# A 6-MINUTE WALK TEST (6MWT) MONITORING AND TRACKING SYSTEM FOR HOME-BASED REHABILITATION

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# A 6-MINUTE WALK TEST (6MWT) MONITORING AND TRACKING SYSTEM FOR HOME-BASED REHABILITATION

ABDELRAHMAN USAMA GABR ABDOU HABIB

A report submitted in partial fulfilment of the
requirements for the award of the degree of
Bachelor of Engineering (Bio-Medical)

School of Biomedical Engineering and Health Sciences
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## DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

## ACKNOWLEDGEMENT

In the name of Allah, the most gracious, the most merciful, all praise and thanks be to God for providing me with strength and on the right direction.

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Finally, thank you to my beloved family for their endless care, love, support, and time. I wouldn’t be where I am without you.

# ABSTRACT

The 6-Minute Walk Test (6MWT) is a walking test that measures exercise capacity for assessing various types of diseases. The primary goal of the test is to measure the distance covered during the 6 minutes. Current method of conducting the test have difficulties for long-term rehabilitation such as cost of transportation and long waiting hours. Meanwhile, fitness mobile applications might not be suitable for the 6MWT indoor due to the large scale of distance measurement. Previous studies found in literature have room of improvements in their approach. Indoor measurement for body activity could be more complicated with smartphone sensors due to high sensitivity to movement. This study aims to develop a 6MWT monitoring platform and tracking Android application that assists in conducting the test in home-based environment as an alternative approach. The developed algorithm utilizes Android smartphone sensors as accelerometer and magnetometer for processing the azimuth angle to detect body rotation at the end of the hallway, and step counter sensor for counting the steps and residual distance calculation. The patient data are transmitted to a web dashboard for clinicians to view the results. A telehealth application is developed using WebRTC to allow post-test consultation and remote monitoring. The algorithm accuracy was validated using for rotation detection and distance measurement by a healthy participant. The average accuracy for rotation detection is 89.2% while performing the test using the application. This accuracy reflected precise distance measurement for most of the trails during the validation, where the distance was estimated to cm precision. The smartphone application also provides audible instructions and test educational information. This study will improve the clinical practice by providing an application for 6MWT measurement and tracking in a non-hospital environment and improve in the method of distance measurement for 6MWT from previous literature. This will benefit the public by providing a simple solution for performing the test by using smartphone, and to clinicians by providing a monitoring dashboard and telehealth applications.

# ABSTRAK

Ujian Berjalan 6 Minit (6MWT) ialah ujian berjalan kaki yang mengukur kapasiti senaman untuk menilai pelbagai jenis penyakit. Matlamat utama ujian adalah untuk mengukur jarak yang ditempuhi selama 6 minit. Kaedah semasa menjalankan ujian mempunyai kesukaran untuk pemulihan jangka panjang seperti kos pengangkutan dan waktu menunggu yang lama. Sementara itu, aplikasi mudah alih kecergasan mungkin tidak sesuai untuk 6MWT dalaman kerana skala ukuran jarak yang besar. Kajian terdahulu yang terdapat dalam literatur mempunyai ruang penambahbaikan dalam pendekatan mereka. Pengukuran dalaman untuk aktiviti badan boleh menjadi lebih rumit dengan penderia telefon pintar kerana kepekaan yang tinggi terhadap pergerakan. Kajian ini bertujuan untuk membangunkan platform pemantauan 6MWT dan aplikasi Android penjejakan yang membantu dalam menjalankan ujian dalam persekitaran berasaskan rumah sebagai pendekatan alternatif. Algoritma yang dibangunkan menggunakan penderia telefon pintar Android sebagai pecutan dan magnetometer untuk memproses sudut azimut untuk mengesan putaran badan di hujung lorong, dan penderia pembilang langkah untuk mengira langkah dan pengiraan jarak baki. Data pesakit dihantar ke papan pemuka web untuk doktor melihat hasilnya. Aplikasi telekesihatan dibangunkan menggunakan WebRTC untuk membenarkan perundingan pasca ujian dan pemantauan jarak jauh. Ketepatan algoritma telah disahkan menggunakan pengesanan putaran dan pengukuran jarak oleh peserta yang sihat. Purata ketepatan untuk pengesanan putaran ialah 89.2% semasa melakukan ujian menggunakan aplikasi. Ketepatan ini mencerminkan ukuran jarak yang tepat untuk kebanyakan laluan semasa pengesahan, di mana jarak dianggarkan kepada ketepatan cm. Aplikasi telefon pintar juga menyediakan arahan yang boleh didengar dan menguji maklumat pendidikan. Kajian ini akan menambah baik amalan klinikal dengan menyediakan aplikasi untuk pengukuran dan pengesanan 6MWT dalam persekitaran bukan hospital dan menambah baik kaedah pengukuran jarak untuk 6MWT daripada literatur terdahulu. Ini akan memberi manfaat kepada orang ramai dengan menyediakan penyelesaian mudah untuk melaksanakan ujian dengan menggunakan telefon pintar, dan kepada doktor dengan menyediakan papan pemuka pemantauan dan aplikasi telekesihatan.

