IoT with Firebase: Smart Ring Android App Using MAX30100 for Fatigue Detection

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***Abstract*— IoT in healthcare enables real-time health monitoring and data evaluation of patient conditions. One of the benefits of IoT wearable devices is protecting a person from getting exhausted. Body fatigue is an indicator of the emergence of several problems such as sudden attacks of dangerous diseases and accidents. The large number of deaths from various diseases and accidents that are triggered by body fatigue makes monitoring the level of body fatigue important to minimize this. Through this research, we proposed the Smart Ring; a tool for monitoring and evaluating the level of body fatigue using a wearable sensor and based on the Internet of Things (IoT). In this article, we focus on developing the software component (Android application) and database management system of the Smart Ring IoT system. Age, heart rate, SpO2, and body temperature are used as indicators to determine user's body condition categories. These data are collected through sensors on the hardware part of the Smart Ring System. The proposed database management system is able to store collected data inside a NoSQL database in the form of documents. Smart Ring Android-based application is capable to monitor three user's body condition and evaluate them to predict the user's condition with classification accuracy of 100% within the defined categorization rules. It offers real-time user monitoring for exhaustion signs and triggering timely alerts with sub-2-second data processing under ideal conditions. The proposed Smart Ring system is expected to become an easy to develop, economical and portable medical device which helps improve the welfare of society 5.0 in the health sector.**

***Keywords*—Flutter, Firebase, Firestore, NoSQL, Android App, Fatigue Detection**

I. Introduction

I. In the era of society 5.0, the development of technology is rapid. All human activities are facilitated by technology [1]. The Internet of Things (IoT) technology has developed very rapidly and can make it easy for humans to access various things effectively and efficiently [2]. The term IoT was first disseminated by researchers from the Auto-ID Center at the Massachusetts Institute of Technology (MIT) in 1999 [3]. In 2015, there were more than 12 billion devices connected to the Internet, and in 2020 there was an increase of 26 times the number of devices connected to the Internet [4].

II. IoT is a highly promising technology for developing smart equipment that can bridge between sensors and everyday devices [5]. IoT has been widely implemented in various fields, for example smart car industry [6], healthcare industry [7], agriculture [8], etc. IoT implementation in various fields can provide various conveniences for humans in terms of notification systems, sensor networks, reactive systems, analysis systems, etc. [9].

III. Recently, the development of IoT in the health sector has become increasingly potential [10]. In particular, it combines sensors, microcontrollers, and cloud databases to provide convenience in monitoring and analyzing patient conditions [11]. Some uses of IoT in the health sector are remote patient monitoring [12], glucose monitoring [13], heart-rate monitoring [14], hand hygiene monitoring [15], and depression monitoring [16].

IV. To be able to build an IoT-based intelligent system, a database server is required to store a huge amount of sensor data [17]. Through this database, the application in the IoT system sends requests of the patient data for monitoring and evaluation purposes. The biggest challenges in database development to store a huge amount of real-time data are access time, security of the data, and development and operational cost [18]. This challenge can be answered by Google Cloud Firestore. Cloud Firestore provides real-time NoSQL databases with JSON data structures. It allows developers to create a storage system for real-time data that is not only easy to maintain but also cost effective and secure because the data is stored on Google's data center infrastructure. The Cloud Firestore is one of the services inside Google Firebase. Therefore, developers are able to integrate their application with many other services of Firebase such as authentication, email notification, cloud messaging, etc. [19].

V. With these various conveniences, developers can save time and costs to develop an IoT-based intelligent system. Therefore, this research is conducted on the implementation of Google Firebase as a storage component of IoT-based smart system on the Smart Ring Android App using the MAX30100 sensor to facilitate patients, medical personnel, and all parties for real-time monitoring of body condition based on temperature, heart rate (Beat Per Minute), and blood oxygen levels (SPO2).

VI. We propose a novel Smart Ring IoT system that enhances the capabilities of conventional smartwatches by incorporating real-time fatigue monitoring and emergency alerting functionalities. The Smart Ring utilizes sensor technology and IoT principles to provide a comprehensive health monitoring solution. Additionally, by leveraging simpler hardware components compared to smartwatches, the Smart Ring offers significant cost advantages in both hardware production and software development. This translates to a more affordable health monitoring solution for a wider range of users. In this article, we focus on developing the software component and database management system of the Smart Ring IoT system.

