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by

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Abstract

Heart disease has become the leading cause of death in Australia and the world, regular cardiac examination is necessary for heart disease patients and people at risk.

The thesis developed an examination system mainly focuses on cardiac diseases, the aim is to support online medical sessions and enable patients with heart diseases to perform simple heart examinations by themselves under the real-time guidance of doctors and receive feedbacks from them. The system is able to receive data from Bluetooth telemedicine devices and show them in real-time software-based video conferences between doctors and patients.

This system is designed to enable patients to complete simple heart tests at home that would previously have required a visit to the hospital, the video conferencing function will allow doctors to provide real-time guidance and assistance to patients who do not possess adequate professional knowledge during examinations. It makes regular examinations more convenient, reduce the time needed for traveling to hospitals, and reduce the risk of getting wrong examination results due to improper operations of patients.

This system also has strong compatibility and extendibility, the design of the Bluetooth module enables it to be extended conveniently. With a few simple extensions, the system could be compatible with more telemedicine devices and used to treat diseases other than heart disease.

Abbreviations

CVDs: Cardiovascular diseases

COVID-19: Corona Virus Disease 2019

GPS: Global Positioning System

NYHA: New York Heart Association (classification)

WebRTC: Web real time communication

FTTP: Fixed line fiber to the premise network

NBN: Australian National Broadband Network

HTTP: HyperText Transfer Protocol

GATT: Generic Attribute Profile protocol

GPA: Generic Access Profile protocol

SDK: Software Development Kit

API: Application Programming Interface

P2P: Peer-to-peer

E2E: End-to-end

MTV: Model template view framework

MVC: Model view controller framework

ORM: Object oriental mapping

HTML: Hypertext markup language

BLE: Bluetooth low energy

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Chapter 1 - Introduction

There are many unhealthy habits in modern life, including smoking, drinking, and staying up late, these unhealthy habits significantly increase the risk of getting cardiovascular diseases (CVDs). The cardiovascular disease has become the leading causes of death in Australia and globally.[1]

There are many ways to avoid the risk of heart disease, including quitting smoking, exercising more, and changing the diet. Besides them, two of the most important things, especially for older people who already have heart disease are to have regular heart check and consult doctors whenever feeling heart troubles.[2]

However, a large proportion of people with cardiovascular disease are elder people with limited mobility [3], it is impossible for them to visits to the hospital for a heart examination too often. Furthermore, many patients live in very remote areas, making it more difficult for them to get to hospitals, and the time needed for appointments, registration and waiting after arriving the hospital also makes traditional heart tests time-consuming.[4][5] In addition, the long journey to the hospital itself may have an impact on patients' health, as many patients may choose not to go to the hospital even if their heart is abnormal, which can leading to serious problems.

Moreover, the same problems exist in the treatment of less serious ailments other than heart disease, such as colds and fevers. These diseases can seriously affect daily life, but they usually have no serious consequences. Many people living in remote areas will feel it is not worth going to hospital for these diseases, which prevents them from being diagnosed by a professional doctor and taking the best approach to recovery. In the worst case, without professional diagnosis, patients may consider the initial stage of some serious illness as a common illness and not go to the hospital and cause serious consequences. The problem could get worse when there is an outbreak, because going to the hospital increases the chance of infection.

There have been devices and applications developed to solve this problem, medical devices that connect to the computer via Bluetooth signal are one of the most useful of them, for example: Bluetooth stethoscopes, Bluetooth blood pressure monitors and Bluetooth heart rate monitors. These devices make telemedicine possible, allowing doctors to monitor patients' health through the internet rather than having them come to the hospital in person, which makes the examination process more time-saving and efficient. The data from these devices can also be stored in a database that enables doctors to have a long-term observation of patients.

However, telemedicine also brings some problems, including its reliability compare to traditional face-to-face medical methods, the lack of sufficient two-way communication and the need for adequate training for patients. [6]

Video conferencing is a good solution to these problems, by combining video conferencing with telemedicine, doctors are enabled to guide patients to use telemedicine devices in real time and perform some simple cardiac tests remotely. There are already some hardware-based video conferencing systems that support telemedicine, they use external microphones, one or more cameras and some other video and audio devices, allowing doctors to instruct patients remotely and provide real-time feedbacks.

However, there are also some problems with the hardware-based video conferencing, the most critical of which is its high cost and complexity. In order to use this system, besides telemedicine devices themselves, patients also need to purchase several video and audio equipment like cameras and microphone, which increases the cost of the system and the difficulty in installing all equipment.[7]

Comparing to hardware-based video conferencing, software-based video conferencing would be a better solution. It can use cameras and microphones embedded in computers or smartphones, eliminate the requirement of any additional audio and video devices but has the ability to accommodate them. It can reduce the cost, makes the process simpler and be more compatible on a variety of devices.[7]

We developed a low cost, compatible, user friendly and extendable telemedicine application that mainly focuses on CVDs patients, especially elder people. It also has the ability to be used for the remote treatment and diagnosis of other less serious diseases. It integrates Bluetooth telemedicine devices with software-based video conferencing, allows patients to use telemedicine devices under their doctors' real time instructions and perform simple health examinations at home by themselves.

This system can be used in the routine heart checking of CVDs patients as well as simple diagnosis of the symptoms of CVDs and other diseases. Patients can ask for real time diagnosis at home from their doctors like traditional face-to-face medical, if doctors think there is necessity for patients to go to the hospital, then they can go to the hospital for a more detailed examination. Otherwise, doctors can give their patients some remote diagnosis and guidance to help them recover at home. It saves patients' time and reduces the hospital's burden, as well as allowing patients receive professional medical support at home.

Furthermore, the doctor side of this system is browser based, which is compatible for any phone and computer. The patient side application us developed with react-native, allows it to run on both android and iOS devices. The system will use embedded cameras and microphones in laptop or mobile devices, allowing users to use its service with their phones, laptops or iPads wherever there is an internet signal.

Chapter 2 - Background

Cardiovascular diseases (CVDs) have become the leading cause of death in Australia and the world. In 2015, heart disease caused 12.4% (19,777) of the 159,052 deaths in Australia, which was the leading cause of death in Australia for both males and females.[8] The figure decreased to 18,590 deaths in 2017, accounting for 11.6% of all deaths, yet it still occupies the largest proportion of death number.[9] Furthermore, CVDs cause 31% of all global deaths, which is 17.9 million deaths every year, and it has been the leading cause of death since the mid-20th century.[1]

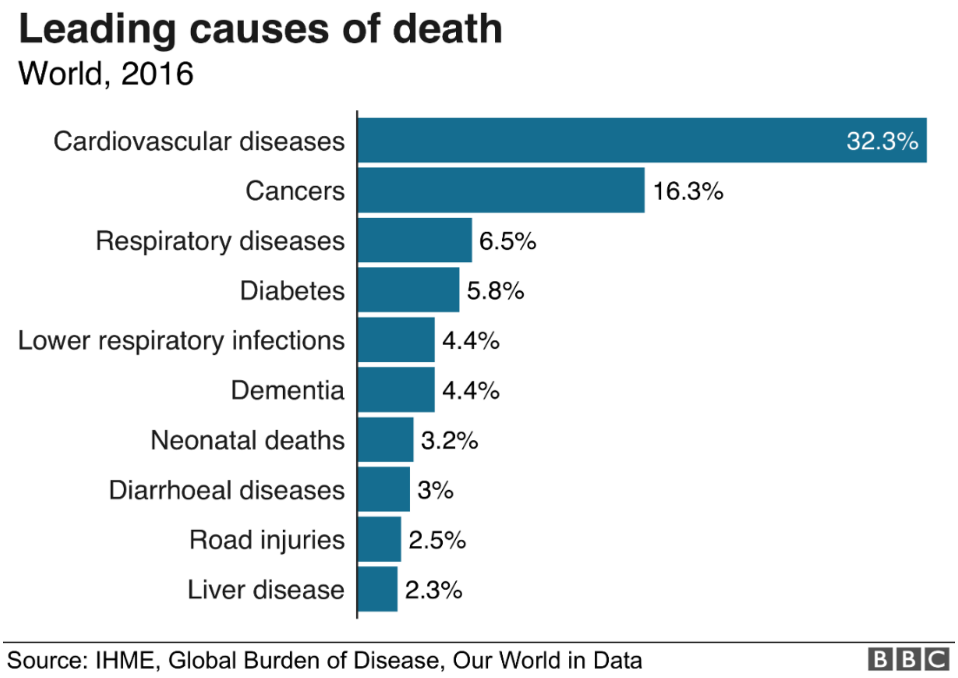

Figure 1: Global leading of death in 2016

It is very important for people with heart disease and those at risk to have regular heart health checks and consult their doctors when feeling unwell about their hearts. However, it could be problematic, even impossible. First, patients may take a long time to get to the hospital, especially for those living in remote areas. In Australia, it takes about 20 minutes to get to the hospital in a densely populated states like New South Wales and Victoria, the time increase to 1.5-3 hours in some remote area like Northern Territory, southern Australia and most region in western Australia. The figure even reaches 8 hours in some areas in south Australia. [5]

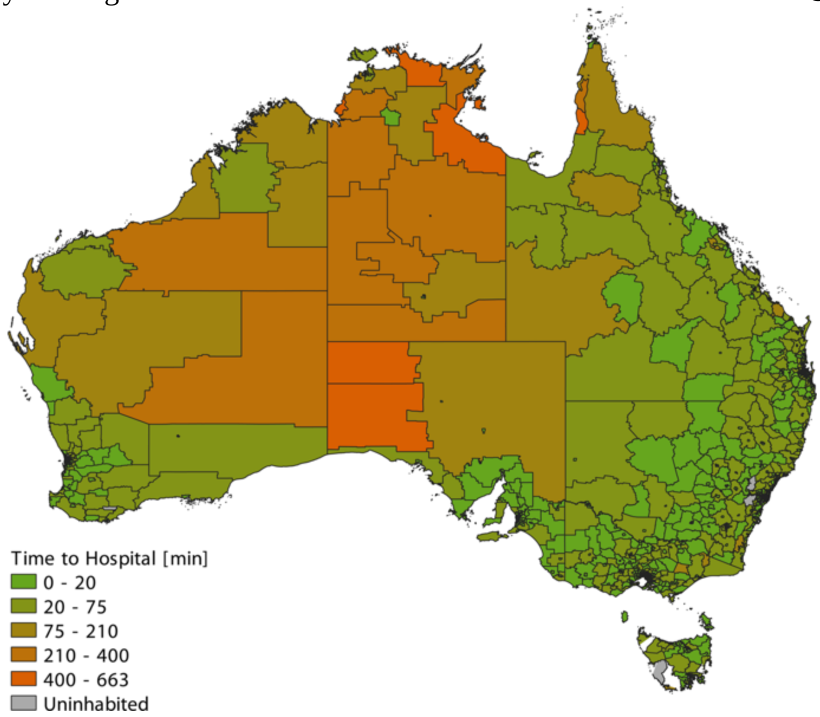

Figure 2: Travel time to hospitals in Australia

Furthermore, the waiting time after arriving the hospital is not satisfiable for many people. In 2018 to 2019, the national 90th percentile emergency wait time in Australian public hospitals was1 hour and 40 minutes. This number was higher in the regions where people need to take longer time to get to the hospital like southern Australia, which makes having a heart check in hospitals more time-consuming for people living in these areas.[4]

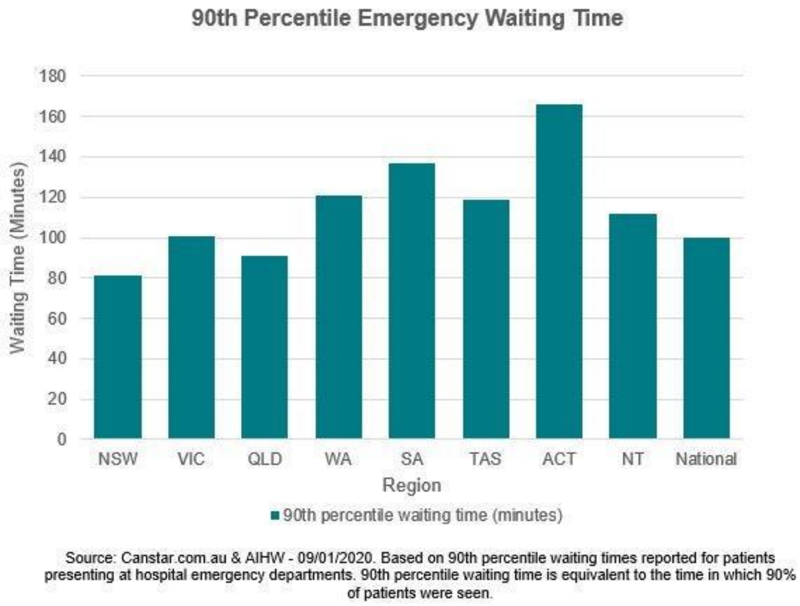

Figure 3: Average emergency department waiting time

Moreover, the proportion of people with heart disease generally increases with age. In Australia, in 2014 to 2015 30.7% of adults aged 75 years had heart disease. And in 2017 to 2018, there were only less than 5% of the proportion heart disease patients was less than 55 years old, then in 2017 to 2018, 25.8% Australians aged 75 years and over had heart disease. [10] Older patients are also at the greatest risk, in 2017, 53% of CVD deaths occurred in people aged 85 years and older.[11] Furthermore, about 60% of world's deaths occur to people over 70 years of age.[1]

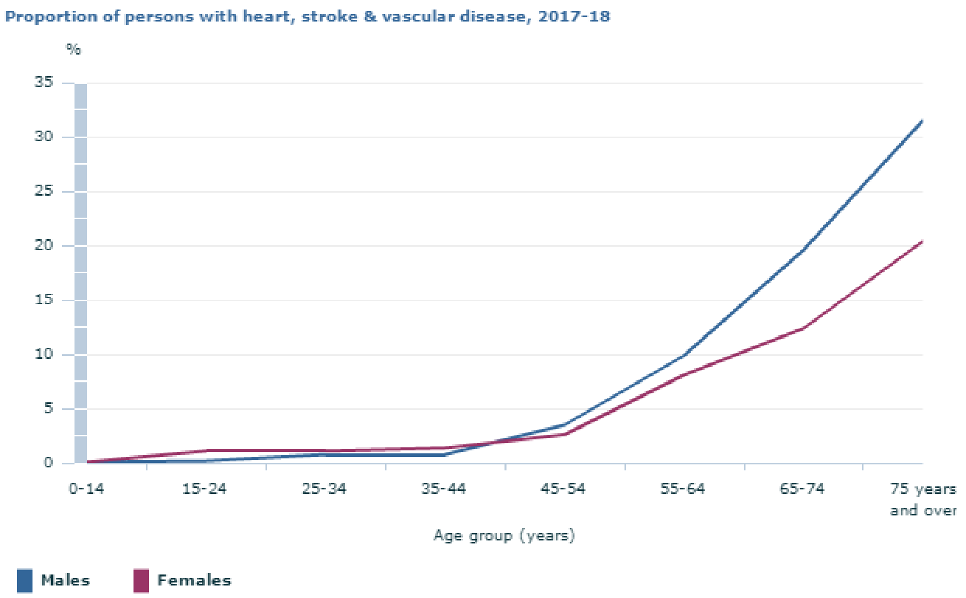

Figure 4: Age distribution of CVDs patients

It would be more difficult for old people with limited mobility. However, they are also the people most affected by heart diseases, the difficulty of going to hospitals could seriously endanger their health.

The same problem applies to the diagnosis and treatment of diseases other than heart disease. Some illnesses, including colds, fevers, and diarrhea, may be ignored because they usually have no serious consequences. Especially for people living in remote areas, it takes a lot of time and energy to get to the hospital, so people tend to recover at home. But due to a lack of professional knowledge, patients may mistake the initial stage of some serious diseases for ordinary diseases, thus missing the best time for treatment. Even if a patient correctly identifies his or her illness, without a doctor's help, the patient may not know the best way to recover. For example, what medicine should be taken, what should be paid attention to in illness.

This difficulty is expanded when there are pandemics like COVID-19, during which the burden on hospitals will increases significantly, making it more difficult for patients to make an appointment. And going to the hospital may increase the chance of infection, which is dangerous for patients, especially the elderly.

Chapter 3 - Literature Review

There are many solutions that have been developed to solve the problem mention in the last chapter, one of the most important of them is telemedicine.

3.1 Telemedicine

World Health Organization`s official definition of telemedicine is:

"The delivery of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities."

This definition will be used in this report for telemedicine.[12]

The simple heart check including 4 main things:

- Measuring blood pressure
- Measuring cholesterol level
- Measuring weight
- Face-to-face diagnosis with a doctor, which includes recording age, asking questions about lifestyle, and finding if there is any family member with heart disease.

If doctor suspects a heart condition, a more detailed tests will be arranged, which must be performed in hospital. It includes electrocardiogram, blood tests and heart ultrasound.[2]

The more detailed heart examination requires more expensive and professional medical equipment, which is impossible for most of the patients to purchase and put at home. On the other hand, the medical devices needed for simple heart check have smaller size and are affordable for patients, therefore the concept of using telemedicine technology in CVDs treatment will focus on allowing patients using telemedicine devices to perform the simple heart check at home by themselves. Besides CVDs, the same concept can also be used for the diagnosis and treatment of other diseases.

Patients can use their telemedicine devices collect their vital parameter values, and doctors can monitor these values and provide diagnosis for their patients. If they decide that there is necessity for patients to receive further examination, patients can then go to hospitals to receive a detailed test. In this way, patients will only go to the hospital when it is necessary, which will significantly save their time and reduce the burden of hospitals.