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| | | |
|---|---|---|
| AES | - | Advanced Encryption Standard |
| ATS | - | American Thoracic Society |
| API | - | Application Programming Interface |
| AWS | - | Amazon Web Services |
| BMI | - | Body Mass Index |
| CVDs | - | Cardiovascular Diseases |
| CR | - | Cardiac Rehabilitation |
| COPD | - | Chronic Obstructive Pulmonary Disease |
| CHF | - | Cognitive Heart Failure |
| COVID-19 | - | Coronavirus Disease 2019 |
| EC2 | - | Elastic Compute Cloud |
| GPS | - | Global Positioning System |
| IHD | - | Ischemic Heart Disease |
| ML | - | Machine Learning |
| MEMS | - | Micro Electro Mechanical Sensors |
| P2P | - | Peer-to-peer |
| 6MWT | - | Six-Minute Walk Test |
| 6MWD | - | Six-Minute Walk Distance |
| SVM | - | Support Vector Machine |
| WebRTC | - | Web Real-Time Communications |

## LIST OF SYMBOLS

| | | |
|---|---|---|
| Ad | - | Acceleration |
| $F$ | - | Force |
| g | - | Gravity Force |

# CHAPTER 1

# INTRODUCTION

This chapter discusses the project background, problem statement, project objective and associated scope, and project significance.

## 1.1 Project Background

Cardiovascular Diseases (CVDs) are the number one cause of death globally (Nag and Ghosh, 2013). They cover a wide array of disorders including diseases of the cardiac muscle and of vascular system supplying the heart, brain, and other vital organs, where 80 percent of the global burden of CVD death occurs in low- and middle-income counties (Gaziano *et al.*, 2006). Common causes of CVD morbidity and mortality could be Ischemic Heart Disease (IHD), stroke, and Cognitive Heart Failure (CHF), which account at least 80 percent of the burden of CVD in all income regions (Gaziano *et al.*, 2006). CVDs are arguably the most important comorbidities in Chronic Obstructive Pulmonary Disease (COPD), which is also associated with increased risk for hospitalization, longer length of stay, and all-cause and CVD-related mortality (Morgan *et al.*, 2018). Recently, Coronavirus Disease 2019 (COVID-19) that rapidly progressed a global pandemic, may be present with a variety of cardiac manifestations including heart failure and cardiac arrest, where those cardiovascular effects are in patients who have pre-existing cardiac conditions (Sattar *et al.*, 2020).

Walking tests are known to be safe, inexpensive, and simple as they correspond more closely to everyday activities, and may be useful as a measure of exercise capacity in patients with certain conditions as chronic heart failure (Guyatt *et al.*, 1985), and chronic respiratory diseases (Holland *et al.*, 2014). The 6-Minute Walk test (6MWT) is a convenient method used by rehabilitation professionals to measure of exercise capacity (Capela *et al.*, 2015), and its result reflects the functional status as well as walking autonomy and efficacy of Cardiac Rehabilitation (CR) on walking endurance, which is more pronounced in patients with low functional capacity such as heart failure and cardiac surgery (Casillas *et al.*, 2013). It is also considered one of the tests that can be used to measure the efficiency of the cardiovascular system (Chodór *et al.*, 2017). The 6MWT has been also used to assess performance in sub-maximal exercise in in a cohort of post-acute COVID-19 patients admitted into a rehabilitation unit, where most those patients had sever disability as shortness of breath for minimal activities and suffered from dyspnea (CURCI *et al.*, 2020).