II. Methods

Smart Ring is designed based on three main components, namely circuit component (hardware), software component, and data communication component. Figure 1 shows the architecture of the system designed in this study.

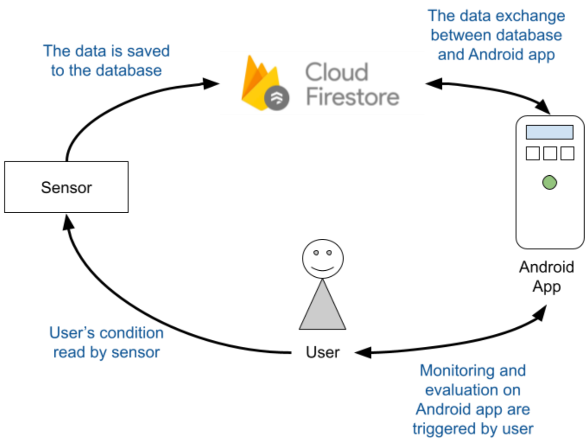

Fig. 1. The architecture of the Smart Ring system

The explanation of each component is as follows.

A. The Hardware Component

The hardware component design is shown by Figure 2.

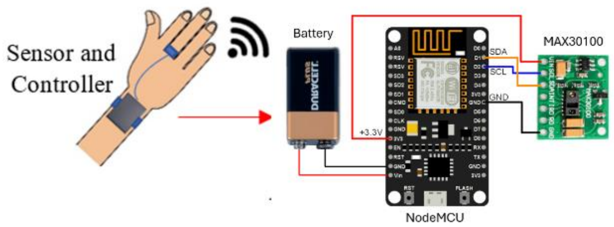

Fig. 2. General overview of hardware components of Smart Ring system

The power used by the microcontroller comes from a 4.5 V battery, while the MAX30100 sensor receives power from the microcontroller at 3.3V. The input comes from wearable sensors MAX30100 [20] used to detect HR, SpO2, and body temperature. The sensors are positioned on the finger. An Android application used to monitor the data readings from the sensors is named Smart Ring App. The data read by the wearable sensors will be transferred to Android using Wi-Fi assistance so that the data can be processed to generate an output, such as HR data, SpO2, and body temperature that can be accessed through the Smart Ring App.

B. The Data Management Component

The data of Smart Ring system that are stored on the Cloud Firestore database server come from two sources, the sensor ("datetime", "pulse", "temperature", and "oxygen") and the Smart Ring Android App ("location"). Figure 3 shows an illustration of the data structure design on the database that is used to store Smart Ring system data in Cloud Firestore.

VII. Unlike SQL databases which consist of tables and rows of data, NoSQL Firestore database stores data in the form of collections and documents. The database built for the Smart Ring system consists of a collection named "users". It is used to store Smart Ring user data in the form of documents. Each document contained in the "users" collection consists of a unique ID, a sub-collection called "tracking", and two fields, i.e., "name" of type String and "age" of type number.

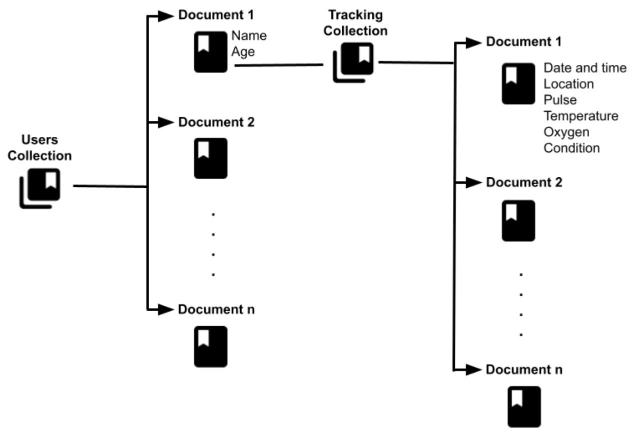

Fig. 3. The design of database for Smart Ring system

The "tracking" collection contained in each document in the "users" collection is a sub-collection. It is used to store all real-time data both generated by the Smart Ring sensor and the Smart Ring Android App. The use of sub-collection is chosen so that the tracking data stored by the Smart Ring system is grouped by user. This is useful for speeding up the process of reading data for each user because the real-time data generated by all users is not stored in one large collection.