To implement this concept, several telemedicine devices have been developed to enable patients to perform the simple heart check remotely at home, which including Bluetooth stethoscopes, Bluetooth blood pressure monitors, Bluetooth heart rate monitors and some other devices. These telemedicine devices connects with phone or computer with Bluetooth signal, send real-time detection data to a computer or mobile phone database. Data can be accessed by doctors though the internet to determine the patient's health condition, furthermore, the database also makes it easy for doctors to observe patients over a long period of time.[13]

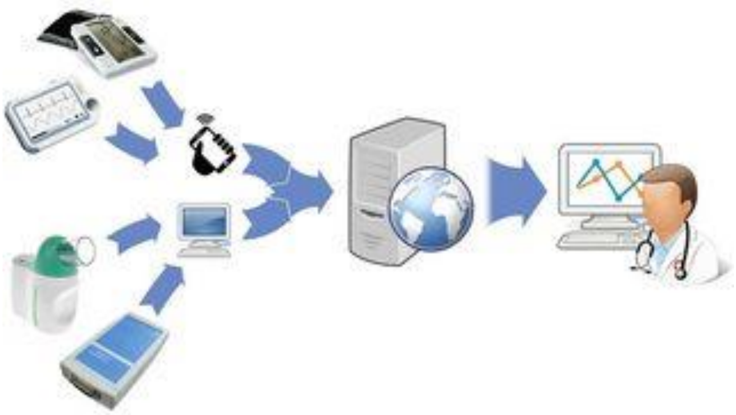

Figure 5: Structure of telemedicine systems

3.2 Previous solutions

In the late 1990s, Alfred Bove, M.D., Ph.D., past president of the American College of Cardiology and professor emeritus at Temple University School of Medicine created a system to monitor patients with heart diseases. In which patients sent their blood pressure, pulse rate, and body weight to their doctors through the internet, then doctors and nurses would provide feedbacks to patients based on these measured data. Nowadays, this system relies on phones and a voice recognition system, patients can dial 800 and recite their blood pressure, pulse, and body weight to a recognition system, then this information will be translated to data and provided to doctors.[14]

In an article published in 2015, Priyanka Kakria created a system using a wearable sensor called Zephyr BT to extract heart rate, an upper Arm blood pressure monitor called Omron Wireless to measure blood pressure and a Bluetooth based temperature sensor called G plus to measure body temperature. These sensors will upload the measured information to a database built in patients' smartphone through Bluetooth, then doctors can access to these data through a web application, which will extract data from the local smartphone database to an online database, and give diagnose to patients. Furthermore, this system installs a GPS application and an alarming System to patients' smartphone, if their medical status become dangerous, the alarming System will send an alarm to doctors, and they can conveniently find patients' location using the GPS application.[15]

Besides wearable non-invasive devices mentioned above, in an article published in 2017, Chih-Chung Hsiao mentioned that an implantable wireless device called CardioMems was also used for heart disease patients. This device monitors patients' pulmonary artery pressure and enable them to be treated based on this information. In a study that enrolled 550 NYHA class III heart failure patients, the admission rate for heart failure of the treatment group, in which patients were implanted with the CardioMems device was decreased by 33% comparing to the control group.[16]

In an article published in 2019, Noman Q. Al-Naggar designed a remote real-time Monitoring System similar to Priyanka Kakria's, it uses a device that integrates circuits of wearable sensors called Arduino Mega 250 R3, which is able to monitor multiple instead of one vital parameter. This device is used to measure electrocardiogram, heart rate and respiratory rate, blood oxygen saturation, and temperature. Measured information will be sent to an android smartphone then sent to doctors through WiFi or 3G/4G signal. To decrease the power consumption and increase the smartphone's performance time, the user application has 2 modes. The first mode is more power consuming, it will continuously transmit data to doctors, the second mode focuses on power saving, which will only transmit data to doctors when abnormality is detected. He and his team also designed a special power bank to ensure the long-time performance of the system and smartphone. With their design, their system is able to work 4 h 21 m 30 s while monitoring multiple parameters simultaneously. Furthermore, his system also has alarming system and GPS system in case any emergency happens to patients.[17]

In another article published in 2019, Massimiliano Donati created a more advanced system, he mentions that most of telemedicine systems only focus on the usage of patients in the out-of-hospital situation, they are not professional enough to be used by doctors or in pharmacies. Therefore, he divided all possible usage of telemedicine systems into telemedicine scenarios:

- The patient self-acquisition scenario. (For patients themselves)
- The doctor's visit scenario. (For doctors and nurses)
- The point of care scenario. (For pharmacy or a residence for elderly people)

There are different user interfaces provided in different scenario, from the easiest and most intuitive interface for patients to the more advanced and complete interfaces for professional operators. Furthermore, Massimiliano Donati also mentioned that most of the telemedicine system only focused on one specific disease, which reduced their flexibility and configurability. He solved this problem by using multiple sensors to monitor eight vital signs at the same time. In this way, his system has high flexibility, and can be used for the treatment of other diseases.[13]

The development in telemedicine technology significantly increases the quality of medical treatment for CVDs patients. Mounica Soma published an article in 2017, which focused on the effectiveness of telemedicine in the management of chronic heart disease. She and other three people reviewed 151 abstracts and 20 articles related to telemedicine for heart disease, 45% of them mentions reduction in hospitalizations and readmissions, 40% of them mentions the improvement in mortality and cost-effectiveness and 35% of them mentions the improvement in health outcomes.[18]

3.3 Problems in previous solutions

Theoretically, telemedicine increases the quality of medical treatment for patients, which should result in the increase in their satisfaction. However, according to Mounica Soma in her 2017 article, only 10% of the documents she reviewed mentions the increase in patient satisfaction.[18] This indicates that there are some problems with existing telemedicine systems.

Maurizio Volterrani mentioned some obstacles that prevent the use of telemedicine systems. Firstly, most of patients are lack of professional knowledge and skills, they often need a lot of training in order to use the telemedicine devices properly and understand the meaning of the data they are measuring. The amount of time and effort required to get enough training to used telemedicine devices independently reduces the satisfaction of patients with the system, especially for the elders.[6]

Secondly, existing telemedicine systems are lack of two-way communication. In the traditional face-to-face medical sessions, doctors and patients can see each other, doctors use medical equipment to measure vital parameter values of patients and provide real-time diagnosis. In telemedicine, although doctors can monitor data form the internet, patients still need to collect their medical data by themselves without the help of doctors. The lack of training and professional knowledge could lead to the low confidence in the telemedicine system. For many patients, even if they use telemedicine devices correctly, they still feel that the data they get is less reliable than what is measured during traditional face-to-face examinations by doctors. The lack of sufficient two-way communication in telemedicine would reduce the reliability of telemedicine system for patients.[6]

Integrating telemedicine system with video conferencing could be a solution for this problem. With the help of video conferencing, doctors can direct patients to use telemedicine devices in real time and provide real-time feedback like face-to-face traditional method. In this way, incorrect operations of patients will be corrected and errors in the measured data will be avoided. Video conferencing will enable telemedicine to have the two-way communication and reliability of traditional face-to-face medicine as well as the timesaving and convenience of telemedicine. Therefore, patients' satisfaction and confidence in the telemedicine system will both be increased.

However, the video conferencing function is not commonly used in personal telemedicine systems,[13] it is often used for remote guidance between hospitals. For example, in an emergent situation, the patient may not be able to reach specialized hospitals, it would require small hospitals having the ability to provide emergency treatment. However, the doctors in these hospitals may lack specialized knowledge and experience and requires remote guidance from specialists.

In a medical journal published in 2004, Sun K. Yoo created a system based on hardware video conferencing, it uses cameras to record real-time image of patients and screens of medical equipment and uses microphone to record sound. This system enables more experienced specialists to remotely instruct medical personnel who are less experienced or knowledgeable and perform operations for patients.[19]

Nevertheless, this kind of hardware-based video conferencing is not the best way to solve the problem of personal telemedicine. Firstly, hardware video conferencing relies on external cameras and microphones to capture video and audio, which increases its complexity. For example, Sun K. Yoo’s system requires 2 cameras, 1 microphone and 1 video capture board. [19] The proper installation and use of these devices can be accomplished by trained medical personnel, but can be very difficult for normal patients, especially the elderly. The complexity may reduce patients' satisfaction and desire for telemedicine.

Secondly, hardware-based video conferencing increases the cost of telemedicine system. For example, Sun K. Yoo’s system requires:

- A Samsung video camera
- A full-quality VC-10 Cannon camera
- An All in wonder ATI Co. Markham video capture board and a microphone[19]

When this report is written, the total cost of these devices is about $325 (Australian dollars). This is not a small cost for many patients, especially the elderly. As a reference, in 2020, the weekly age pension is $472 for single people and $356 for couple (each) in Australia,[20] which means the cost of above devices is about 70% to 90% of the weekly income of elders. The cost of these video equipment and the cost of telemedicine devices themselves will prevents it from being accepted and used on a large scale.

3.4 Technologies needed for a new solution

Software video conferencing is a good way to increase the two-way communication between patients and doctors in telemedicine and control the cost. It takes advantages of the built-in microphone and camera in laptop and smart phone, allowing users to have video conferences directly on their smartphones or laptops, eliminating the need for additional audio and video equipment, which significantly decreases the cost and the complexity of the system, overcomes the problem caused by the hardware-based video conferencing. It can be implemented by WebRTC, which belongs to cloud computing.[21]

WebRTC stands for Web real-time communication, it is an open-source research that aims to incorporate videoconferencing directly into browsers. WebRTC is based on browsers, allowing users to open a webpage containing WebRTC code written in JavaScript and directly have video conferencing on that webpage. Therefore, it is compatible in any devices with a required browser like Firefox, no matter what operating system it is using. It provides some standard APIs, allows developers to set up a video conference on browsers by simply calling the APIs without paying attention to low level operations like multimedia digital signal processing. These features make WebRTC has strong compatibility and expansibility. [21]

WebRTC involves cloud computing, which is a concept of delivering computing services via a distributed network like the Internet.[22] It breaks a large data computing program into several small programs, which are then processed and analyzed through a system of multiple servers to get the results back to the user. Its feature is that when a user wants to use a service, much of the computation is done not on the local machine but on several servers elsewhere, and the user gets the results through a distributed network like internet. Typical cloud computing approaches includes infrastructure as a service, platform as a service and software as a service.

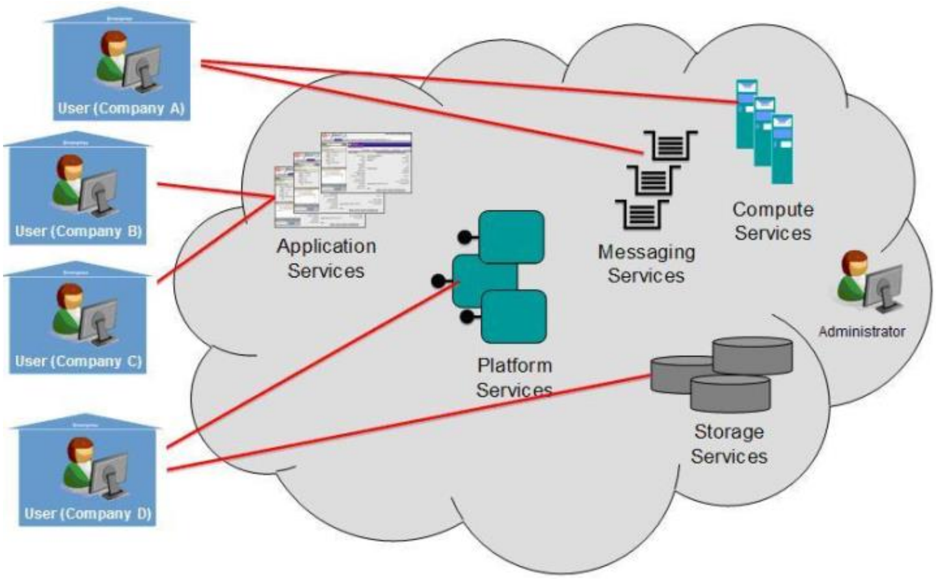

Figure 6: Concept of cloud computing

For WebRTC video conferencing, it is a software-based system, although local hardware (laptop or smartphone with camera and microphone) is still needed, the video conferencing and data management software is somewhere else on the internet, users use the services provided by this software. They can access WebRTC applications through browsers and directly set up video conferences using the built-in microphone and camera in their laptops or smartphones.[21] It minimizes the hardware and software prerequisites for video conferencing, the browser-based feature makes it compatible in almost any device. It will be friendly to users, especially the elderly.

3.5 My solution

The thesis developed telemedicine system that integrates WebRTC video conferencing with Bluetooth telemedicine devices, enable to detect multiple vital parameters and record the real-time image of patients and show them to doctors in video conferences. This system mainly focuses on CVDs patients, especially the elders, it will support them to use Bluetooth medical devices to perform simple heart tests at home under the real-time guidance of doctors.

The system has two parts, a patient-side mobile application that can be run on both Android and iOS devices, a browser-based doctor-side web application that can be used on any laptop or computer with embedded cameras and microphones. The patient-side application should be able to connect to Bluetooth telemedicine devices (for example: Bluetooth heart rate monitors) to receive real-time medical data sent through Bluetooth signal and share it with the doctor-side application. Furthermore, the system has ability to compatible with various kind of devices and detect multiple vital signs, it makes it also useful for the diagnosis and treatment of other diseases, which gives it strong compatibility and extendibility.

The system is designed to fulfil following requirements:

- The system should be able to support real-time telemedicine video sessions between doctors and patients.

- The system should be user friendly for elder patients.
  - Elder patients should be able to use this system by themselves after short training from doctors or reading texture instructions.

- The patient-side application should be able to receive the measurement of several vital parameter values transmitted through Bluetooth signal, then share it with the doctor side application and show them in the video conferencing interface.

- The security of the measured medical data should be ensured.
  - Data should be encrypted.
  - Data should directly be sent from patients to doctors.

- The system should use software-based video conferencing.
  - The cost of using this system should minimized.
  - Users can use this system on directly their smartphone or laptop without any additional video or audio equipment.

- The system should be implemented by WebRTC technology.
  - The doctor-side application should be browser based, no need to install any other applications or plug-in, and can be accessed on any mobile devices and laptop/computer.

- The video quality of the conferencing should be acceptable.
  - The number of reconnection (if needed) of a session should be less than 2.
  - The number of frequency and duration of image artifacts (posterization, freeze frames, pixelization) in a one-hour session should be less than 8.

3.6 Feasibility of my solution

The key to feasibility of this quality and stability of video conferencing with existing WiFi, 3G/4G networks, and the condition of how widely it can be accepted by elders. There have been several studies on these matters.

In 2013-2014, Kai Zhang from Maryland U.S conducted a test of video conferencing quality on different devices under different network conditions. In the experiment, he tested a variety of video conferencing applications on both Android and iOS system under 3G, 4G and WiFi condition. 3 different mobile devices were used in the experiment in order to get a more representative result, which includes iPad, Galaxy and Nexus 7. The video quality judgment in this experiment was done by Kai Zhang and his team members, because not all of applications provided network jitter and packet loss. They determined the quality of videos by the frequency and duration of image artifacts (posterization, freeze frames, pixelization) during a 15–30-minutes test session. In their standard, good indicates there were no artifacts appeared or one to two very minor, and poor indicates artifacts appeared several times or consistently, or an application stopped and had to be restarted. In this experiment, applications performed poorly under 3G condition, whereas both iOS and Android applications performed acceptably under 4G and Wi-Fi condition. When mobile devices were moving, the data rate ranged from 104 Kbps to 1.2 Mbps, which increased to 1.2 to 1.3 Mbps when tested at a fixed location. The overall iOS and Android apps' averages were about 400–600 Kbps.[7]

Similar experiments have been conducted in Australia. During 2013 to 2014, the Flinders Telehealth in the Home trial (FTH trial) that was conducted in South Australia. In this trial, the clinical care was delivered from the Repatriation General Hospital, Adelaide, South Australia. All participants were over 65 years old and were lent Apple iPad tablets. They received video calls from doctors on their loaned iPads at home and had medical sessions with their doctors. The connectivity in this telemedicine process was achieved by fixed line fiber to the premise network (FTTP) from the Australian National Broadband Network (NBN), or 3G/4G provided by Telstra. The quality of telemedicine sessions was determined by the failure and re-established number call, the absent or delayed audio or video, significant pixilation of the video and the feedback from patients. As a result, of all 1021 sessions, 91.67% were considered successful, 71.6% of telemedicine sessions were considered mere effective or equivalent to a traditional home visit, and the telemedicine experience was considered better than or equivalent to a traditional home visit under 90.3%, judged by clinicians.[23]

Furthermore, Australia's mobile and fiber-optic networks are growing rapidly, which makes existing network conditions better than those described in the experiments above. In 2017, the average mobile network's download rate and upload rate in Australia was 44.2 Mbps and 14.32 Mbps, and the download rate and upload rate for fixed broadband was 24.12 Mbps and 8.48 Mbps.[24] 99.4% of the Australian population are able to access mobile services at home in 2019, 11.7 million premises will be ready to connect to NBN by mid-2020 and 70% of regional households will have access to a fixed broadband connection at the end of the NBN rollout 3.[24]

Moreover, in 2012 to 2013, 46% of older persons over 65 years old were internet users and 44% accessed the internet from home in the last 12 months.[25] It is reasonable to assume these values is higher now in 2020. This means although older people are unlikely to be able to use complicated computer functions such as software installation, a large amount of them have the ability to use the Internet and open websites, which is almost the only requirement of the browser based WebRTC system for users, making it easier to be accepted and used by elders.

In conclusion, above data and research prove the telemedicine system with WebRTC software-based video conferencing function is feasible in Australia and is likely to be accepted by elder CVDs patients.

Chapter 4 - Methodology

4.1 React-native

React Native is used for the patient side mobile application.

React Native is an open-source framework for building Android and IOS applications. It uses a React-liked language, allows developers to describe the appearance and behavior of their user interfaces using React components and access the APIs of their platform using JavaScript.

When developing an APP for cell phones or iPad, the compatibility issues between Android and iOS have been a problem. The two systems have different UI components and methods of operation, as a result they need separate applications using different programming languages. For Android, Kotlin and Java is widely used, and Swift and Objective-C are languages for iOS. In order to run on both devices, developers have to develop two different applications in multiple languages, which increase the amount of work for developers in development.[26]

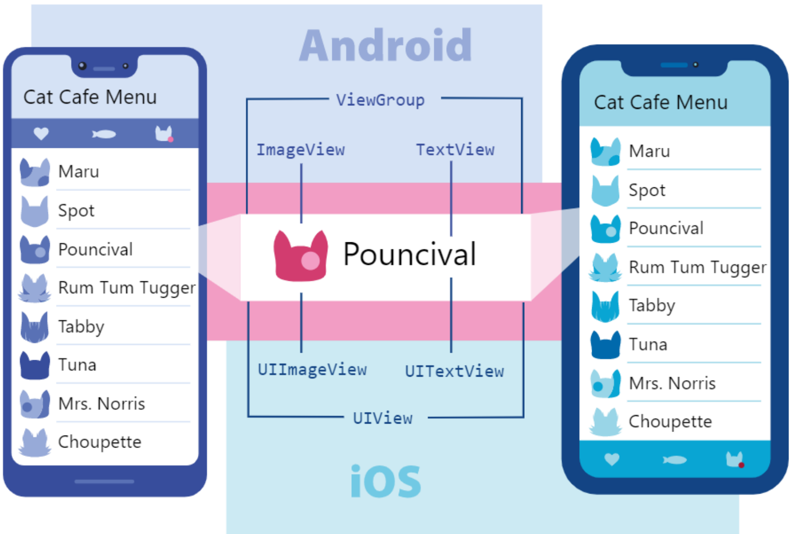

Figure 7: Compatibility of Android and iOS

React-native can create Android and iOS views with React components, these components are called native components, they are backed by Android and iOS components with the same view, and therefore compatible on both Android and iOS devices. It provides a set of encapsulated ready-to-use native components called core components for developers to develop their applications conveniently. Developers can also build their own native components for Android and iOS to fulfil the requirement of their products. The new native components they create can be uploaded to the react-native community to serve as new ready-to-use components for other developers.[26]

REACT NATIVE UI COMPONENT	ANDROID VIEW	IOS VIEW	WEB ANALOG	DESCRIPTION
`<View>`	`<ViewGroup>`	`<UIView>`	A non-scrollling `<div>`	A container that supports layout with flexbox, style, some touch handling, and accessibility controls
`<Text>`	`<TextView>`	`<UITextView>`	`<p>`	Displays, styles, and nests strings of text and even handles touch events
`<Image>`	`<ImageView>`	`<UIImageView>`	`<img>`	Displays different types of images
`<ScrollView>`	`<ScrollView>`	`<UIScrollView>`	`<div>`	A generic scrolling container that can contain multiple components and views
`<TextInput>`	`<EditText>`	`<UITextField>`	`<input type="text">`	Allows the user to enter text

Figure 8: React native, Android, iOS and web components

React-native decreases the needs of learning multiple languages and making multiple systems in the mobile application development. It is very similar to React, with simple learning, a React web application developer should be able to develop Android and iOS applications, which previously required learning for at least two additional languages. Furthermore, because it uses react-liked language, a react-native mobile application has the ability to be transferred to a react web application. As it was advertised, “Learn once, write everything.”.[26]

4.2 Twilio & React-native-twilio-video-webrtc

In my system, the doctor side web application used standard Twilio JavaScript SDK, and the patient side react-native application used an open-source module “react-native-twilio-video-webrtc”.

