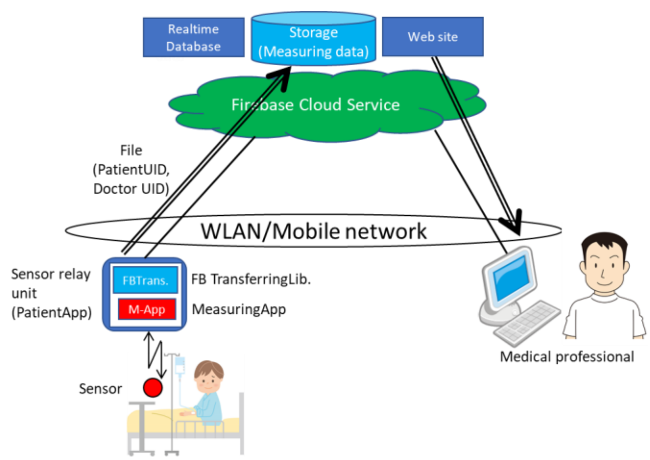


Figure 17. Configuration of the data collecting system.

B. *System configuration*

The data collecting system, also designed on Firebase, contains the following functions:

(1) Measured data upload function: The sensor relay unit measures medical data using sensors and uploads the data to Firebase as files.
(2) Measured data download function: A medical professional accesses Firebase and downloads medical data files.

We developed a PatientApp program that works on the sensor relay unit and a WebSite program that works on Firebase to provide these functions. The PatientApp uploads the measured data file to the Storage on Firebase. The WebSite collaborates with the Storage and provides a file download function to a medical professional through the Web browser. In this subsection, we introduce sequence flows that provide these functions.

1) Measured data upload function (Fig. 18)

PatientApp consists of "MeasuringApp" and "FB TransferringLib" programs. The MeasuringApp program provides the User interface needed to login, enter information, measure medical data and create a file. The FB Transferring Lib. Program uploads the file to the Storage in GFB.

Before developing a PatientApp program, a developer accesses Firebase to download a configuration file. An Android application package file (Apk File) is then made as a building application and connects to Firebase as shown in Fig. 4. These steps are the same as those in the building application given in subsection III_B_1). Before using an Android terminal as the sensor relay unit, the PatientApp in the sensor relay unit must create its own account in the Realtime Database with the Anonymous certification in the same project. After a measured file has been made, the PatientApp uploads the file to the storage server in Firebase as shown in Fig. 18. The storage server generates the file download URL, which is managed in the Realtime Database.

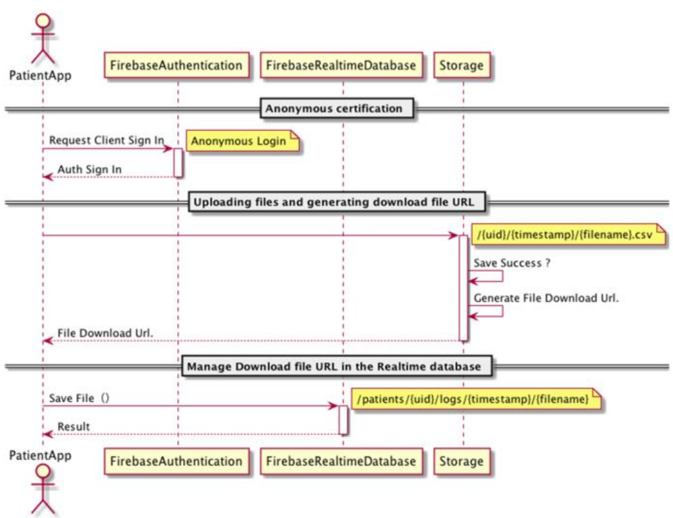


Figure 18. Sequence flow to upload measured files.

2) Measured data download function (Fig. 19)

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 Fig. 19. When medical professionals access the Website, they log in with their assigned ID and password.

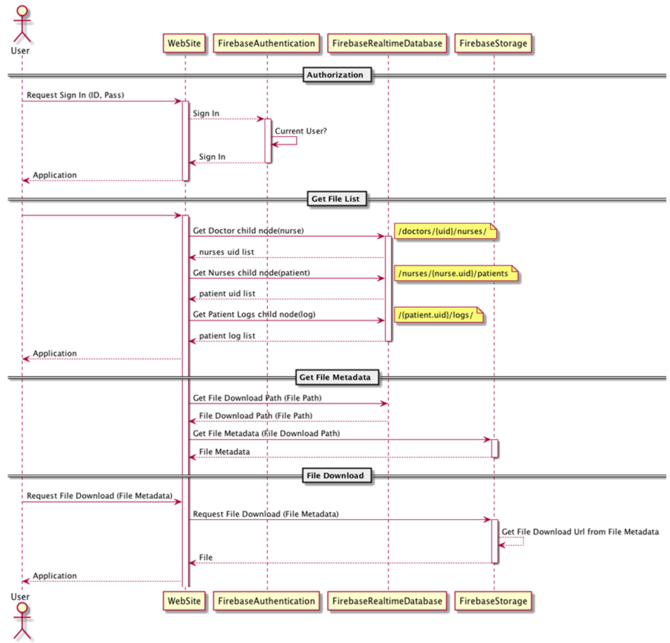


Figure 19. Sequence flow to download measured files

After login, the Website application accesses the Realtime Database to get information related to nurses and patients and presents them. 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 web page, the Website application accesses the indicated file on the Storage through the access path. Finally, the indicated file is downloaded.