Each document in the "tracking" collection has a unique ID and six fields. The five fields include the "location" field of type geopoint to store the location of the user's presence consisting of latitude and longitude coordinates, the "datetime" field of type String to store information about the time when the sensor reads the user body's condition based on the three indicators used, the "pulse" field of type number to store pulse data, the "temperature" field of type number to store body temperature data, the "oxygen" field of type number to store blood oxygen level data, and the "condition" field of type String to store the user's condition category. The data in the "datetime", "pulse", "temperature", and "oxygen" fields are obtained from the MAX30100 sensor which is sent to the Cloud Firestore database via the internet. Meanwhile, the data in the "location" field is obtained from the location of the user's device used to run the Smart Ring App and then is sent via the internet to the database server. The flowchart of data exchange on the Smart Ring system can be seen in Figure 4.

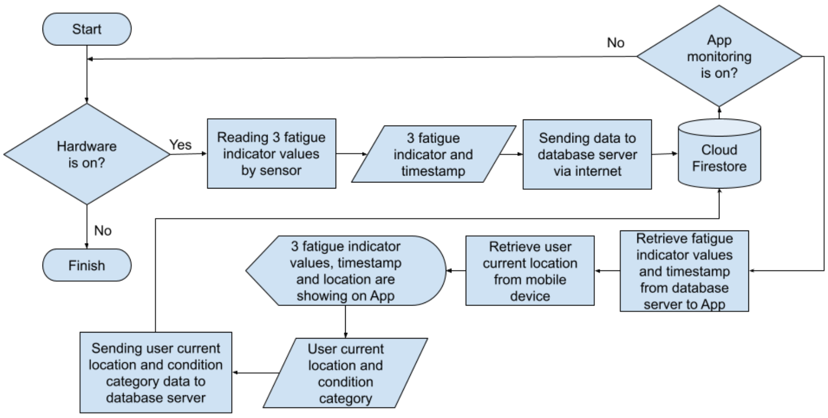

Fig. 4. The design of data exchange on Smart Ring system

The data of three indicators of body fatigue along with its timestamp monitored by the sensor of the Smart Ring system are sent to Cloud Firebase via the internet to be stored in the database server. If there is no request from the user to display the latest real-time data on the Android application, then the Android application will not send any requests to Cloud Firestore to stream the data. However, if the user makes a request to display the latest real-time data from the database server on the Android application, the application will send a streaming request to Cloud Firestore to obtain the latest real-time monitoring data and display it on the application. The user's presence location data is obtained from the mobile device used when running the Smart Ring App. The location data will then be stored in the database server and then be synchronized with the data that has been generated by the Smart Ring system sensor.

C. *The Software Component*

In this study, the Android application is designed to be able to carry out three main functions, i.e., displaying the three indicators of body fatigue data generated by sensor, providing user location information so that make it easier to identify the user's presence in a state of emergency due to the user's body experiencing fatigue, and providing fatigue notifications. The Smart Ring Android app is designed to connect to the database server in Cloud Firestore via the internet. Figure 5 shows the interface design of the Smart Ring Android App.

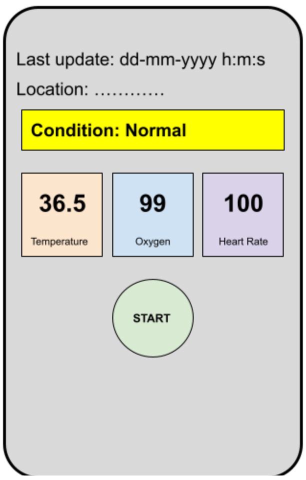

Fig. 5. The design of Smart Ring Android app interface

The explanation of each feature contained in the software component is as follows.

1) *Monitors Three Body Fatifue Indicators Data*

In order to display data on three indicators of body fatigue stored in Cloud Firestore database, the application sends a request for the most recent data to the database. The application listens to every upcoming data from the sensor. The application will stop listening for recent data only if the user stops the monitoring process through the stop button. In the real-time process of reading the most recent sensor data from the database, the application sends queries to the database to access the "users" collection and obtain the required documents. Afterwards, the "tracking" subcollection inside every document in the "users" collection is retrieved.

2) *Data Provides Information About User's Location*

The moment a user experiences an emergency condition due to fatigue; its location must be immediately discovered. In this study, the user's location is tracked via a GPS signal on its smartphone when the Smart Ring application is running. When a user places Smart Ring hardware on its finger and activates the Smart Ring Android App, the device location is sent to the database server and stored along with the fatigue indicators data.