The video conferencing system is implemented using Twilio, which is a WebRTC product, possessing all the advantages of WebRTC. It is a cloud computing technology, providing service as a Twilio cloud, developers can use the account id and authority token of their Twilio account in their applications to use its services. It provides JavaScript SDK for Web application development, Android SDK and iOS SDK for APP development on multiple platforms. It provides built APIs that allows developers to set up video conferencing connections and send data without considering too much underlying details like multimedia digital signal.[27]

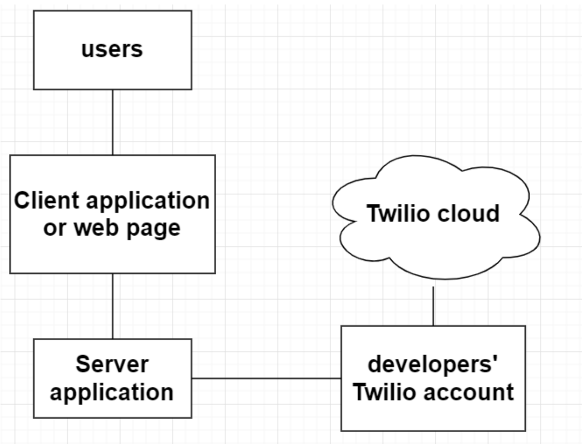

Figure 9: Structure of Twilio products

Twilio services are architected in two layers: Signaling Plane and Media Plane. Signaling Plane is responsible for information control, it will make agreements among participants about what will be communicated (e.g., audio, video, etc.) and how will them be communicated. (e.g., codecs, formats, etc.) Media Plane is the information itself; it transports encoded and encrypted audio and video bits.[28] In Twilio, a video conference is called a room, and users using that room are call participants. Each room has a room name, all rooms created by a Twilio account must have unique room names. [29] The data transmitted between participants are called tracks, there are 3 different tracks: audio track, video track and data track. Audio track is a stream of bytes generated by an audio source like a microphone, video track is a stream of bytes from a video source like a screen, and data track the arbitrary data participants send to each other.[30] Twilio uses publisher and subscriber model, a track published by a participant will be subscribed to other participants.[27]

Twilio provides 3 kind of rooms: Peer-to-peer (P2P) Room, Small Group Room and Group Room. Their respective maximum number of participants is 10, 4 and 50 ether of them is enough for a medical session. Data in Peer-to-peer Room is encrypted end-to-end (E2E), it will be directly transmitted between participants. Twilio will not mediate in the Peer-to-peer media exchange, it is only responsible for setting up the connection between participants. Small Group Room and Group Room does not have these features, and data in these rooms does not have E2E encryption. Based on thesis features, P2P room is used for the video conferencing system, because it can ensure the security of the medical information of patients better.[28]

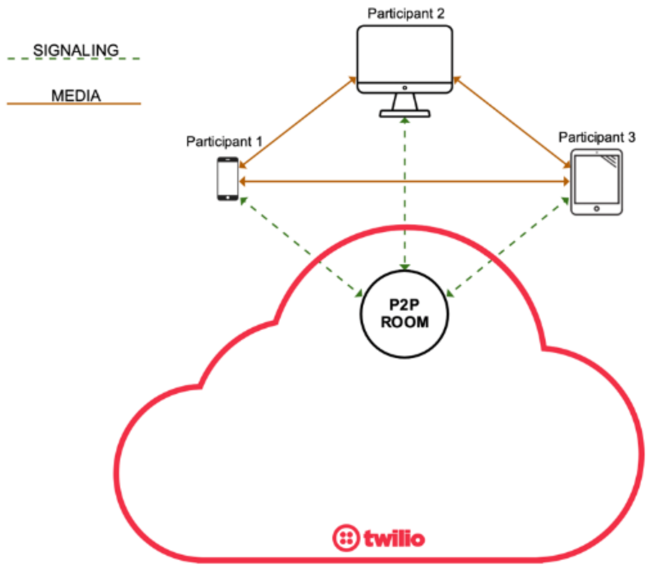

Figure 10: Structure of Twilio P2P rooms

There are 2 ways to create a room in Twilio, sending POST request to Twilio REST API and using SDK connect primitive. The first way will create an empty room before any participants join in, the room will be destroyed if it remains empty for 5 minutes after the creation. it will be destroyed 5 minutes after the last participant leave the room. Each participant can connect to the room for 4 hours, after which they will be automatically disconnected. Rooms created by the second way are called Ad-hoc rooms, it will be created at the time the first participant join the room and destroyed after the last participant leave the room. The maximum connection hour for each participant in Ad-hoc rooms is also 4 hours, enough for a medical session. The first method is normally used in the backend, when all rooms must be created by servers, and second way can be used in the frontend, when client-side room creation is allowed. [28] In this system, only the doctor side application is allowed to create a new room, and the second way is used.

The program for creating an Ad-hoc rooms in the web frontend using JavaScript is similar to this:

```
const { connect } = require('twilio-video');
//Requires the access token created by the backend server
connect('$TOKEN', { name:'ROOM_NAME' }).then(room => {
  console.log(`Successfully joined a Room: ${room}`);
  room.on('participantConnected', participant => {
    console.log(`A remote Participant connected: ${participant}`);
  });
}, error => {
  console.error(`Unable to connect to Room: ${error.message}`);
});
```

The room names for rooms created by a Twilio account must be unique, because if the room with the room name is already existed, above program will join in the existing room rather than create a new room with this room name.[29]

Because Twilio does not has a standard SDK for react-native application, an additional open-source module called "react-native-twilio-video-webrtc" is used to allow the patient side application to utilize Twilio. This module allows react-native application to used Twilio WebRTC easily by adding a <TwiloVideo> tag in the render function. It has pre-defined events including onParticipantAddedVideoTrack, onParticipantRemovedVideoTrack, onRoomDidConnect, onRoomDidDisconnect, and onRoomDidFailToConnect, corresponding to other participants joining the conferencing, leaving the conferencing, user himself joining the conferencing, leaving the conferencing and fall to join the conferencing. The developer can specify the behavior the application should take in these cases by binding functions to these events. [31]

```
<TwilioVideo
  ref="twilioVideo"
  onParticipantAddedVideoTrack={ this.addParticipant }
  onParticipantRemovedVideoTrack= { this.removeParticipant }
  onRoomDidConnect={ this.roomDidConnect }
  onRoomDidDisconnect={ this.roomDidDisconnect }
  onRoomDidFailToConnect= { this.roomDidFailToConnect }
/>
```

Users can join and exit meetings through its built-in "*connect*" and "*disconnect*" functions of this module similar to this: [31]

"**this.refs.twilioVideo.connect({ roomName: roomnameValue, accessToken: token})**"

"**this.refs.twilioVideo.disconnect()**"

It can also send real-time data through the Twilo data stream by "*sendString*" function like this: [31]

"**this.refs.twilioVideo.sendString(strResult)**"

For now, this module only support string transmitting through the Twilio data stream, more complex data transmitting function is still being developed. However, it's still powerful enough to support the sharing of medical data between doctors and patients generated by health care devices. [31]

4.3 Django

Django is a web framework using Python. It uses MTV structure, divided a web application into 3 parts: model, template, and view which is the extension of traditional MVC (model, view, controller) framework.[32] In the MTV, M represents model, which is the ORM (Object oriental mapping) functions that manages the database. It allows developer to build databases tables as Python classes and automatically translate them into SQL command lines to build tables in a MySQL database. It also provides some functions to modify tables (edit, delete, search etc.). Django ORM functions eliminating the need for developers to write SQL commands by themselves, makes the development process simpler and more straightforward.[33][34]

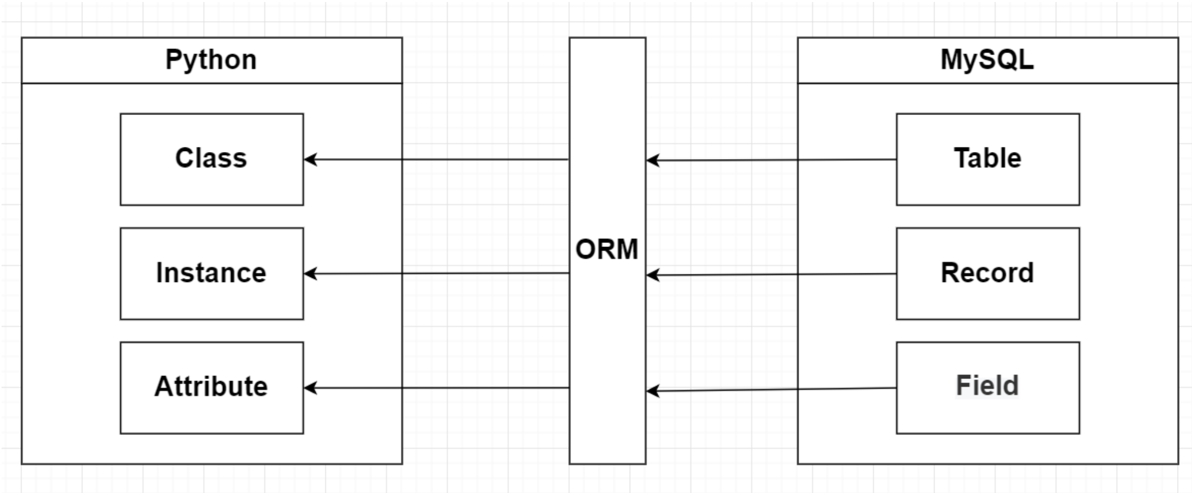

Figure 11: Structure of Django ORM

T stands for template, and V stands for view. It breaks the view part in the traditional MVC framework into two parts: what will be seen by users (view) and how will they see it (template).[35] Template contains frontend components, (HTML files, JavaScript files, Bootstrap frontend framework etc.) it is the part that directly interact with users. It provides the interface for users to interact with the system and present visualized data for users in most intuitive and user-friendly way.[36] View contains business logic, which is similar to the concept of view in SQL, it will decide what will be shown in the template. It is usually implemented in views.py file, which can define many different functions to handle various requests sent from users. [37]

Developers need to implement an URL dispatcher in the urls.py file, it will handle the requests sent from users and choose the corresponding view function to process this request. Together urls.py and views.py share the responsibility of the controller in MVC framework.[38]

For example, the process of Django receiving a request of visiting the test.html webpage then render some HTML tags in that file and show it to the user is similar to this:

In the urls.py:

```
from django.urls import path

from . import views

urlpatterns = [
    path('test/', views.test_func),
]
```

In the views.py:

```
from django.shortcuts import render

def test_func(request):
    views_dict = {"name":"test_name"}
    return render(request, "test.html", {"views_dict": views_dict})
```

In the test.html file in the template directory:

```
<p>{{ views_dict }}</p>
<p>{{ views_dict.name }}</p>
```

The whole process of Django framework handle a HTTP request is similar to this:

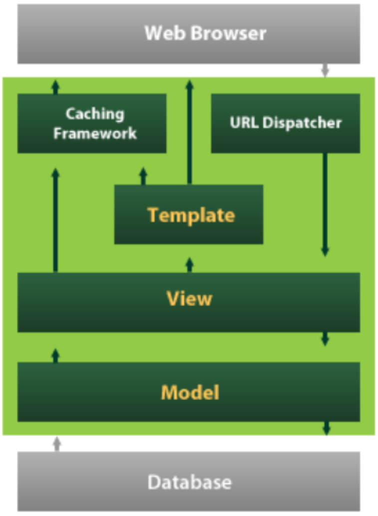

Figure 12: Process of Django handling a request

First, a user sends a HTTP request through the web browser to the Django web application. This request will be received by the URL dispatcher (urls.py) and it will choose a proper view function to handle this request. The chosen view function contains some business logic, it will decide what will the result be for the request. If it is needed, the view function will interact with the model to operate the database. (addition, editing, searching, deletion) After obtaining the result, the view will choose the correlated template file for the request and send the result to it. (render in a HTML tag, send a HTTP respond etc.) The template already has some existing frontend style defined by the developer, (HTML files with CSS and JavaScript, Bootstrap frontend framework etc.) it usually returns a

HTML page with the result to the user or use the result a to do some changes on the webpage the user is using. If it is needed, the result can be temporarily stored in a caching framework to be used in the future.

4.4 Bluetooth low energy (BLE) & react-native-ble-plx

Bluetooth low energy (BLE) is a technology widely used for the health care application. It was developed around 2010, compared with classic Bluetooth, it can greatly reduce power consumption while ensuring transmission range. BLE has been integrated into Bluetooth 4.0 in 2009, it uses ready-built infrastructure to lower the cost, be able to link wireless devices to 70% of phones and computers. [39][40]

BLE uses only 1 to 5 percent of the power of classic Bluetooth and has a transmission range of 15 to 30 meters, which is approximately the same as the range of traditional Bluetooth, which is maximum 30 meters. Same as the classic Bluetooth, BLE uses the unlicensed electromagnetic spectrum (2.4GHz), it uses 40 2MHz-wide channels, 3 of them are used for advertising, they have frequencies that can avoid interference with popular default WiFi channels. The rest 37 Channels are used for data transmitting. Its data transfer speed is 1Mbps, lower than that of classic Bluetooth, which using hopping technology in 79 1MHz-wide channels and had a data rate of 1 to 24MHz. Nevertheless, it is sufficient to support the data transmit between telemedicine devices and computers or phones. [40][41]

In addition to the advantages in energy saving, BLE also has outstanding performance in other aspects. A proper wireless connectivity technology for health care devices should fulfil following requirements:

- Interoperability
- Low-power operation
- Electromagnetic Compatibility
- Data Security

BLE is the first protocol that meets all of these requirements. [40]

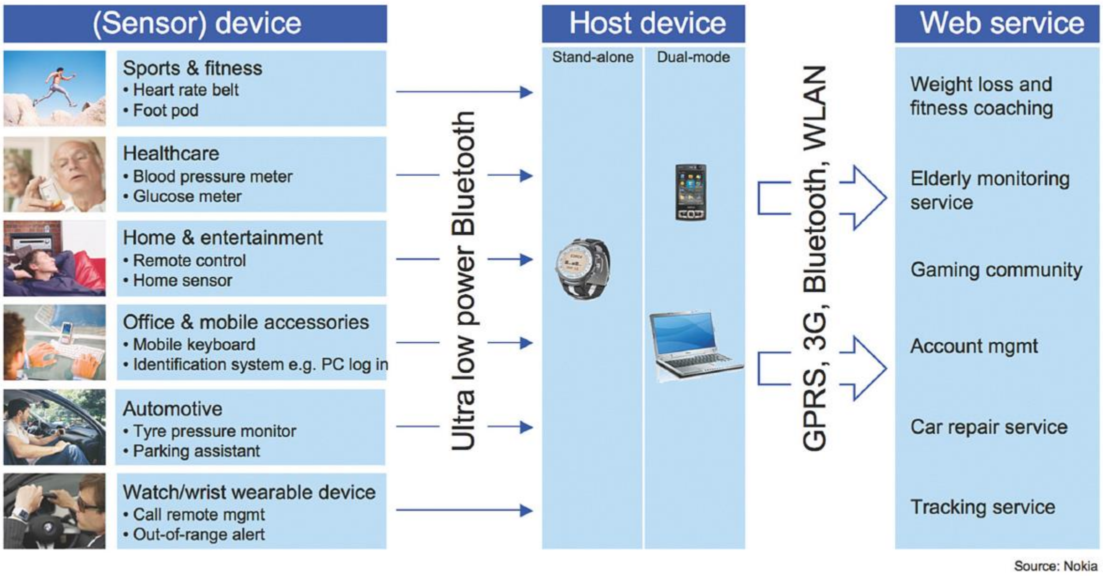

Figure 13: Bluetooth low energy used in health care devices.

Among all interoperable technologies, which includes Wi-Fi, ZigBee, classic Bluetooth, and Bluetooth low energy. BLE has lower cost than WiFi, higher data rate than ZigBee (250 kbps, only 1/4 of the data rate of BLE) and lower power consumption than classic Bluetooth. [40]

For the electromagnetic compatibility, health care wireless monitors need a strong ability of immunity from the interference of other radio sources to ensure communications. To achieve this, BLE uses the similar frequency hopping technology used in classic Bluetooth, which has been proven effective and reliable. In the connection phase, it will use one of its advertising channels to establish the link, is no signal is received, it will use the other 2 in turn. Once the connection is established, it will hop rapidly between its 37 data channels in a synchronized pseudo-random pattern to minimize the possibility of communicating in the same frequency with other radio resources. [40]

To ensure the confidentiality of the data it transits, BLE inherits the encryption, authentication, and authorization security algorithm from the classic Bluetooth. It used a standard-128 algorithm to encrypt the data, which is an encryption standard used by the US government. BLE also has the ability of employing privacy protection to prevent tracking, it uses a random address and change it frequently. [40]

React-native-ble-plx is a module developed to enable react-native to use BLE.