C. *Example application*

We developed a measuring application that uses the above data collecting system. In this application, motions of the wrist and lumbar region were measured with a 3D-acceleration sensor. We used two SONY Smart Watch 3 units as the 3-D acceleration sensor [20]. 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 Fig. 20. Both were connected to a sensor relay unit with Bluetooth. A patient's name is input and then the body parts corresponding to sensors are input. In this case, we input "Wrist" and "Lumbar." After inputting above words, the page shown in Fig. 21 has been presented. There are four buttons in this page. "QR CODE" button is used to make a connection with a nurse. Clicking "START" button starts measuring and clicking "STOP" button stops measuring. Clicking "TRANSFER" uploads a measured data file to the storage server in Firebase.

After a medical professional logged onto the WebSite program, the patients' names and measured data files appeared as shown in Fig. 22. Clicking the name of a file downloads the file.

Sample graphs of measured data for the wrist and lumbar region are shown in Fig 23. The orange (Wrist X), gray (Wrist Y) and blue (Wrist Z) lines show respectively the data obtained when the arm moved up/down, forward/backward and in a twisting motion. The yellow (Lumbar X), blue (Lumbar Y) and green (Lumbar Z) dot-lines show respectively the anteflexion, lean and twist of the upper body. In this example, the participants used chopsticks to eat. When eating, they first twisted their arm so that it faced the mouth. Then they moved the arm up to the mouth while simultaneously leaning the upper body forward a little. After putting food into the mouth, they moved the arm back to where it had been. However, they continued to lean forward while eating.

We will release further details of this application in the near future.

Figure 20. Participant having two sets of SONY Smart Watch 3

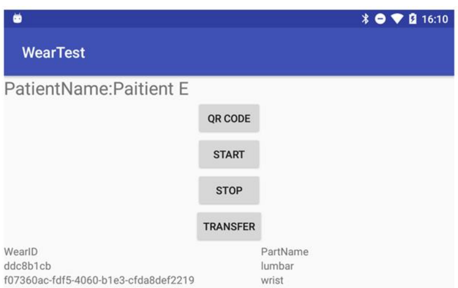


Figure 21. User interface of PatientApp

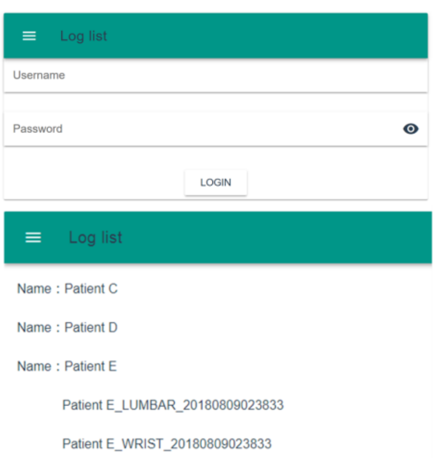


Figure 22. WebSite user interface.

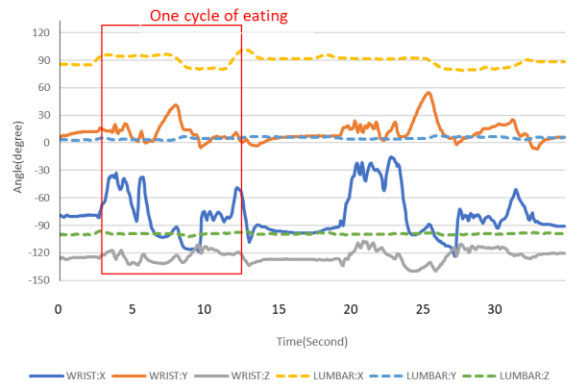


Figure 23. Sample graphs of measured data for the wrist and lumbar region.

V. Conclusion

We have developed and propose a novel patient monitoring platform for healthcare facilities. The easy to use platform consists of a notification system for event monitoring applications and a data collecting system for data measuring applications. In the notification system, monitoring devices are paired with mobile terminals by reading a Quick Response Code on monitoring terminal (sensor relay unit) displays. It is possible to pair them at the bedside of a patient without a console terminal and operator. When the sensor devices detect a patient having trouble, event messages are sent to a mobile terminal, not to a nurse station. Therefore, no operations are performed with the console terminal and medical devices can be easily installed at the patient's bedside.

We also developed a data collecting system with which medical data files measured by sensor devices are automatically uploaded to a cloud server and can be downloaded from the server by authorized medical professionals. No operations are performed with the console terminal in this system.

It is possible to develop monitoring or measuring application using the proposed platform and several manufactured sensors. This means that our platform keeps interoperability.

We have proposed to jointly develop commercial version of the proposed platform and/or applications to several companies. Some companies are interested, however, we do not have yet contracts with these companies.

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