3) *Provides Risk for Fatigue Notification*

In order to determine the user's fatigue condition, this study refers to [21][22][23][24][25][26][27][28]. Besides body temperature, blood oxygen levels, and heart rate, age is also used as an indicator to determine a person's fatigue condition. User conditions are grouped into three categories, namely "rest", "normal", and "at risk of fatigue" which are determined based on the range of values for each indicator as shown in Table 1.

When the sensor detects the values of the three indicators of body fatigue and the application determines the category of the user's body condition based on these values, the application will send a warning notification only if the body condition is in the category of "Risk of Fatigue". Notifications pushed by the app contain information regarding the user's location, body temperature (°C), blood oxygen level (SpO2), and heart rate (BPM). This notification will later appear in the notification tray on the user's smartphone.

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TABLE I. BODY FATIGUE CONDITION DETERMINATION BASED ON FOUR INDICATORS

Age	Body Temperature (°C)	SpO2	Heart Rate (BPM)	Category
20-24	35-37.5	≥ 95	< 100	Rest
			100-150	Normal
	< 35 or > 37.5	< 95	> 150	Risk for Fatigue
25-29	35-37.5	≥ 95	< 98	Rest
			98-146	Normal
	< 35 or > 37.5	< 95	> 146	Risk for Fatigue
30-34	35-37.5	≥ 95	< 95	Rest
			95-142	Normal
	< 35 or > 37.5	< 95	> 142	Risk for Fatigue
35-39	35-37.5	≥ 95	< 93	Rest
			93-138	Normal
	< 35 or > 37.5	< 95	> 138	Risk for Fatigue
40-44	35-37.5	≥ 95	< 90	Rest
			90-135	Normal
	< 35 or > 37.5	< 95	> 135	Risk for Fatigue
45-49	35-37.5	≥ 95	< 88	Rest
			88-131	Normal
	< 35 or > 37.5	< 95	> 131	Risk for Fatigue
50-54	35-37.5	≥ 95	< 85	Rest
			85-127	Normal
	< 35 or > 37.5	< 95	> 127	Risk for Fatigue
55-59	35-37.5	≥ 95	< 83	Rest
			83-123	Normal
	< 35 or > 37.5	< 95	> 123	Risk for Fatigue
60-64	35-37.5	≥ 95	< 80	Rest
			80-120	Normal
	< 35 or > 37.5	< 95	> 120	Risk for Fatigue
65-69	35-37.5	≥ 95	< 78	Rest
			78-116	Normal
	< 35 or > 37.5	< 95	> 116	Risk for Fatigue
>= 70	35-37.5	≥ 95	< 75	Rest
			75-113	Normal
	< 35 or > 37.5	< 95	> 113	Risk for Fatigue

III. RESULTS AND DISCUSSION

This section will explain the development result of the Smart Ring system from the application structure to the collected data stored inside the database.

A. *The Hardware System*

The data acquisition system utilizes wearable sensors strategically positioned on the finger to accurately measure Heart Rate (HR), Blood Oxygen Saturation (SpO2), and body temperature. These physiological parameters are critical indicators of an individual's health status, and their real-time monitoring can provide valuable insights for both healthcare professionals and individuals.

The choice of the finger as the sensor location as shown by Figure 6 is based on its proven efficacy in yielding reliable physiological measurements. The peripheral capillaries present in the fingertips offer a clear, direct path for photoplethysmography—a widely used method in wearable sensors for detecting blood volume changes. This technique is integral to the accurate determination of both HR and SpO2 levels.

To interface with these sensors, the Smart Ring App is developed for Android devices. This application serves as the primary interface for users to interact with and monitor their health data. Upon capturing the data, the wearable sensors utilize a Wi-Fi connection to transmit the information to the Android device. This method of data transfer ensures a seamless, real-time update of health parameters, which is crucial for timely medical decision-making and personal health management.

Once the data reaches the Android device, it undergoes processing to ensure accuracy and reliability before being presented to the user. The final output accessible via the Smart Ring App includes up-to-date readings of HR, SpO2, and body temperature, enabling continuous health monitoring in a non-intrusive manner. This system not only enhances individual health management but also has potential applications in remote patient monitoring and telemedicine, thus contributing to more proactive and preventive healthcare approaches.