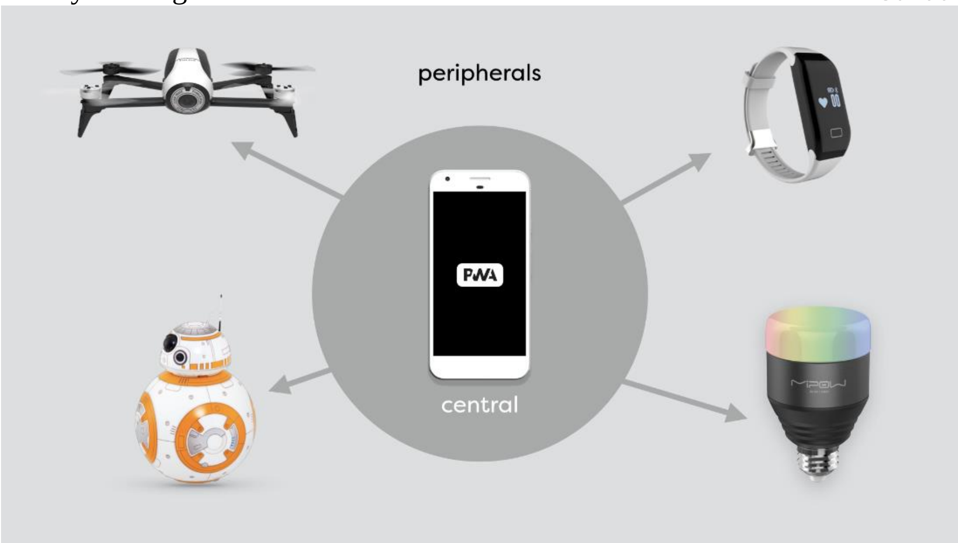

Figure 14: Structure of traditional Bluetooth

BLE treats devices as a central and several peripherals. Peripherals are Bluetooth devices having some specific functions like heart rate monitors, central is the device that receives and processes data from peripherals or sends data to control peripherals like a smartphone. Peripherals can transmit data to the central, but they cannot transmit data to each other. [42]

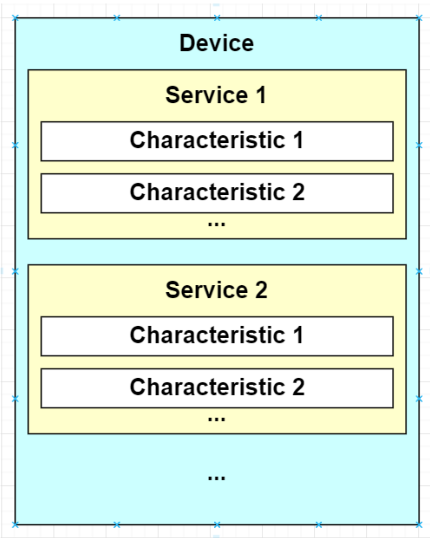

Figure 15: Structure of Bluetooth Low Energy

In BLE, peripherals are treated as devices. Each device provides several services, and the central sends requests to get these services. There are multiple characteristics inside each service, the values of these characteristics are the data related to the service. Each device, service and characteristic have a unique UUID to be identified. [43]

The react-native-ble-plx module could be easily called in react-native class constructor. [44]

```
import { BleManager } from 'react-native-ble-plx';

constructor() {
    super();
    this.manager = new BleManager();
    ...
}
```

It can let central scan devices using the following code: [44]

```
scanAndConnect() {
  this.manager.startDeviceScan(null, null, (error, device) => {
    if (error) {
      // Handle error (scanning will be stopped automatically)
      return
    }else{
      //Scaned device information is stored in the device variable
      ....
    }
    ...
  });
}
```

Then, it can connect to one of the scanned devices: [44]

```
device.connect()
    .then((device) => {
        return device.discoverAllServicesAndCharacteristics()
    })
    .then((device) => {
       // Do work on device with services and characteristics
    })
    .catch((error) => {
        // Handle errors
    });
```

After the connection is established, the discoverAllServicesAndCharacteristics() function can discover all service and characteristic information of the connected device. Then it can use functions like monitorCharacteristicForDevice() to monitor a selected characteristic of the device and receive the monitored value sent through the BLE signal. [44]

4.5 Testing environment of my system

The doctor-side and patient-side systems are developed on Windows computers.

In all tests, the patient-side mobile applications will be tested on an Android phone. Since the React Native is compatible with iOS system, the patient-side system also has the ability to work in iOS devices.

The doctor system will be tested under three conditions. First, the doctor side used a Windows system HP Pavllion laptop with a built-in camera and microphone, and the web application was run on the Chrome browser. This is an ideal experimental situation, using software-based video conferencing condition and equipment with the same operation system as the one development device. In this test, an external screen larger than the laptop itself was used to enlarge the frontend interface. Its goal was to test the results of the responsive design of the front-end page and its ability to adapt to different screen sizes.

In the second test, doctor side used a Canon EOS Series external camera, a Windows laptop and the Microsoft Edge browser. This test is to prove that although the system is designed for software video conferencing, it can still be compatible with devices using hardware video conferencing. In addition, Chrome browser, which was used during development, was not used in this experiment, and the goal was to prove that the doctor side system could be compatible with multiple browsers, because many hospitals would use other browsers instead of Chrome.

The third test was conducted on an Apple computer, using the Chrome browser with a built-in camera and microphone. The purpose of this experiment is to prove that the doctor's application can run in the IOS system. The patient-side application used a VPN, which caused the network condition to deteriorate to test the data transmission speed between the doctor and the patient under the low network speed.

In all tests, a BLE simulator was used to simulate Bluetooth medical devices of patients. It uses BLE protocol, is able to simulate the data transfer of real medical devices.

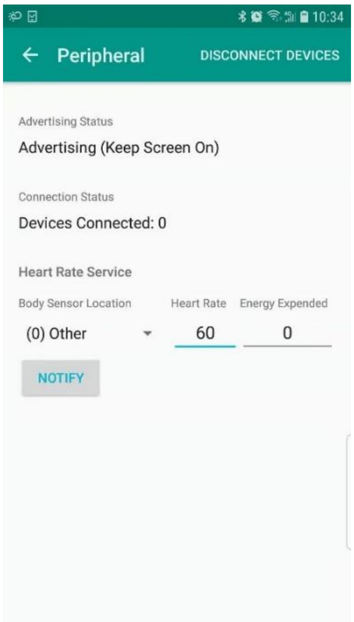

Figure 16: BLE simulator used in the tests

Chapter 5 – Result

5.1 Structure or my solution

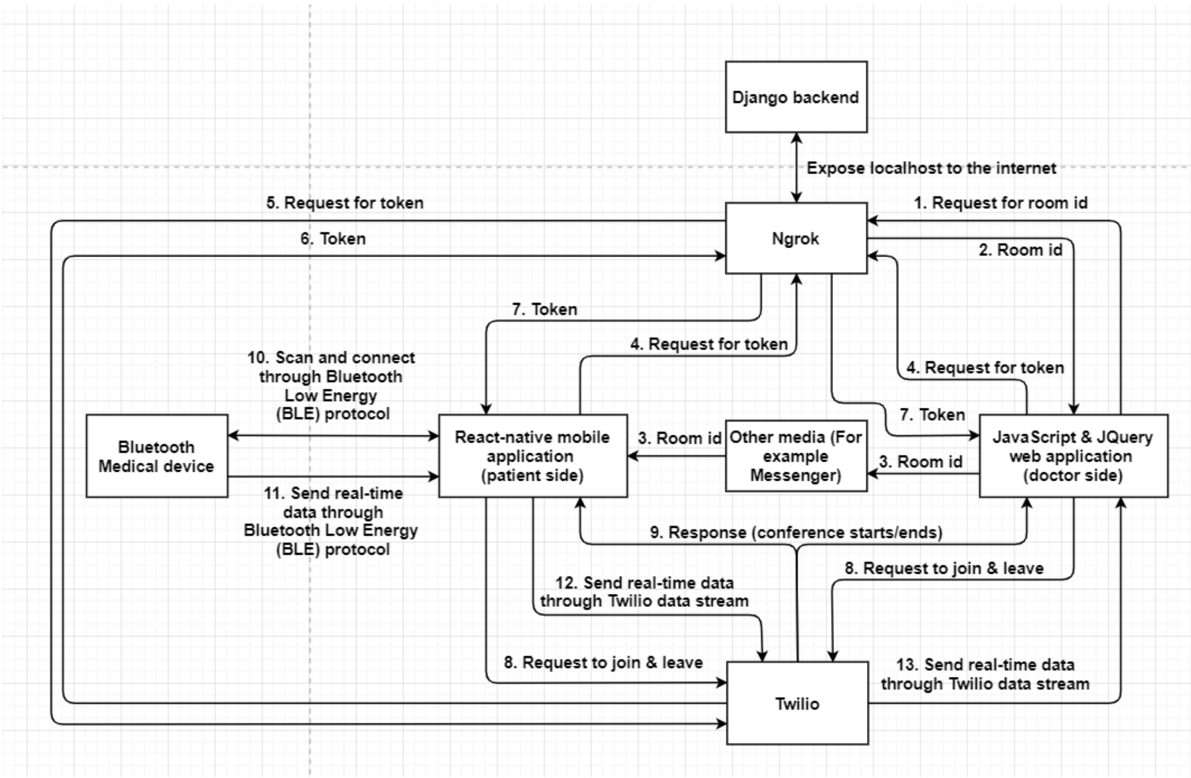

Figure 17: Structure of the system

The system will be constructed by 5 parts:

- Bluetooth telemedicine devices.
- The patient side react-native mobile application on a smartphone/laptop/computer.
- The doctor side Web application.
- A Django backend server.
- Twilio cloud.

The Bluetooth telemedicine device could be any wireless devices using BLE protocol, for example Bluetooth heart rate monitors, Bluetooth blood pressure monitors and Bluetooth stethoscopes. With the help of these instruments, the system can monitor real-time data like heart rate, blood pressure and auscultation results. This system can be used by smartphones, laptops, or computers as long as they have built-in microphones and cameras and some most used browsers like Foxfire and Chrome. For devices without a built-in camera, the system is also compatible with external microphones and cameras, allowing users to choose the video and audio devices used for video conferences. A Twilio account will be used by the web server to access the services provided by Twilio cloud. The frontend webpages will be implemented using JavaScript and jQuery.

The process of a medical video conferencing between a patient and a doctor:

1. A Doctor uses the browser on his smartphone/laptop/computer to access the web application (a website). Then click a “Create room” button to ask the backend to create a unique room name. The patient side mobile APP does not have this button, only doctors can create a new meeting room.
2. The backend creates a unique room name for the doctor, shows it on the website frontend interface and stores it in the live room name list.
3. The doctor can inform his patients through other social media like email, Messenger or phone.
4. The doctor input the room name and his username in the website frontend and click a “Join call” button, the patient can do the same on the patient side react-native APP. Then the web application and the mobile application will ask the backend for access tokens to enter the meeting room.
5. The backend will ask the Twilio cloud to create access tokens for the doctor and the patient using its Twilio API key.
6. After checking the validity of the API key possessed by the backend server, Twilio cloud will create access tokens and send them back to the server.
7. The server will send the tokens to the doctor side web application and the patient side mobile application.
8. After getting the tokens, patient and doctor side applications will automatically use them

to join the meeting room. The token can also be used when leave the meeting room.

9. Twilio establishes the connection of video, audio and data stream after getting the join room request, the meeting starts.

10. When the doctor and the patient are both in the room, the patient could click the “scan for device” button on the mobile application to scan for the Bluetooth medical device he wants to use. All scanned device names or their UUIDs will be shown in the application. After discovering the wanted device, the patient can click on its name to establish a connection with the device. the patient can also choose the service and characteristic of the device he wants to use.

11. After setting up the connection and selected the wanted service and characteristic, the application can start receiving the real-time data sent from the connected medical device.

12. The patient side application will send the real-time medical data to Twilio cloud, which is maintaining the data stream for the video conference. The medical data will be encrypted.

13. The Twilio cloud will forward the medical data to the doctor side web application though data stream of the video conference. The data will be shown in the frontend interface of the doctor side application to allow the doctor provide diagnoses and instructions for the patient.

5.2 My product

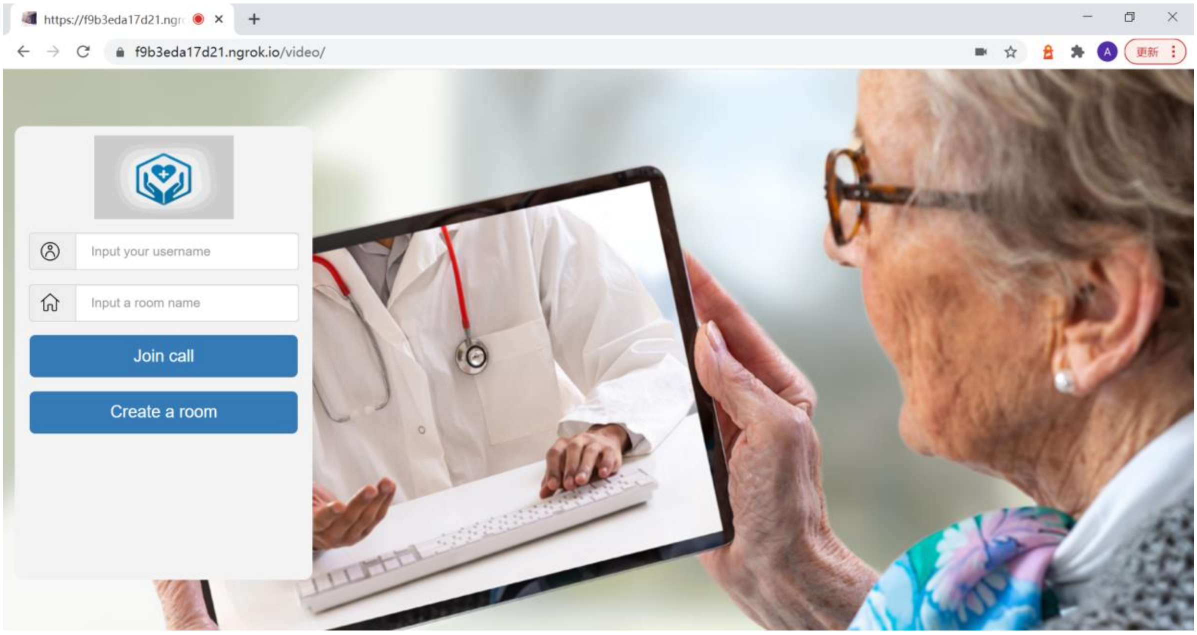

Figure 18: The join room page of the doctor side application

Doctors can open their browser and type in the URL (https://5883372ce004.ngrok/video in this case) to access the doctor-side web application. For now, the system does not have a fixed URL or domain name because it is using ngrok without a paid account, it can be improved in the future.

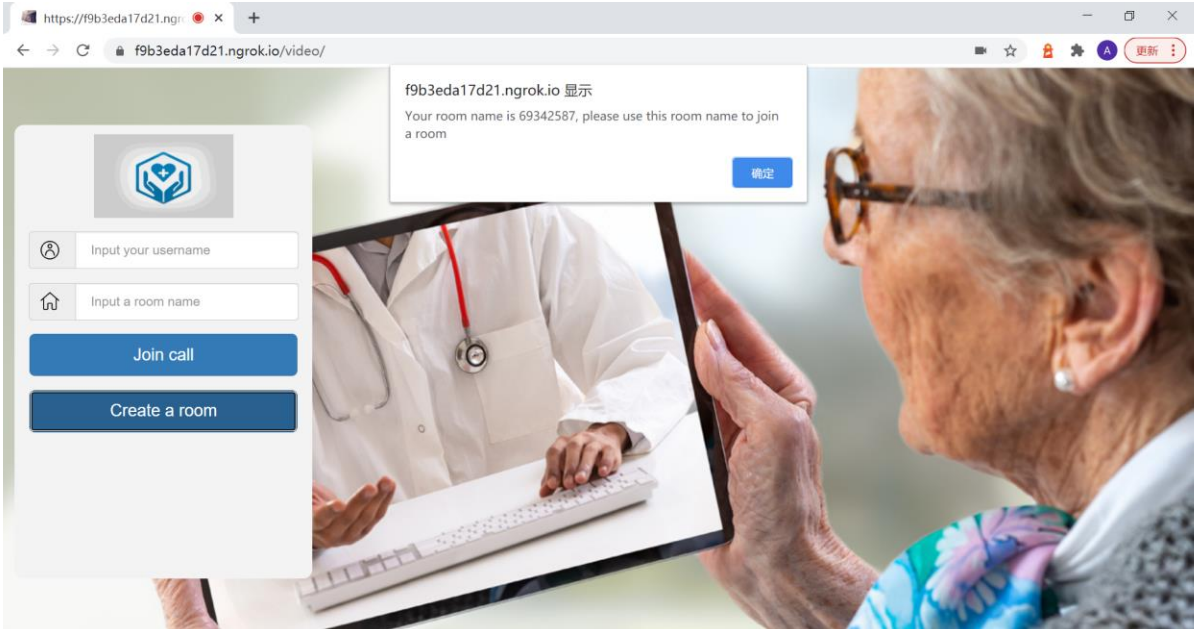

Figure 19: Clicking "Create a room" button in the doctor side application

Doctors can click the "Create a room" button to let the server generate unique names for them and store created names in the system. Because each Twilio room is identified by its name, so doctors are not allowed to create room name by themselves to eliminate duplication.

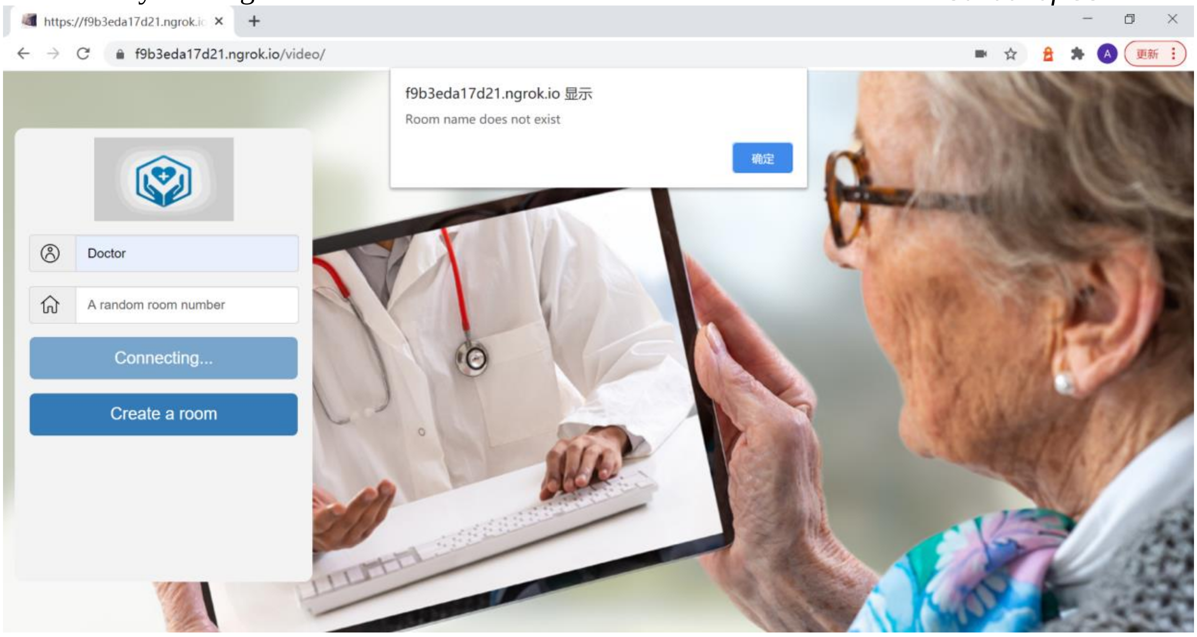

Figure 20: Inputting a random room number in the doctor side application

If a not stored room name is used, then the application will not join the room but report an error.