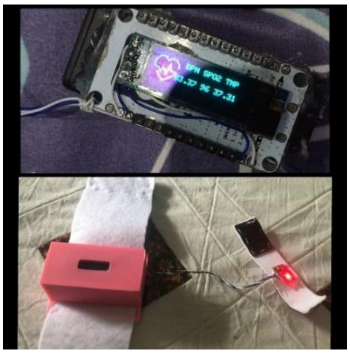

Fig. 6. Hardware implementation of Smart Ring

B. *The Data Management System*

The Firebase project needs to be created in advance before the Firestore database can be used. Figure 7 illustrates the implementation of "users" collection on Cloud Firestore database for storing data generated by Smart Ring system. The "users" collection consists of documents that store a unique ID, two fields ("age" and "name"), and a sub-collection called "tracking".

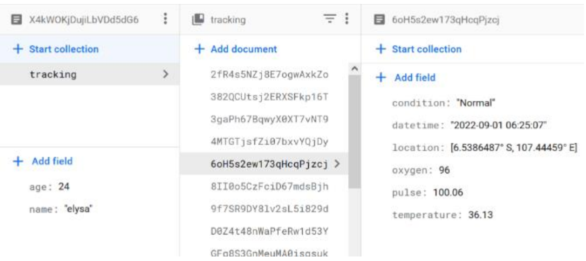

Fig. 7. The implementation of "users" collection

The sensor-generated data is grouped by users. Each user document has their own sub-collection to store the fatigue indicators data in the form of documents. The implementation of "tracking" sub-collection is shown by Figure 8. The use of sub-collection has an impact on the searching process. By using sub-collection, every time the application sends a request for the data to be displayed on the screen, the database server does not execute a query to find the most recent data in a large collection that contains all sensor data belonging to all users. Instead, it is going to search only in sub-collection of a document of a specific user. That way, the process of searching data becomes more efficient.

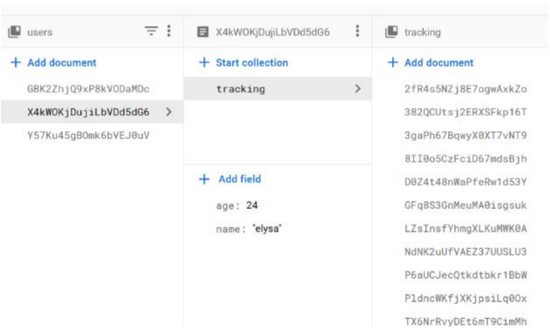

Fig. 8. The implementation of sub-collection "tracking"

Figure 9 points out fields inside a document stored in "tracking" sub-collection. The values inside "pulse", "temperature", "oxygen", and "datetime" fields are obtained from the hardware part of the Smart Ring system. Furthermore, the "location" and "condition" fields store the data originating from the Android application. These two data fields are available only if the user activates the monitoring process on its smartphone.

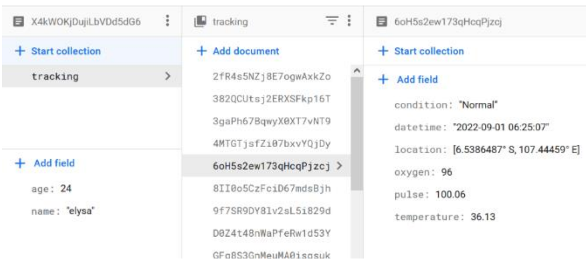

Fig. 9. The detail structure of a document inside sub-collection "tracking"

C. *The Software System*

The Android application of the Smart Ring system is developed by using the Flutter framework with Dart programming language. In order to connect to the Firestore database, the Flutter application must first be registered with the Firebase project. The Firebase SDK is added to the already created Flutter project in order that the app can send queries to the database.

The user interface of the Smart Ring Android-based application is shown in Figure 10. It consists of several containers to deliver different kind of information to user. The topmost container is used to display information regarding the last update time of the monitoring and evaluation process. Other than that, it is used to provide information about the user's current location. The next container is used to present the category of the user's body condition.

In the center of the application there are start and stop buttons which function to regulate the monitoring and evaluation of data generated by the Smart Ring system sensors. When the user wears the Smart Ring on his finger and starts the body condition monitoring process, the user can choose whether to monitor and evaluate the results through an application on his smartphone or not. If not, then the data that has been generated by the sensor is only stored in the database and not displayed in the application.

The designed application has several functions including displaying body fatigue indicators data, providing user's current location information, and rendering fatigue notifications. The explanation of each function is as follows.

1) *Monitors Three Body Fatifue Indicators Data*

The three fatigue indicators data is displayed using three containers, each of which consists of a collection of widgets and text icons. The displayed values are not constant, but constantly changing along with the monitoring that runs on the sensor side where the data is stored in the database.

Fig. 10. The Android-based application interface of the Smart Ring system

To be able to provide the indicators of user fatigue data, the application first sends a query to the collection in the database to obtain the latest sensor monitoring data. The query drills through the "users" collection in order to obtain the required document. Afterwards, the next process is to search within the "tracking" sub-collection that belongs to the document. The documents in the sub-collection are then sorted by the "datetime" field and searched for a document with the latest value in the "datetime" field. Once the desired data is obtained, the data is immediately sent to the three containers whose job is to display indicators of the user's body fatigue.

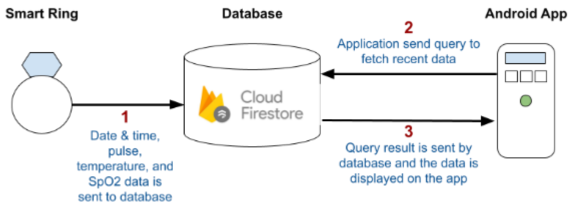

Fig. 11. Data streaming process and dynamically displays the latest data on the application he Android-based application interface of the Smart Ring system

The data exchange latency between sensors, the database, and the Android-based Flutter application, as illustrated in Figure 11, exhibits a range of 1 to 2 seconds. The application utilizes the StreamSubscription class and listen(event) method to continuously monitor the incoming data from the sensors of the Smart Ring system to the Firestore database. That way, whenever new data is generated by the sensor and stored in the database, the application sends the read query to Firestore so that the latest data can be immediately obtained and displayed on the application. In order for the application to display the latest data dynamically, the ValueListenableBuilder class is used in the interface component of the application to display text that changes according to the flow of the data stream obtained.

When the user stops the monitoring and evaluation process in the application by pressing the "stop" button, the object of the StreamSubscription class calls the cancel() method to stop the process of streaming data from the database. That way, the latest incoming data saved to the database stops being displayed in the application interface. The values displayed on the user's body fatigue indicator widget are also reset to default values.

2) Determines User's Body Condition and Provides Fatigue Notification

When all the required data has been retrieved from the database, the application then parses these values as arguments for the parameters in the function that are in charge of determining the user's body condition category. Determining user conditions is carried out by implementing the rules in Table 1 into conditional statements. The output of the function is then displayed on the application interface by leveraging the *ValueListenableBuilder* class. The *ValueListenableBuilder* is used because the value of the user's body condition category changes dynamically according to the body fatigue indicator data read by the hardware part of the Smart Ring system. If the condition is in the "At Risk of Fatigue" category, then the application calls the function to push alert notification.

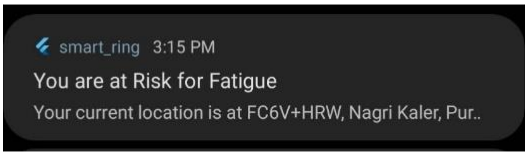

Fig. 12. Fatigue notification is displayed in the notification tray on user's smartphone

The application generates real-time notifications with minimal latency upon user state evaluation transitioning to the "At Risk of Fatigue" category. In order to provide alert notification, the application utilizes the Flutter plugin, namely, *flutter_local_notification*. The plugin is used to display notifications on the user's device as shown in Figure 12. When the user clicks on the notification, the user is directed to a page that displays data that causes the user to be in the "At Risk of Fatigue" category. The information provided includes body temperature, blood oxygen level, heart rate, and the user's location based on the device location. The warning page is shown by Figure 13.

Fig. 13. The detailed information on warning page of the Smart Ring application

3) Provides User Location Information

In order to monitor the user's location, the Flutter application designed in this study utilizes the Geocoding and Geolocator plugins. Geocoding is used to obtain geographic coordinates in the form of latitude and longitude values from the location of the device used. The Geolocator then converts the geographical coordinates that have been obtained into full addresses. That way, the user's location based on the device used can be displayed and easily understood by the user. The information related to the user's location that is provided in the application is continuously updated according to the point where the device is located.