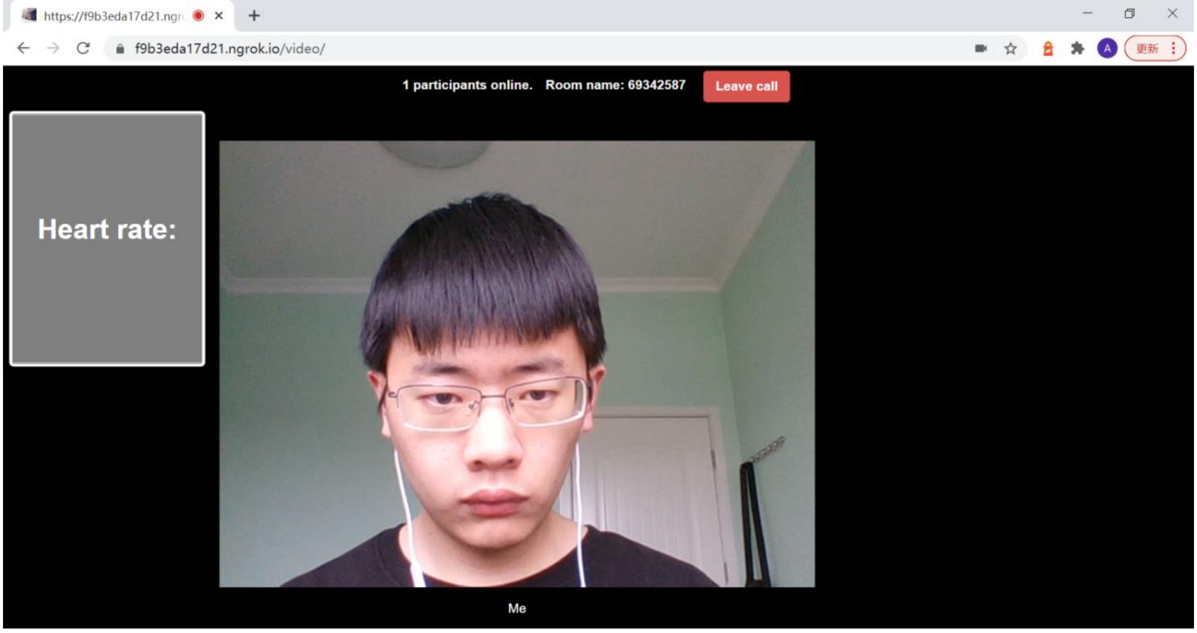

Figure 21: After joining a just created video room in the doctor side application

After joining the room, doctors can see themselves and wait for patients to join in. They have to tell the room name to their patients through other social media channels like email or phones. (it works like Zoom)

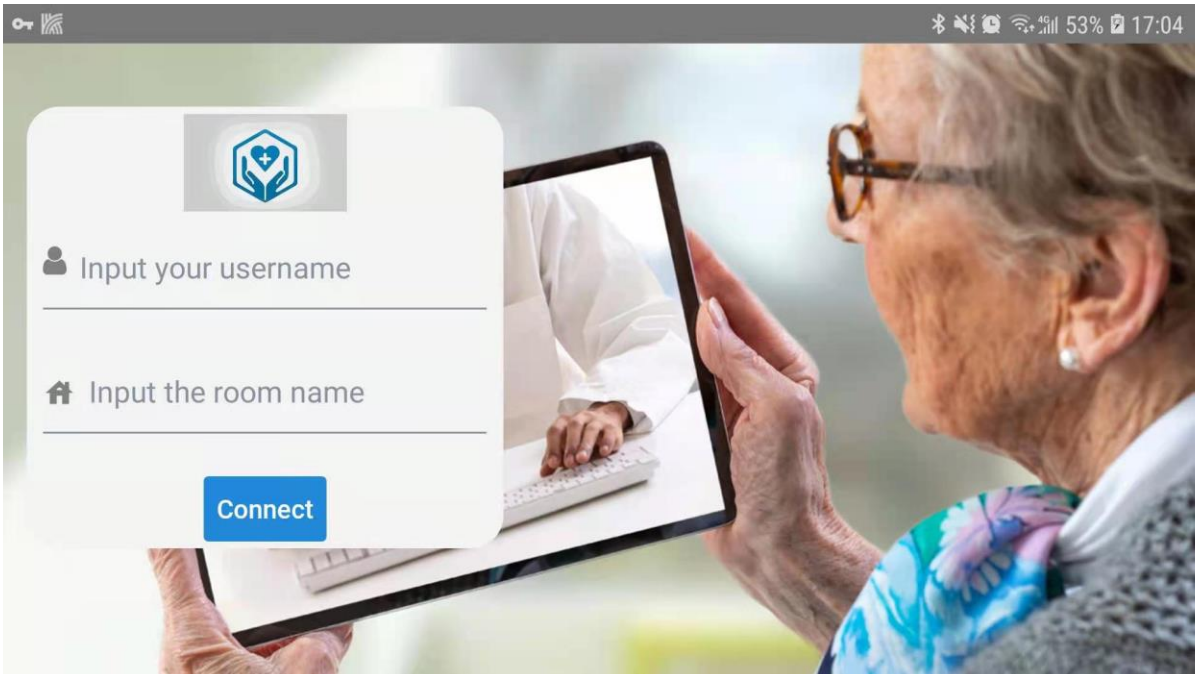

Figure 22: The join room page of the patient side application

Patients can access the patient-side mobile application from their phones or iPads. They do not have the “Create a room” button because only doctors are allowed to create rooms, patients can get room names from their doctors after they create the rooms.

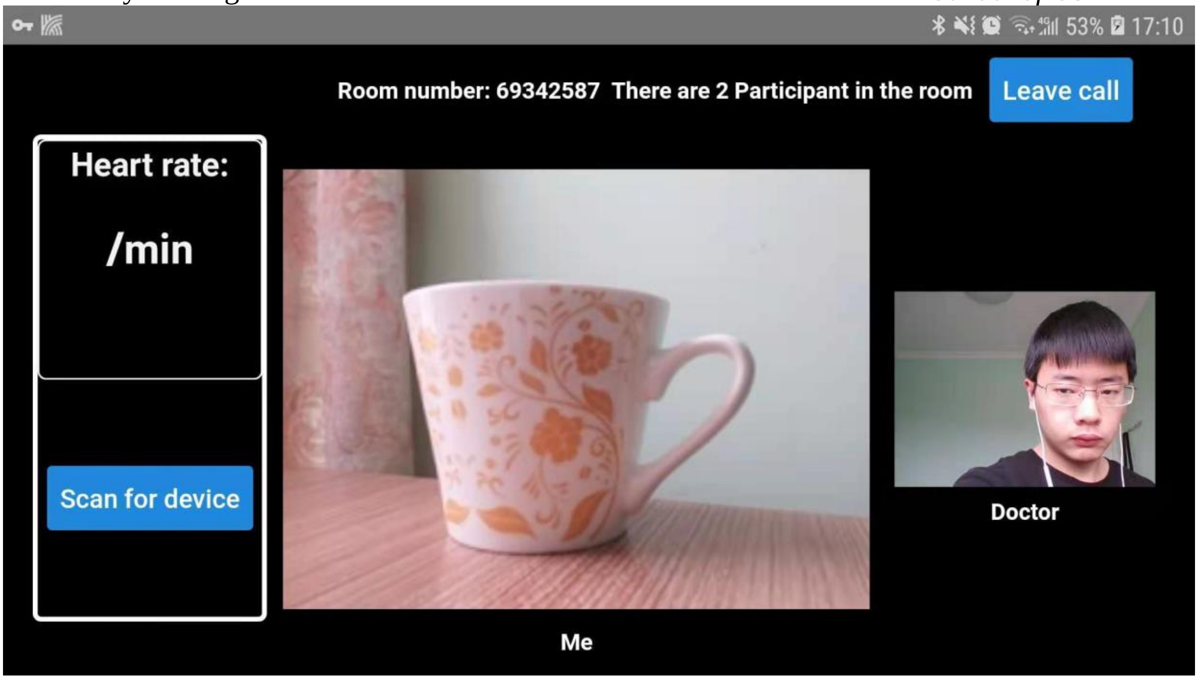

Figure 23: After joining a video room in the patient side application

Figure 24: Adjusting screen size in the patient side application

After joining the video conferencing room, patients can see their doctors' real-time image. They can touch the image of themselves or their doctor to make it bigger or smaller. The reason for not making the two screens the same size is to allow the user to resize the screen as needed to get a clearer image.

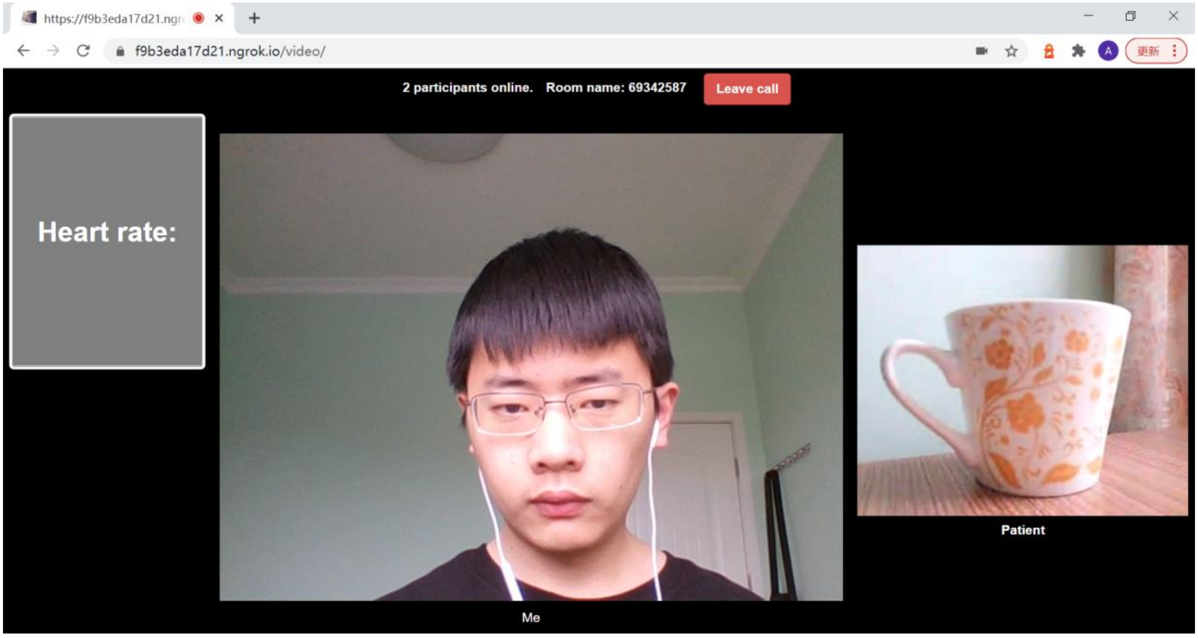

Figure 25: After patient joining the room in the doctor side application

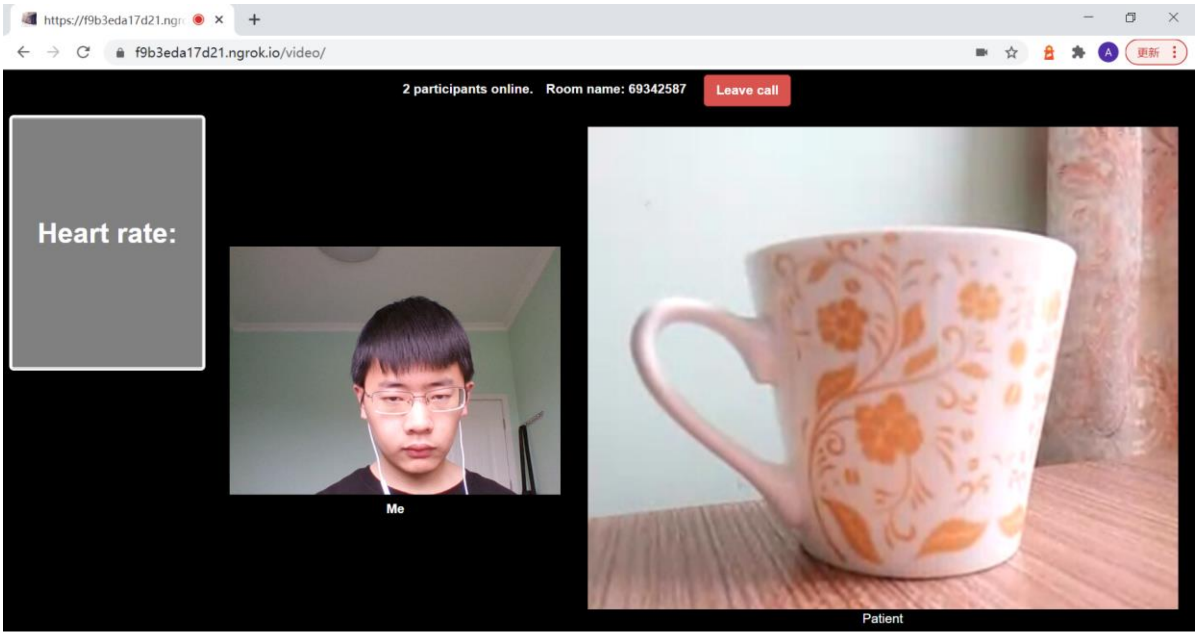

Figure 26: Adjusting screen size in the doctor side application

The doctor-side application also has the same screen adjusting ability.

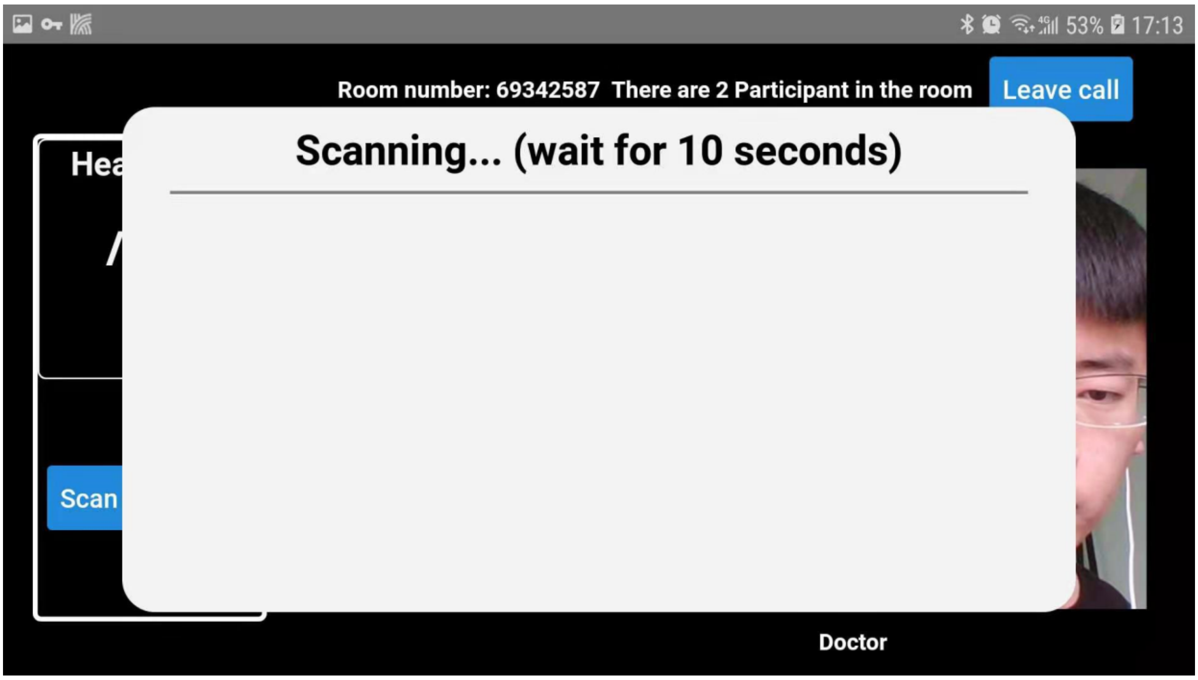

Figure 27: Clicking "Scan for device" button in the patient side application

When both the doctor and the patient are in the room, the patient can start scanning for their Bluetooth medical devices. The app takes a 10-second scan after the patient clicks the button.

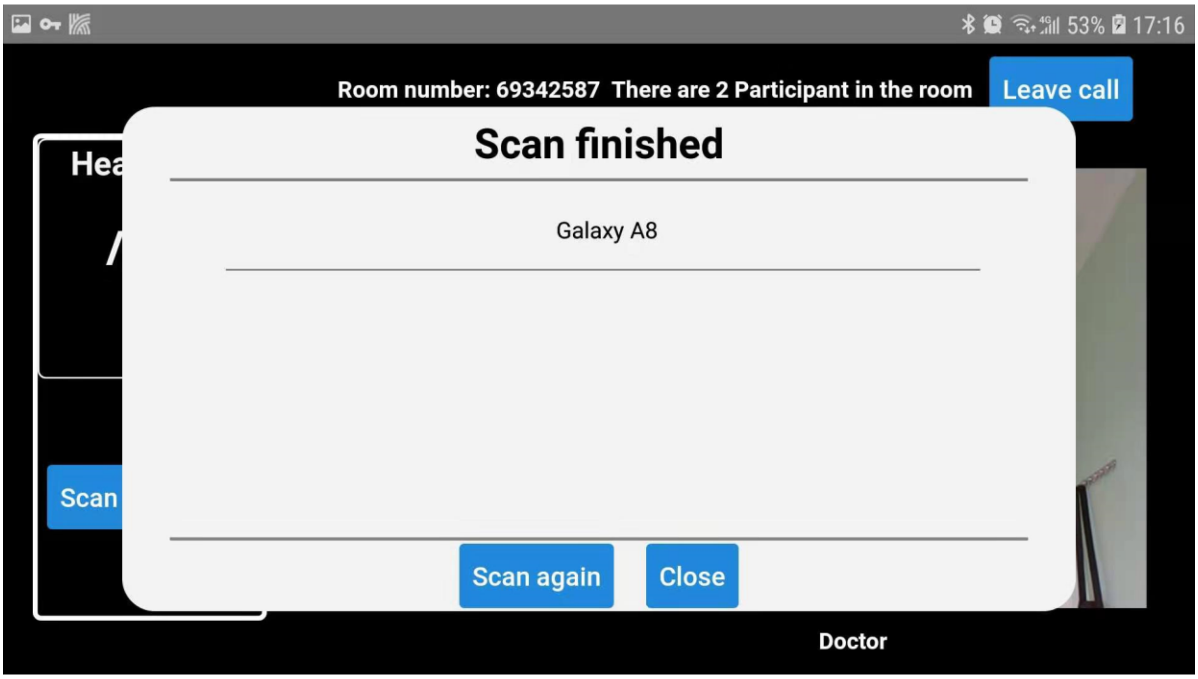

Figure 28: The scanning result of the patient side application

When the scanning is finished, all scanned devices name (or UUID if the device does not have a name) will be listed.

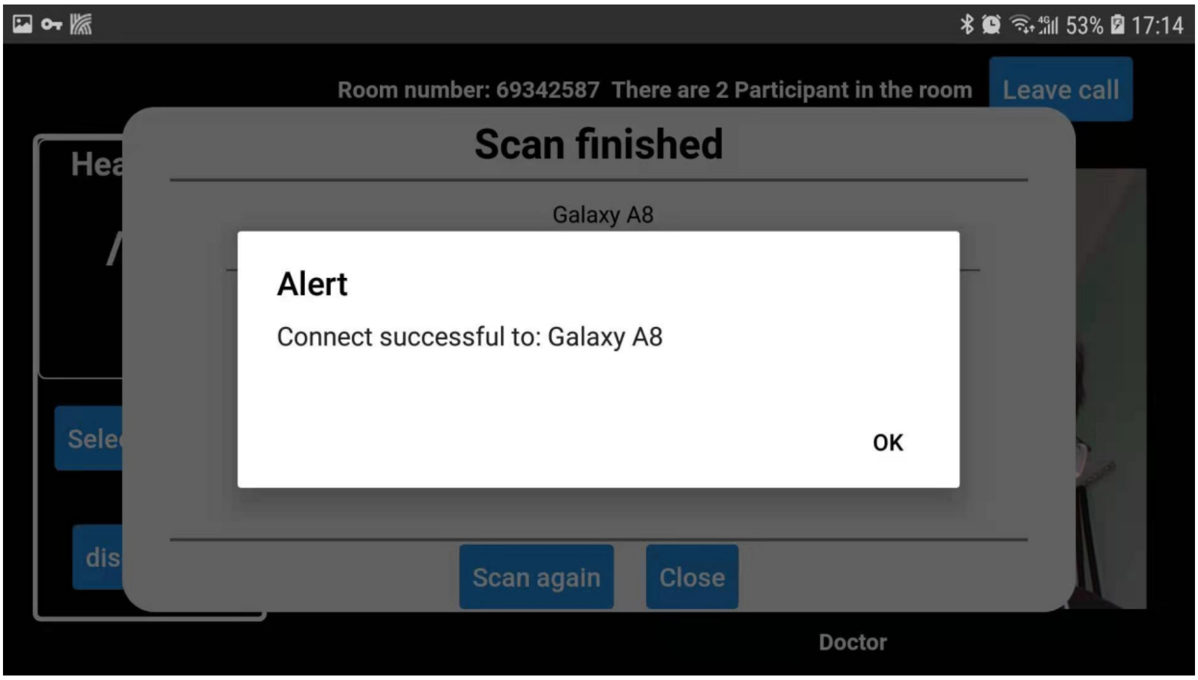

Figure 29: Connecting to a Bluetooth device in the patient side application

The patient can connect to the device by clicking on the listed device name.

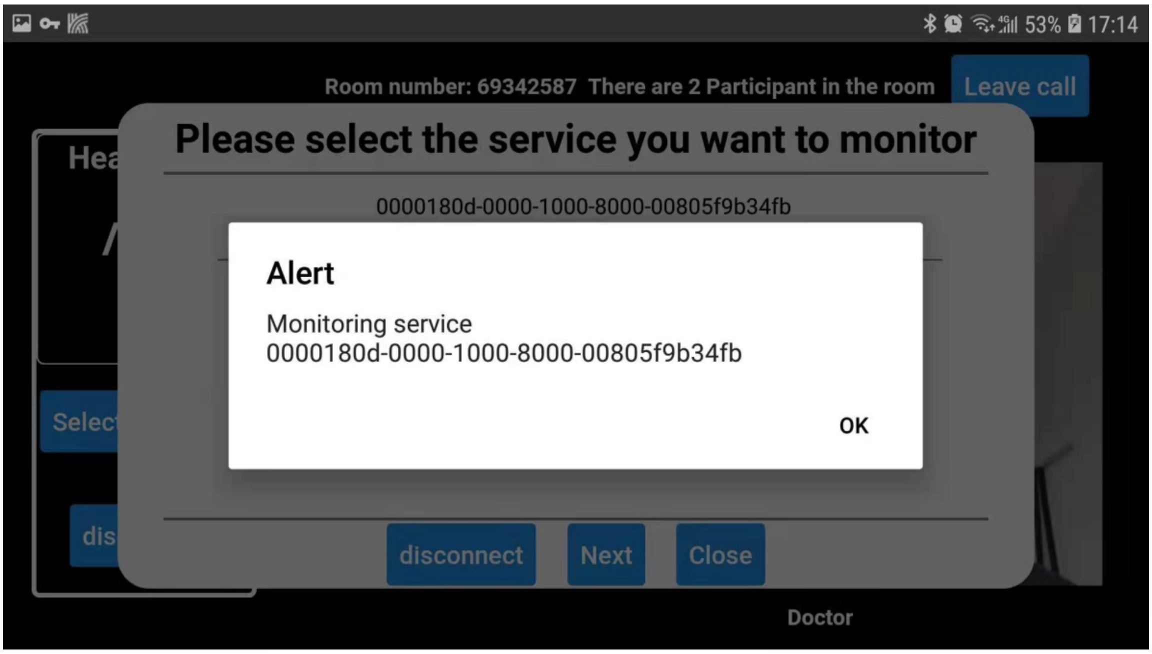

Figure 30: Selecting a BLE service in the patient side application

After connecting to the device, patients should then click the “Select a service” button to choose the service they want to use from the device. All services’ UUIDs will be listed, and patients can select a service by clicking on its UUID.

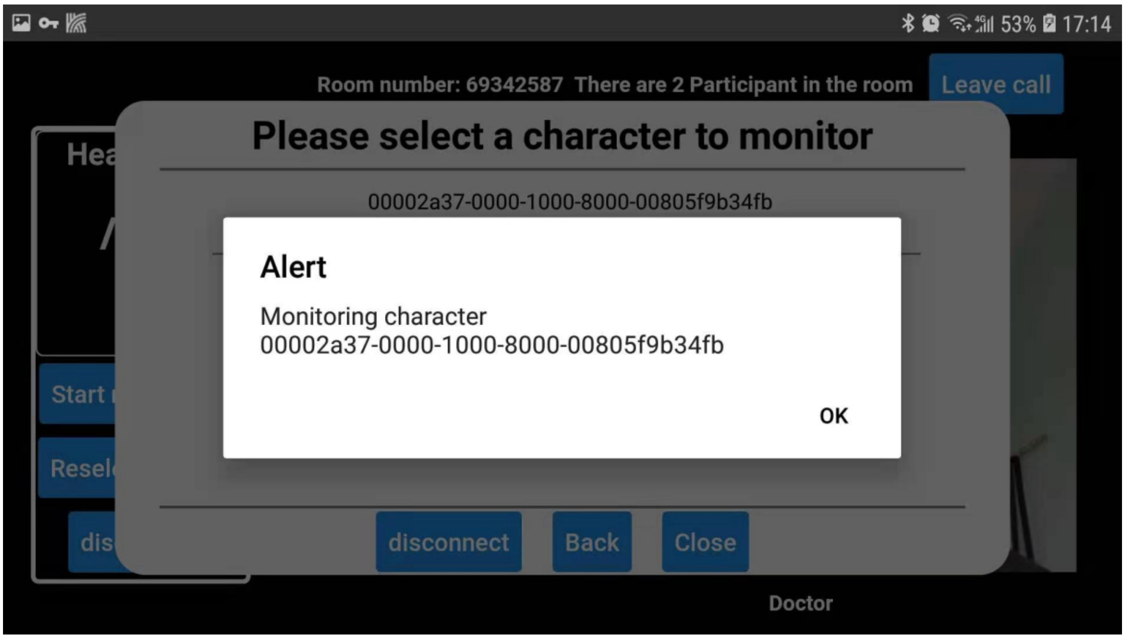

Figure 31: Selecting a BLE characteristic in the patient side application

Then patients can click the “Next” button to choose the characteristic of the service they want to monitor, all characteristics are shown and can be selected same as the service information.

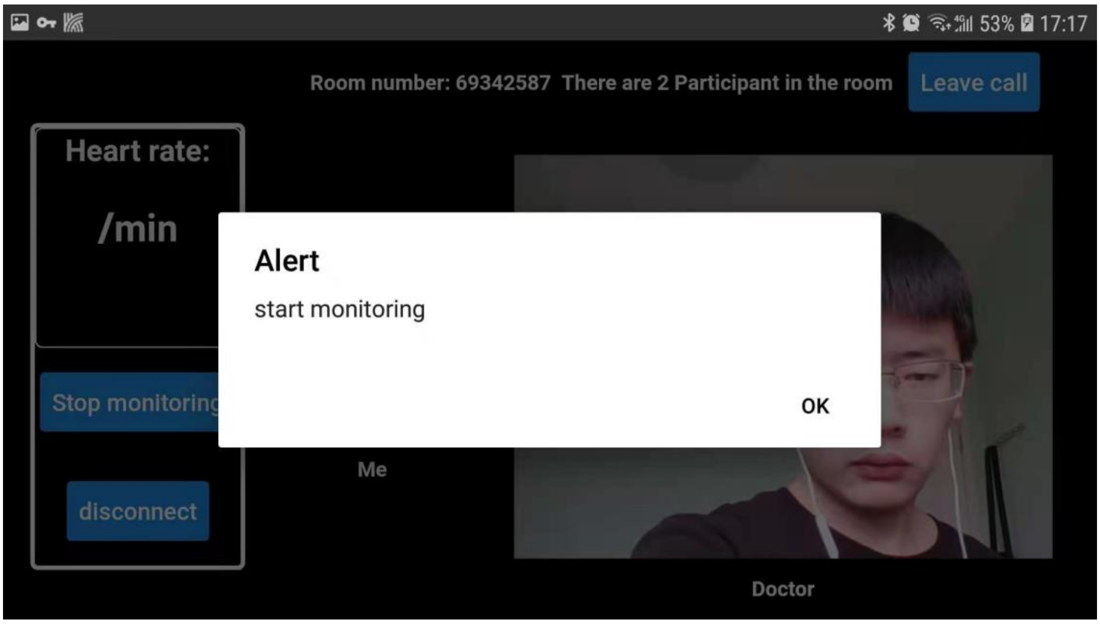

Figure 32: Starting monitoring in the patient side application

After both service and characteristic are selected, a "Start monitoring" button will appear, patients can let their application start to receive data from the connected medical device by clicking this button.

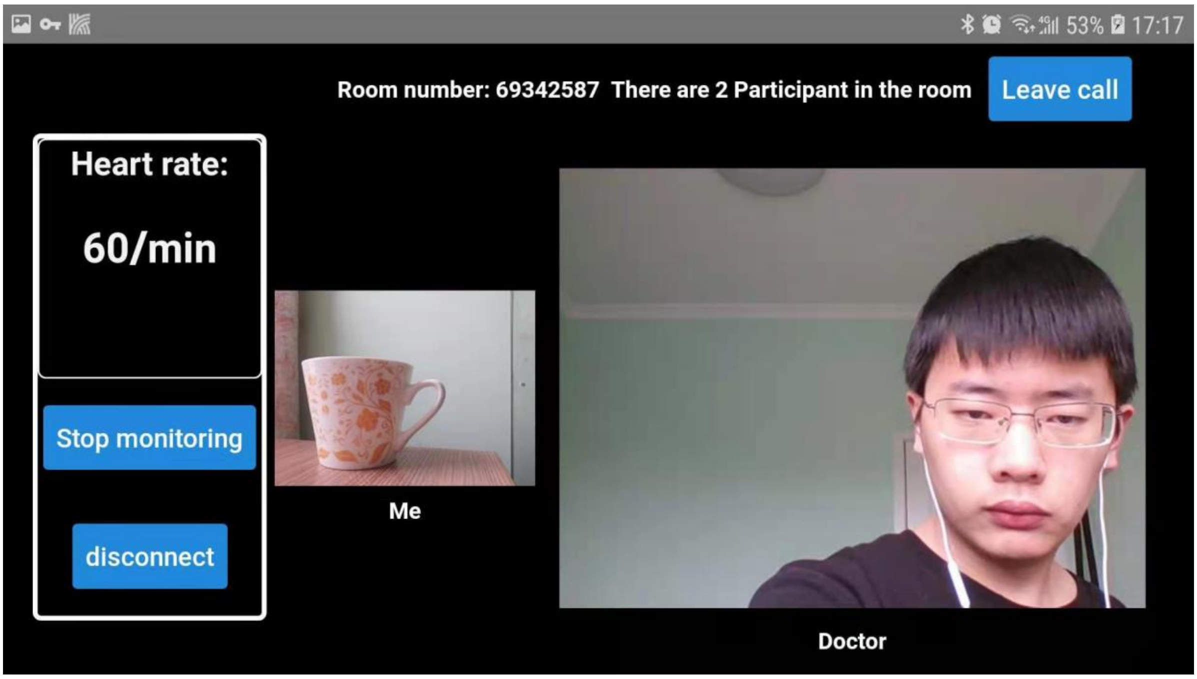

Figure 33: Receiving medical data in the patient side application

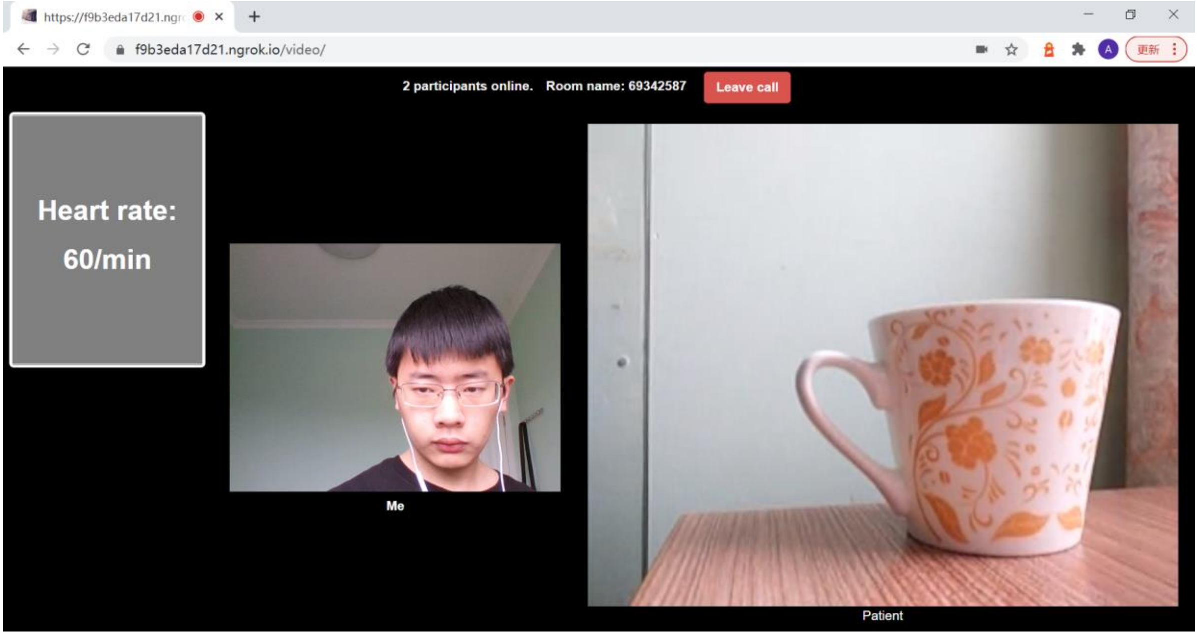

Figure 34: Receiving data shared by the patient side application in the patient side application

When receiving a data from the medical device, the patient side application will send the data to the doctor side through Twilio data stream. The data can be received by the doctor side in half a second.

5.3 Test result

For all tests, the patient side were all run on an Android system Samsung phone.

3 tested was conducted with doctor side used in different conditions. In all 3 tests the server was located in China, Xian, (the 'x' in the following figure) where the patient side was used. In test 1 and 3, doctor sides were used in Sydney, (the square in the following figure) and in test 2 the doctor side was used in China, DongGuan. (the circle in the following figure)

Figure 35: The location of 3 tests

Tests have shown that the system can operate internationally, allowing patients to receive a doctor's diagnosis even when they travel or work abroad.

Test 1:

The doctor side used a Windows system HP Pavllion laptop with a built-in camera and microphone, and the web application was run on the Chrome browser.

Doctor side:

Figure 36: The interface of the doctor side application in test 1

Patient side:

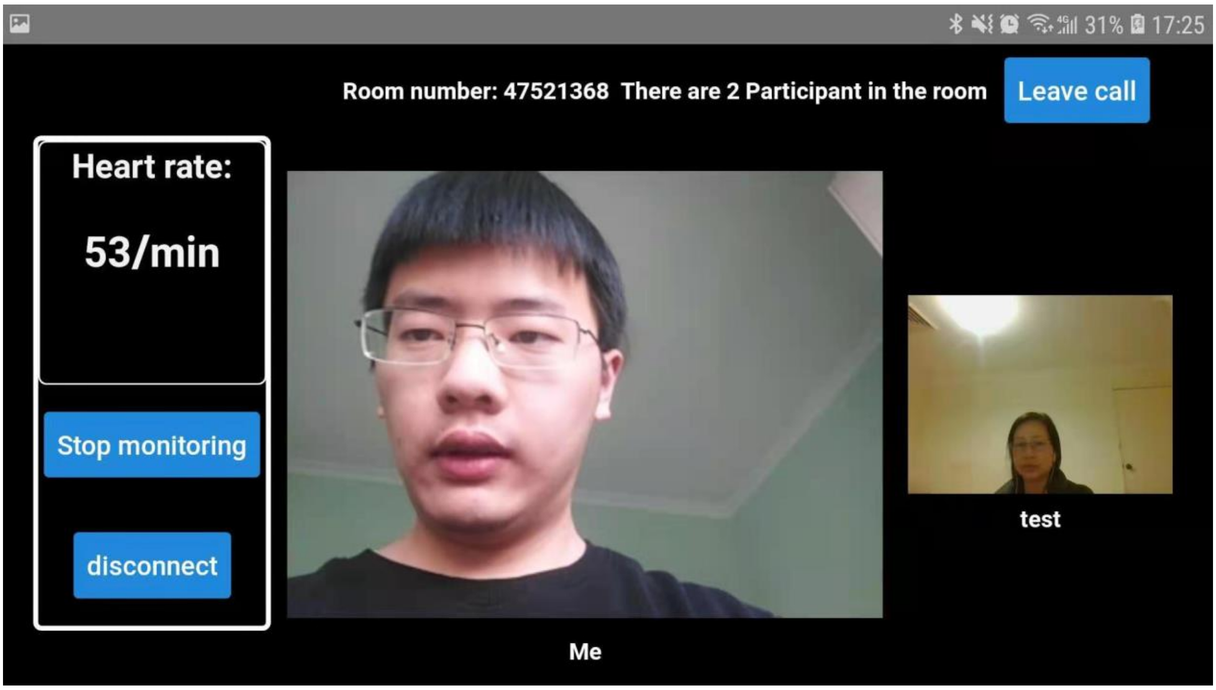

Figure 37: The interface of the patient side application in test 1

3-participants mode was also tested in this test, to simulate the situation of 1 patient use mobile application and 2 doctors used web applications to join the same room. The following figure is the performance of the patient side in the 3-participants mode, “Me” is the image captured by the phone’s camera, “test” is the image captured by the Pavllion laptop, and “Andrew2” is the second doctor in the conferencing room, it used a Windows ThinkPad laptop with Chrome browser.