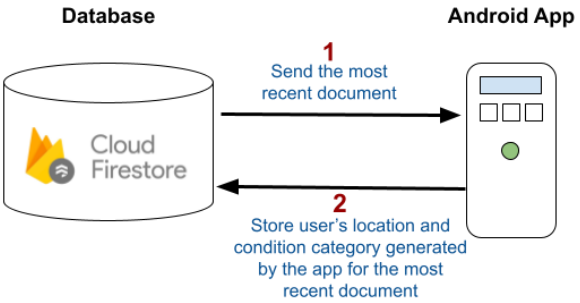

Fig. 14. The process of transfering device location and condition category data to Firestore

The application stores user's location data as well as user's condition category to the database according to the latest document being read. It sends an update query to fill the location and condition fields. The process is illustrated by Figure 14. An example of a document in the "tracking" sub-collection equipped with a location and user's condition category data is shown in Figure 15.

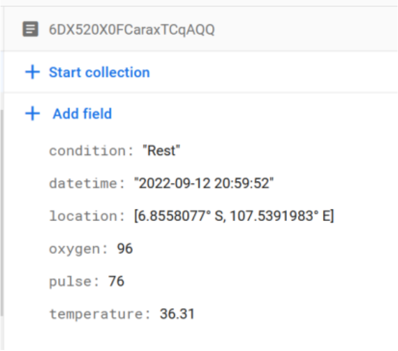

Fig. 15. Example of a document inside the "tracking" sub-collection that contains condition and location fields

B. Collected Data

To evaluate the proposed application, we examine the Smart Ring system to one user. The user is 25 years old. We ask the user to put on the hardware component of the system on their finger and activate the Smart Ring application on their device with GPS on. User is asked to perform various types of activities ranging from light to heavy activities. Table 2 breaks down several data collected from the experimental process that is stored inside the Firestore database. It represents document-based data with table structure. Based on the data presented in Table 2, the application exhibits a strong capability to monitor user data and estimate the user's body condition with a 100% accuracy.

TABLE II. COLLECTED SMART RING DATA ON FIRESTORE DATABASE

datetime	location	oxygen	pulse	temperature	condition
2022-09-12 20:58:30	__GeoPoint__-6.8558077### 107.5391983	96	67.65	36	Rest
2022-09-12 20:59:52	__GeoPoint__-6.8558077### 107.5391983	96	76	36.31	Rest
2022-09-12 21:00:43	__GeoPoint__-6.8558077### 107.5391983	96	71.95	37	Rest
2022-09-12 21:03:07	__GeoPoint__-6.8558077### 107.5391983	96	70.75	36.63	Rest
2022-09-12 21:06:26	__GeoPoint__-6.8558077### 107.5391983	96	28.55	35.88	Rest
2022-09-13 06:00:11	__GeoPoint__-6.8558077### 107.5391983	96	98.56	36.81	Normal
2022-09-13 06:03:23	__GeoPoint__-6.8558077### 107.5391983	97	100.31	37.1	Normal
2022-09-12 06:03:55	__GeoPoint__-6.8558077### 107.5391983	97	100.32	37.1	Normal
2022-09-12 06:05:02	__GeoPoint__-6.8558077### 107.5391983	97	100.65	37.21	Normal
2022-09-12 06:06:31	__GeoPoint__-6.8558077### 107.5391983	97	100.65	37.19	Normal
2022-09-12 07:17:32	__GeoPoint__-6.8558077### 107.5391983	95	146.10	37.55	Risk for Fatigue
2022-09-12 07:19:04	__GeoPoint__-6.8558077### 107.5391983	95	146.12	37.55	Risk for Fatigue

V. CONCLUSION

In this work, we developed an IoT-based system called Smart Ring which consists of MAX30100 sensor, Google Firebase as a storage component and Flutter-based Android application to facilitate patients, medical personnel, and all parties for real-time monitoring of body condition based on temperature, heart rate (Beat Per Minute), and blood oxygen levels (SPO2). This article investigates the development of the software component within the Smart Ring system. We demonstrate that the software effectively monitors real-time sensor data originating from the hardware component. The user interface displays three fatigue indicators with minimal latency, ranging from 1 to 2 seconds. Furthermore, the software employs fatigue indicator data to estimate user state and achieves a classification accuracy of 100% within the defined categorization rules. Real-time notifications are delivered upon user state transition to an "exhausted" condition.

This work opens many possibilities for future research. It will be interesting to develop the Smart Ring application that can determine the user's body condition using machine learning algorithms. More effective techniques can be designed for determining fatigue condition so that the process can be done more accurately.

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