Patient side:

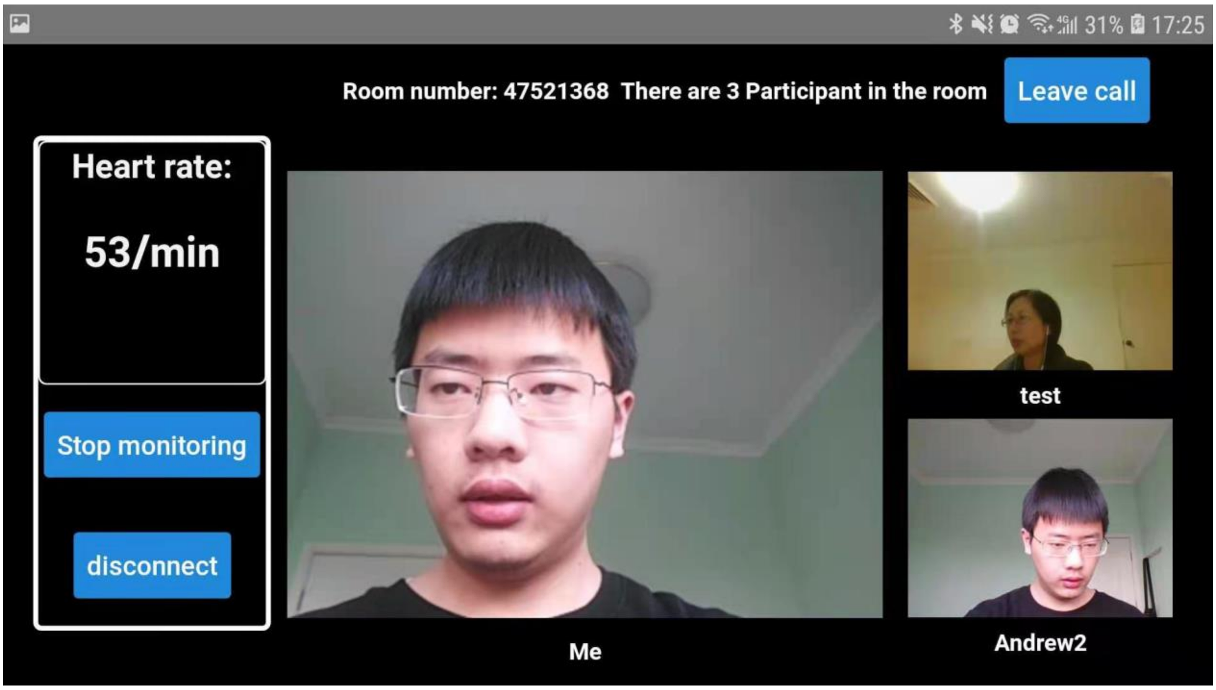

Figure 38: 3 participants mode interface of the patient side application in test 1

Doctor side:

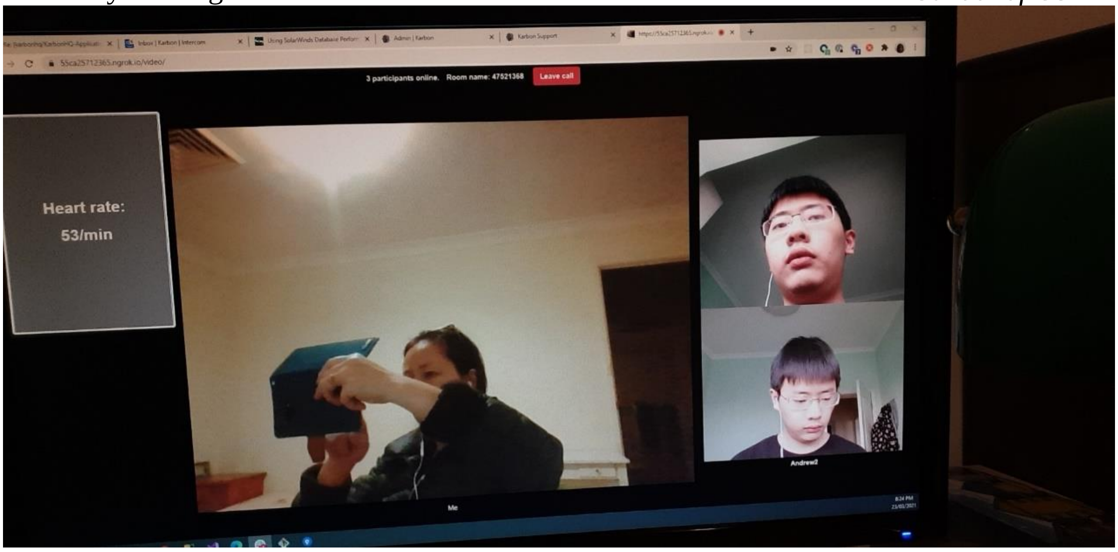

Figure 39: 3 participants mode interface of the doctor side application in test 1

In this test, the picture and sound quality remained clear, with no noise, delay, or blur. The data on the patient side can be received by the doctor side within half a second. When three participants joined the meeting, the picture and sound quality were not affected, and the data transmission time was still less than half a second. Overall, this was a successful test, with both the patient side and the doctor side applications achieving the desired performance.

Test 2

In this test doctor side used a Canon EOS Series external camera, a Windows laptop and the Microsoft Edge browser.

Patient side:

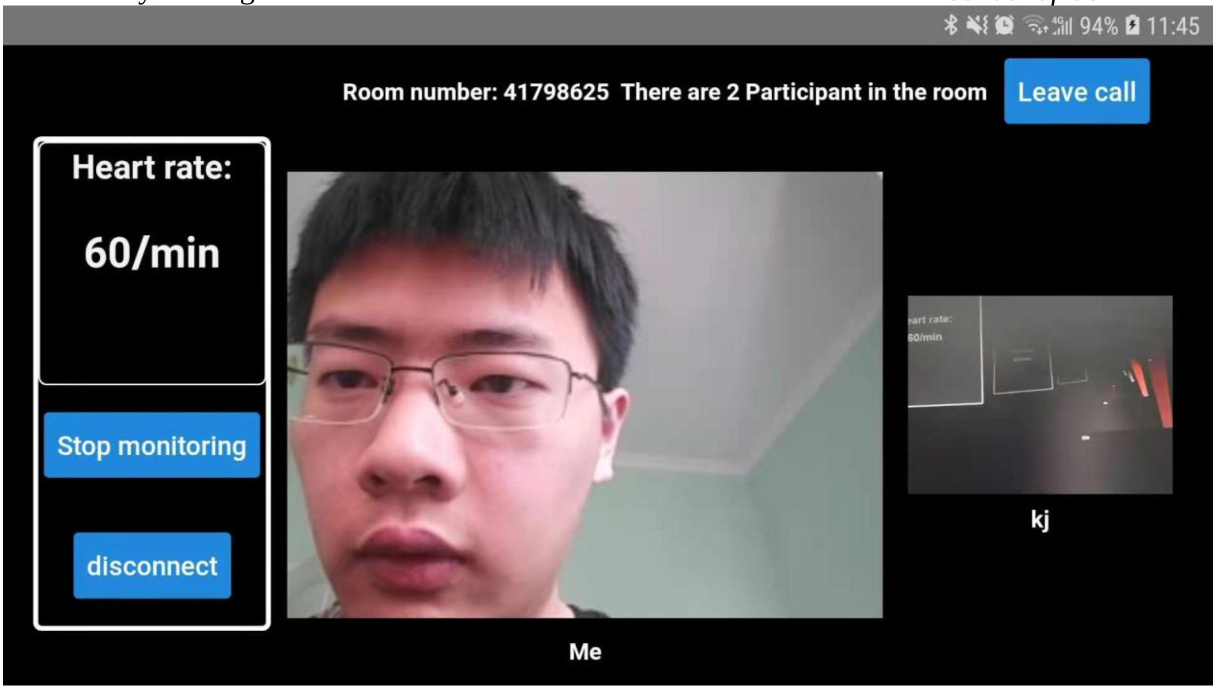

Figure 40: The interface of the patient side application in test 2

Unfortunately, in this test, the person who used the doctor side refused to show his face or room, therefore he pointed the external camera to the laptop screen, but the medical data on the patient side can still be seen matched the data on the doctor side.

The video and audio quality were excellent in this test, without any delays or blurring, and the picture was clearer than the other two tests, thanks to the use of the external camera with better resolution than the laptop embedded camera. The average data transmission time remained in half a second. In general, this test reached the desired result.

It also proved that although the system was designed for software-based video conferencing, it was still compatible for hardware-based video conferencing. This ability allows the system to run within existing hardware-based videoconferencing systems used by many hospitals, reducing the cost of using the system for doctors.

Test 3:

In this test, a registered nurse was asked to use the doctor-side application on an Apple computer, using the Chrome browser with a built-in camera and microphone. The patient-side application used a VPN, which caused the network condition to deteriorate to test the data transmission speed between the doctor and the patient under the low network speed. When using VPN, average download rate and upload rate were 26.83 Mbps and 14.99 Mbps. Without VPN, average rates were 36.98 Mbps and 40.42 Mbps.

Patient side:

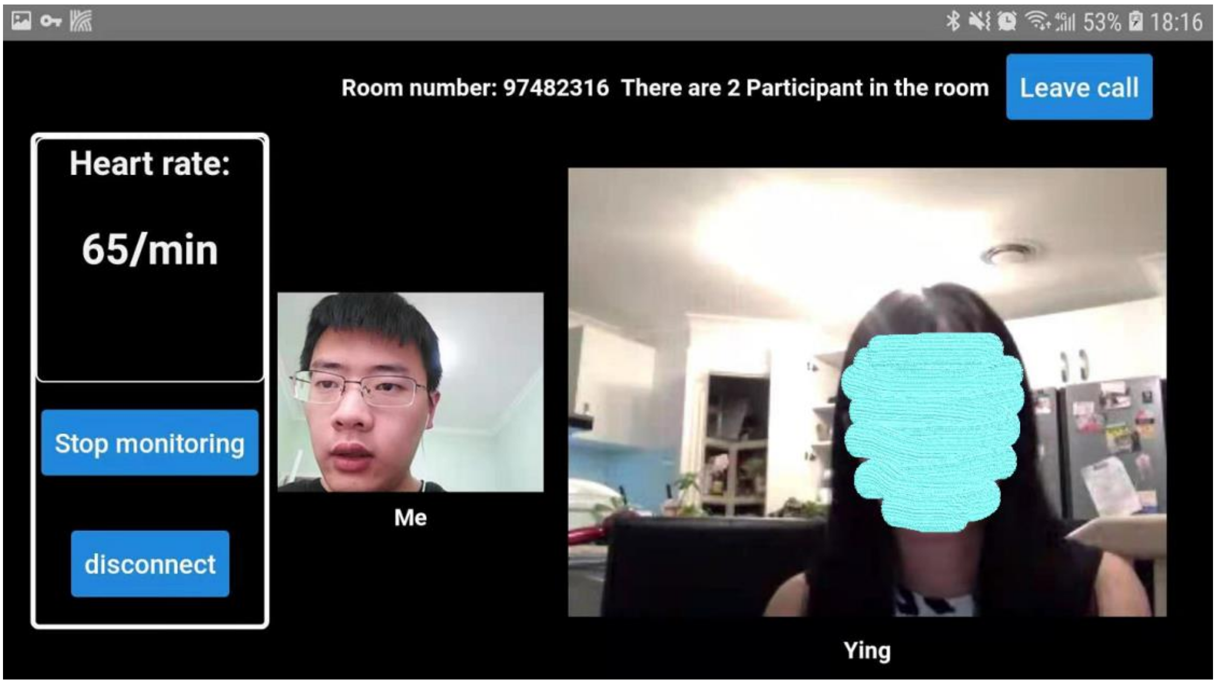

Figure 41: The interface of the patient side application in test 3

Doctor side: (before the patient joined)

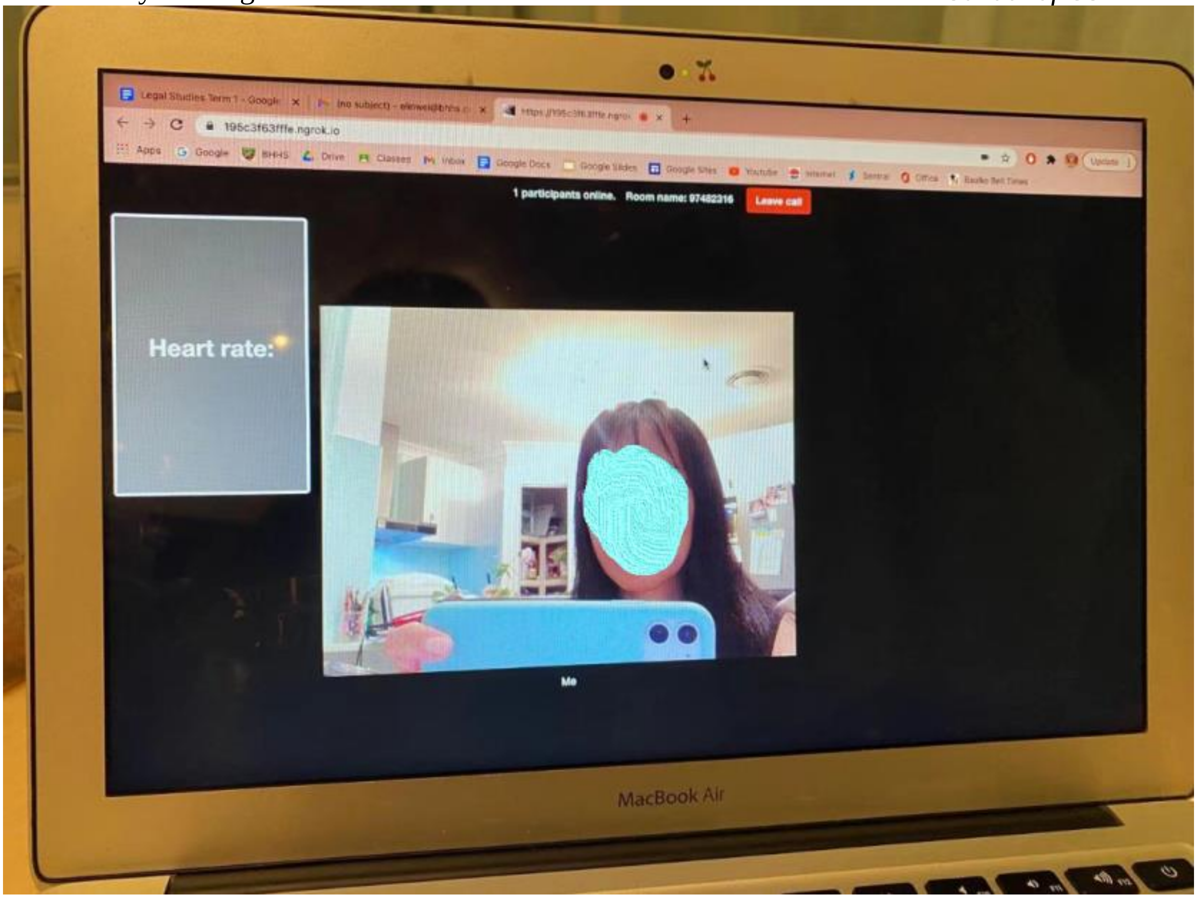

Figure 42: The interface of the doctor side application in test 3

In this experiment, When the doctor’s application is running on a Mac, all parts still work properly, demonstrating the system's ability to run across operating systems. Due to the decrease of the network speed, the picture quality began to become unclear and miscellany points began to appear, and the sound was sometimes delayed or stalled. Although affected, the conversation between the doctor side and the patient side applications could take place. The most important data transfer speed can still be maintained in this case, the doctor can still receive the data sent by the patient within half a second to a second. This test proves the ability of the system to operate normally under harsh network conditions.

Chapter 6 - Discussion

6.1 Result

The test results of this system prove the applicability of the system combined with Bluetooth low energy technology and software-based video conferencing ability in the telemedicine for heart disease.

Video conferencing allows doctors to provide real-time guidance and diagnosis to patients, especially those who lack medical knowledge. At the same time, the ability to connect directly to Bluetooth medical devices and transmit data in real time will allow doctors to obtain more information about patients and provide more accurate diagnoses.

The system relies on Twilio, an excellent WebRTC service provider, which provides high-quality video and audio transmission and encryption, and provides users with clear conversation conditions in video conferencing while ensuring privacy and security. It provides a series of ready-to-use APIs and SDKs that make it easy for developers to develop new applications with video functionality without paying attention to the underlying design. It also supports a steady stream of data in video conferencing, which can transmit data quickly and steadily even under poor network conditions.

Experiments have shown that the system is compatible with hardware-based video conferencing. When users' devices do not have embedded cameras or microphones, they can use traditional external devices to solve problems. In addition, the existing video conferencing equipment in many hospitals is based on hardware, so the compatibility of this system will reduce the requirements for doctors to use this system.

The system has also demonstrated its ability to operate internationally in tests. When patients travel abroad on business or for travel, they can still receive routine health checks and guidance from their own doctors without having to go to a local medical system with which they are not familiar and who may have language difficulties in communication.

The experiment also proves the ability of the system to run on different platforms. The React-Native application on the patient side has the ability to run on both Android and iOS systems. The doctor side web application also has strong compatibility because it is browser-based. The compatibility of this system enables doctors and patients to use it in almost any device, significantly reducing usage requirements and costs.

This system has Bluetooth function module, which can scan, connect and monitor Bluetooth devices using BLE. Since BLE is the most widely used Bluetooth technology for home medical devices, other developers can use this module to easily enable the system to adapt new Bluetooth medical devices when needed. This capability allows the system to be used not only for routine checking of heart disease, but also for remote treatment of other less serious ailments such as colds and fevers after a simple extension of its functionality.

In addition, the system has been proved to be able to be used in poor network conditions. The simulated poor download rate and upload rate were 26.83 Mbps and 14.99 Mbps, which were much lower than the average mobile network's download rate and upload rate in Australia (44.2 Mbps and 14.32 Mbps), and slightly higher than the rates for the old, fixed broadband (24.12 Mbps and 8.48 Mbps).[24] This shows that the system can be used normally under most network conditions in Australia, and users do not need to spend extra money to improve the network conditions.

6.2 Comparison to previous solutions

This section mainly compares this system with the previous solutions mentioned in Chapter 3.2.

Comparing to the Alfred Bove's solution late 1990s based on telephone, my system has clear advantages. Alfred's system relies on patients using health care devices to measure their own medical data alone and send it to doctors via their mobile phones or the internet. [14] In this process, the doctor is unable to provide any guidance in the measurement process, and if the patient makes an error in the measurement, the doctor will make a diagnosis based on the wrong data. In addition, the data is manually entered by the patient rather than automatically transmitted, which creates the possibility of incorrect or incomplete data being entered by the patient, especially if the patient lacks medical knowledge.

For 2015, Priyanka's solution, in which the data is measured by a wearable wireless medical device and uploaded to a central database accessible to doctors. [15] The main advantage of my system is the two-way communication that video conferencing provides. It can improve patients' satisfaction and trust in telemedicine. In addition. In addition, allowing doctors to see patients via video conferencing could be a supplement to medical equipment that patients do not have, such as blood oxygen levels, as measured by facial color.

Priyanka's solution has the advantage of having a database that can store data and allow doctors to make long-term observations, doctors can refer to a patient's previous health records to provide a more accurate diagnosis. In addition, Priyanka's system also has an automatic alarm and a GPS system, when the patient's medical data is unnormal, the system will automatically give an alarm to the doctor and provide the real-time location of the patient, my system does not have the function at present. [15]

Another previous solution was mentioned in a 2017 article wrote by Chih-Chung Hsiao. It was an implantable wireless device called CardioMems, it measures patients' patients' pulmonary artery pressure to monitor their health condition. [16] The drawbacks of this implantable device are obvious, patients need to have a foreign device implanted in their bodies, which is time-consuming and expensive, and is unacceptable to many patients. And if the equipment breaks down for some reason, it can be extremely difficult to replace or repair. Furthermore, this solution is almost limited to one condition and has no extendibility to the treatment of other diseases. My system has clear advantages in these areas.

Comparing to Noman's solution in 2019, My system has no obvious advantages except the communication benefits of video conferencing. Noman's system uses integrated wearable sensors to measure multiple medical data. To extend the working time of his equipment, his system can be set to two modes, one focused on performance and energy consumption, and the other focused on energy conservation. [17] My system currently lacks consideration for energy conservation, which can be improved in the future.

Another system developed in 2019 by Massimiliano Donati is similar to Noman's solution. What makes it unique is that it designs different modes based on the user's expertise, from the most informative and complex doctor mode to the simplest patient mode. [13] My system can be improved according to this idea. For example, the current function of selecting Bluetooth service and characteristic on the patient side application can be performed remotely by doctors from the doctor side application, it can reduce the difficulty for patients to use my system.

6.3 limitations & future work

The shortcomings of my solution are mainly in the following aspects: the difficulty of patient use, the lack of communication between doctors and patients outside of videoconferencing, the lack of a database to store long-term medical data, and the lack of doctor-patient account management. These are where my system needs to be improved in the future.

Firstly, the patient-side application has a strong capability to be compatible with BLE medical devices, but it also requires patients to operate the Bluetooth component to scan, connect and select the Bluetooth service and characteristic to use. This may be difficult for some patients, especially older users.

This problem can be solved by adding a remote-control function between the doctor and patient applications. When the patient side authorizes, the doctor side can send commands to the server, such as clicking a scan button to connect to a device with a specific name. The patient-side application then retrieves these commands from the server and executes them. In this way, the more complex Bluetooth debugging process will be completed by trained doctors, reducing the difficulty for patients to use the system.

Secondly, now that the system has a ZOOM -like video conferencing function, when a doctor creates a room, he or she must send the room number to the patient via another channel, such as Messenger or over the phone. Twilio's data stream only works if both parties join the meeting. In the future, an online chat module could be added to the system, providing another channel for doctors and patients to communicate beyond video conferencing. This allows the doctor to send messages to the patient and answer simple questions in a convenient way.

Thirdly, unlike Noman's solution mentioned in 3.2, my system does not have a database for long-term data storage. [17] In the future, such a database could be added to record the patient's medical data for each remote video conferencing diagnosis. Doctors can access the database to observe the long-term health conditions of their patients and use this long-term information to provide patients with more accurate and effective treatment.

Furthermore, my solution now has no account management system, so doctors and patients can create or join a video conference without logging in, which raises security and privacy issues. Security and privacy in video conferencing are now depends on the uniqueness of room numbers and Twilio's encryption capabilities. The backstage generates a unique room number at random, and doctors tell this room name to their patients. Once the patient and doctor join the room, Twilio can ensure the security of video conferencing by its encryption algorithm.

In the future, a user management system can be added to my solution to create an account for each doctor and patient. Users need to be logged in to use the system, and after creating video rooms, doctors can designate patients to attend. Patients can only attend video conferences with their own doctors, and doctors can only invite their own patients to meetings.

Moreover, the present video conferencing function of this system is still relatively elementary, which only guarantees the most basic video and audio functions. More functions can be developed in the future, for example shared screen, whiteboard, chat box, and remote control.

Another possible improvement would be to develop a browser-based web application for the patient side as well. Web applications have higher compatibility, can be used directly in any browser without the need to install plug-ins. It could be developed by adding Bluetooth components to the doctor-side application and modifying the user interface.

The main problem with this solution is that it requires technology that allows web applications to connect directly to Bluetooth devices. Traditional Bluetooth modules, no matter it is written in Java, python, C# or other backend languages, require installing plug-ins on users' devices. This removes the advantage of not having to install plug-ins for web applications.

Web Bluetooth can solve this problem, which makes a newly developed technology. It is written in JavaScript, which can be put in the frontend webpage, it allows web applications to directly receive Bluetooth signal from ports in the frontend rather than receive Bluetooth data from installed plug-ins as HTTP. It uses generic Attribute Profile (GATT) protocol, provides some standard APIs for developers to obtain data from some specific Bluetooth devices.[43]

In Web Bluetooth, peripherals are treated as servers, and the central is treated as a client. Each server provides several services, and the client sends requests to get these services.[45] There are multiple characteristics inside each service, the values of these characteristics are the data related to the service. Web Bluetooth defines some standard servers and services, it also provides APIs for these servers to obtain their data. For example, heart rate monitor is one of the standard servers defined by Web Bluetooth, it is structured like this:[46]

- Heart rate monitor (Server)
  - Heart Rate Service (service)
    - Heart Rate Measurement (characteristic)
    - Body Sensor location (characteristic)
    - Heart Rate Control Point (characteristic)
  - Device Information Service (service)

    …

Each service and each characteristic in Web Bluetooth are identified with a UUID. The value of the "Heart Rate Measurement" will be the heart rate data it measures. It can be obtained using JavaScript code like this:

```
navigator.bluetooth.requestDevice({
  //Find the heart rate monitor
  filters: [{
    services: ['heart_rate'],
  }]
    //Connect with the heart rate monitor
}).then(device => device.gatt.connect())

 //Get heart Rate Service
.then(server => server.getPrimaryService('heart_rate'))
.then(service => {
  return Promise.all([

        //Get heart rate measurement characteristic
         service.getCharacteristic('heart_rate_measurement')
     .then(handleHeartRateMeasurementCharacteristic), //Use the heart rate
  ]);
});
```

With this JavaScript code, a frontend web application should be able to utilize Bluetooth ports on a smartphone or laptop to find the heart rate monitor, set up connection with it and extract the heart rate data without the help of a local client application.

Chapter 7 - Conclusion

This essay combined video conferencing with Bluetooth telemedicine, it can possess both the conveniences of telemedicine and the two-way communication feature of traditional medical sessions, which integrating the advantages of both systems and solve their problems. The utilizing of software-based video conferencing will significantly reduce the cost and complexity of the system, makes it easier to be accepted by users. The compatibility of react-native and WebRTC enable this system to run on any device. The wide application and compatibility of BLE make this system have strong extendibility. It can be compatible with new medical hardware in the future and be used for the treatment of more diseases. These technical features of the system make it easy to use, minimizes the cost and maximizes the compatibility and extendibility. Enable it to meet the requirements of performing simple heart examinations for CVDs patients and leave the opportunity for it to be used for the treatment of other diseases.

Chapter 8 - Bibliography

[1]: World Health Organization. (2020). *Cardiovascular Diseases*. 2020 WHO. https://www.who.int/health-topics/cardiovascular-diseases/#tab=tab_1

[2]: Healthdirect. (2018, November). *Should I be tested for heart disease?* https://www.healthdirect.gov.au/should-i-be-tested-for-heart-disease

[3]: AIHW. (2019, August 30). *Cardiovascular disease*. https://www.aihw.gov.au/reports/heart-stroke-vascular-disease/cardiovascular-health-compendium/contents/deaths-from-cardiovascular-disease

[4]: Bradbury, J., Nancarrow, S., Avila, C., Pit, S., Potts, R., Doran, F., & L Freed, F. (2017). Actual availability of appointments at general practices in regional New South Wales, Australia. *Australian Family Physician*, *46*, 321–324. https://www.racgp.org.au/afp/2017/may/actual-availability-of-appointments-at-general-practices-in-regional-new-south-wales,-australia/

[5]: Barbieri, S., Jorm, L. Travel times to hospitals in Australia. *Sci Data* **6,** 248 (2019). https://doi.org/10.1038/s41597-019-0266-4

[6]: Volterrani, M., & Sposato, B. (2019). Remote monitoring and telemedicine. *European Heart Journal Supplements*, *21*(Supplement_M), M54–M56. https://academic.oup.com/eurheartjsupp/article/21/Supplement_M/M54/5691338

[7]: Zhang, K., Li Liu, W., Locatis, C., & Ackerman, M. (2016). Mobile Videoconferencing Apps for Telemedicine. *Telemed J E Health*, *22(1)*, 56–62. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4739126/

[8]: Australian Bureau of Statistics. (2017, July 26). *3303.0 - Causes of Death, Australia, 2015*. https://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/3303.0Main+Features100012015?OpenDocument

[9]: Australian Bureau of Statistics. (2018, September 26). 3303.0 - Causes of Death, Australia, 2017. https://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/3303.0~2017~Main%20Features~Australia's%20leading%20causes%20of%20death,%202017~2

[10]: Australian Bureau of Statistics. (2018, December 12). 4364.0.55.001 - National Health Survey: First Results, 2017-18. https://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/4364.0.55.001~2017-18~Main%20Features~Heart,%20stroke%20and%20vascular%20disease~55#:~:text=In%202017%2D18%2C%20the%20proportion,and%20over%20had%20heart%20disease.

[11]: Australian Institute of Health and Welfare. (2019, August 30). Cardiovascular disease. Australian Institute of Health and Welfare 2020. https://www.aihw.gov.au/reports/heart-stroke-vascular-disease/cardiovascular-health-compendium/contents/deaths-from-cardiovascular-disease

[12]: World Health Organization. Telemedicine: opportunities and developments in Member States: report on the second global survey on eHealth. Geneva: World Health Organization, 2010.

[13]: Donati M, Celli A, Ruiu A, Saponara S, Fanucci L. A Telemedicine Service System Exploiting

BT/BLE Wireless Sensors for Remote Management of Chronic Patients. Technologies. 2019; 7(1):13.https://www.mdpi.com/2227-7080/7/1/13/pdf

[14]: Mended Hearts. (2020). Telemedicine's Expanding Role in Cardiac Care. https://mendedhearts.org/story/telemedicines-expanding-role-in-cardiac-care/

[15]: Kakria, P., Tripathi, N. K., & Kitipawang, P. (2015). A Real-Time Health Monitoring System for Remote Cardiac Patients Using Smartphone and Wearable Sensors. International journal of telemedicine and applications, 2015, 373474. https://doi.org/10.1155/2015/373474

[16]: Chung Hsiao, C., Peng Tsai, J., Tzu Sung, K., Ying Lee, P., In Lo, C., Hung Huang, W., Lin Chang, W., & Lieh Hung, C. (2017). Telemedicine in Cardiovascular Disease. Telemedicine in Cardiovascular Disease, 28, 133–139. http://www.tsim.org.tw/journal/jour28-3/03.PDF

[17]: Al-Naggar, N. Q., Al-Hammadi, H. M., Al-Fusail, A. M., & Al-Shaebi, Z. A. (2019). Design of a Remote Real-Time Monitoring System for Multiple Physiological Parameters Based on Smartphone. Journal of healthcare engineering, 2019, 5674673. https://doi.org/10.1155/2019/5674673

[18]: Kruse, C. S., Soma, M., Pulluri, D., Nemali, N. T., & Brooks, M. (2017). The effectiveness of telemedicine in the management of chronic heart disease - a systematic review. JRSM open, 8(3), 2054270416681747. https://doi.org/10.1177/2054270416681747

[19]: Yoo, S. K., Kim, K. M., Jung, S. M., Kim, N. H., Kim, S. H., Park, J. B., Park, I. C., Oh, J. H., & Kim, S. H. (2004). Real-time emergency telemedicine system: prototype design and functional evaluation. Yonsei medical journal, 45(3), 501–509. https://doi.org/10.3349/ymj.2004.45.3.501

[20]: DRURY, B. (2020, June 29). Australian Age Pension rates (March 2020 to September 2020). SuperGuide. https://www.superguide.com.au/accessing-superannuation/age-pension-rates#Current_Age_Pension_rates_March_2020

[21]: Liu, W. L., Zhang, K., Locatis, C., & Ackerman, M. (2015). Cloud and traditional videoconferencing technology for telemedicine and distance learning. Telemedicine journal and e-health : the official journal of the American Telemedicine Association, 21(5), 422–426. https://doi.org/10.1089/tmj.2014.0121

[22]: Mell P, Grance T. The NIST definition of cloud computing. Version 15.10.07. Gaithersburg, MD: Information Technology Laboratory, National Institute of Standards and Technology, 2009 http://faculty.winthrop.edu/domanm/csci411/Handouts/NIST.pdf

[23]: Taylor, A., Morris, G., Pech, J., Rechter, S., Carati, C., & Kidd, M. R. (2015). Home Telehealth Video Conferencing: Perceptions and Performance. JMIR mHealth and uHealth, 3(3), e90. https://doi.org/10.2196/mhealth.4666

[24]: Ookla. (2017, November 8). 2017 Australia Speedtest Market Snapshot. Speedtest. https://www.speedtest.net/reports/australia/

[25]: Infrastructure Australia. (2019). Australian Infrastructure Audit 2019 - 8. Telecommunications. Australian Infrastructure Audit 2019, 562–563. https://www.infrastructureaustralia.gov.au/sites/default/files/2019-08/Australian%20Infrastructure%20Audit%202019%20-%208.%20Telecommunications.pdf

[26]: Facebook. (2021). Core Components and Native Components. React Native · Learn Once, Write Anywhere. https://reactnative.dev/docs/intro-react-native-components

[27]: Lopez, L. (2020, March 10). Basic Concepts. Twilio Docs. https://www.twilio.com/docs/video/tutorials/basic-concepts

[28]: Lopez, L. (2019, August 27). Understanding Video Rooms. Twilio Docs. https://www.twilio.com/docs/video/tutorials/understanding-video-rooms

[29]: Lopez, L. (2020). Getting Started - JavaScript. Twilio Docs. https://www.twilio.com/docs/video/javascript-getting-started

[30]: Lopez, L. (2020c, April 1). Understanding Video Rooms APIs. Twilio Docs. https://www.twilio.com/docs/video/tutorials/understanding-video-rooms-apis#understanding-track-types-client-sdk-api

[31]: black experiments. (2016, November 5). react-native-twilio-video-webrtc. Blackuy / React-Native-Twilio-Video-Webrtc. https://github.com/blackuy/react-native-twilio-video-webrtc

[32]: Gour, R. (2019, April 16). Working Structure of Django MTV Architecture. Towards Data Science. https://towardsdatascience.com/working-structure-of-django-mtv-architecture-a741c8c64082

[33]: Makai, M. (2020). Django ORM. Full Stack Python. https://www.fullstackpython.com/django-orm.html

[34]: tutorialspoint. (2020a). Django - Models. Django. https://www.tutorialspoint.com/django/django_models.htm

[35]: tutorialspoint. (2020). MVC Framework - Architecture. MVC Framework. https://www.tutorialspoint.com/mvc_framework/mvc_framework_architecture.htm

[36]: tutprialspoint. (2020). Django - Template System. Django. https://www.tutorialspoint.com/django/django_template_system.htm

[37]: tutorialspoint. (2020a). Django - Generic Views. Django. https://www.tutorialspoint.com/django/django_generic_views.htm

[38]: tutorialspoint. (2020c). Django - URL Mapping. Django. https://www.tutorialspoint.com/django/django_url_mapping.htm

[39]: Pollicino, Joe (25 October 2011). "Bluetooth SIG unveils Smart Marks, explains v4.0 compatibility with unnecessary complexity". Engadget. Oath Tech Network AOL Tech. Retrieved 17 April 2018. https://www.engadget.com/2011-10-25-bluetooth-sig-unveils-smart-marks-explains-v4-0-compatibility-w.html

[40]: Omre, H. (2010). Bluetooth Low Energy: Wireless Connectivity for Medical Monitoring. Bluetooth Low Energy: Wireless Connectivity for Medical Monitoring, 4(2), 457–463. https://doi.org/10.1177/193229681000400227

[41]: Kindt, P. H.; Saur, M.; Balszun, M.; Chakraborty, S. (2017). "Neighbor Discovery Latency in BLE-Like Protocols". IEEE Transactions on Mobile Computing. PP (99): 617–631. arXiv:1509.04366. doi:10.1109/tmc.2017.2737008. ISSN 1536-1233. S2CID 1954578.

[42]: Alberti, S. (2018). Application Protocol Reverse Engineering. Reverse Engineering BLE Devices. https://reverse-engineering-ble-devices.readthedocs.io/en/latest/protocol_reveng/00_protocol_reveng.html

[43]: Beaufort, F. (2017, February 7). GATT Communication is shipped in Chrome on Android, Mac, and ChromeOS. W3C. https://www.w3.org/community/web-bluetooth/2017/02/08/gatt-communication-is-shipped-in-chrome-on-android-mac-and-chromeos/Dialog. (n.d.). The Generic Attribute Profile (GATT). Create a Custom GATT Profile Characteristic. http://lpccs-docs.dialog-semiconductor.com/tutorial-custom-profile-DA145xx/gatt.html

[44]: react-native-ble-plx (2.0.2). (2020). [BLE module for react native]. https://polidea.github.io/react-native-ble-plx/

[45]: Beaufort, F. (2017, February 7). GATT Communication is shipped in Chrome on Android, Mac, and ChromeOS. W3C. https://www.w3.org/community/web-bluetooth/2017/02/08/gatt-communication-is-shipped-in-chrome-on-android-mac-and-chromeos/Dialog. (n.d.). The Generic Attribute Profile (GATT). Create a Custom GATT Profile Characteristic. http://lpccs-docs.dialog-semiconductor.com/tutorial-custom-profile-DA145xx/gatt.html

[46]: W3C community group. (2020, July 1). Web Bluetooth Draft Community Group Report. Web Bluetooth Draft Community Group Report. https://webbluetoothcg.github.io/web-bluetooth/#introduction-examples