The primary measurement for the 6MWT is the 6-minute walk distance (6MWD) (Holland *et al.*, 2014), patient blood oxygen saturation, and perception of dyspnea during exertion can be collected as well for further investigation (Enright, 2003). The test is conducted on a known length corridor where the user walks as much as possible back and forth to cover as much distance during the 6 minutes. Those patients can also be provided additional care through telehealth due to their difficulties in breathing and walking. A study (Tsai *et al.*, 2017) was conducted on a group of COPD patients with home-based telerehabilitation exercise programs using real-time video conferencing software and different exercise tests, including 6MWT, had shown improvements in the endurance exercise capacity and self-efficacy compared with usual care.

Telehealth, a very popular example of streaming technology, allows doctors to provide care for patients through phone calls, text messages, and most commonly, video calls. This is done by sharing media streams between the patient and the doctor through an online website or application. A common technique that is used in setting up an easy, cost-effective, and secure media transmission is known as Web Real-Time Communications (WebRTC), which allows real-time video, audio, and data transmission through two web browsers, through a set of free, open-source JavaScript application programmable interfaces (APIs). Telehealth programs had shown high satisfaction for patients based on the quality of service they received (Polinski *et al.*, 2016). With the accessible internet and modern technology, telehealth applications have higher chances of spreading widely to the public. This application can also assist in rehabilitation programs by cutting out the time needed for traditional visit consultation or follow-ups. After performing the 6MWT indoors in-home, the patient will not need to travel or waste any time reaching a clinician to follow up on his test results and progress.

Hence, this project proposes a 6MWT monitoring and tracking system for both patients to conduct the 6MWT in a home-based environment and clinicians to review the patient test results and progress, as well as provide a telehealth application to allow online video consultation between patients and doctors.

## 1.2 Problem Statement

In the last decade, many research efforts have been devoted to improving the healthcare by utilizing smartphone applications, as smartphones have become essential and inevitable to virtually every aspect of our modern lives. At the same time, it can provide necessary processing power, non-invasive, and cost-effective sensors as well as wireless communication capabilities (Park *et al.*, 2015). Those advantages come with the complexity and restrictions from smartphone sensors and different operating systems. Existing embedded smartphone sensors, such as accelerometers and magnetometers, provide a high amount of noise within the delivered signal as they are sensitive to the device movement, thus introducing more challenges in utilizing raw smartphone sensor signals in interpreting daily activities and healthcare smartphone applications.

Recently, few promising approaches were found to utilize smartphone sensors in the scope of 6MWT tracking (Capela *et al.*, 2015; Salvi *et al.*, 2020). Considering the algorithm approach, the step counting mechanism had been found heavily processing where there are now built-in sensors that can be used to reach same conclusion. Implementing new step counting sensor approach as suggested by previous studies with the rotation detection could lead to promising results with a simpler and accurate implementation. Moreover, telehealth applications are rarely found to be integrated with 6MWT applications for remote monitoring and remote supervision purposes, while data security is another concern of patient's privacy. Those approaches can be further improved in the aspect of test parameters measurements precision, as well as additional features to be implemented. One core aspect is the telehealth video calling for the purpose of video conferencing for post-testing remote consultation and monitoring.

Besides, current fitness applications offered by many wearable devices such as smart watch and wearable wristband may not be suitable for the 6MWT, as they are primarily built for general physical fitness exercises and do not provide a platform for clinicians to follow up with their patients. The distance measurement for 6MWT could be significantly small up to few meters or even centimetres depend on the disease severity of a patient. Fitness applications, however, reports the distance covered primarily in the unit of kilometres or meters, and were not proved to be used for medical purposes for indoor assessment. As indoor assessment for the 6MWT should be precise, measuring the distance in an indoor environment with a fixed distance could be challenging if those fitness application that utilizes Global Positioning System (GPS) instead of built-in sensors, which is in most of the cases for tracking the distance.

## 1.3 Research Objectives

Based on the aforementioned problem statements, the project is conducted to achieve the following objectives:

(a) To develop an Android mobile application based on a custom developed U-turn detection algorithm for self-administered 6MWT tracking in a non-hospital environment.

(b) To develop a web-based telehealth application for clinicians to perform remote post-testing consultation and rehabilitation plan revision.

(c) To conduct functionally validation and performance measurement of the developed 6MWT tracking algorithm and system.

## 1.4 Project Scope

Firstly, this project involves development of a full monitoring and tracking system for conducting the 6MWT by developing a high accurate distance measurement algorithm for tracking the body rotation and step counting as introduced by earlier studies to calculate the distance covered. This system is developed based on less computational approach using sensor fusion technique, which involved three Android sensors consists of accelerometer, magnetometer, and step counter. The system also equipped together with audible instruction based on the American Thoracic Society guidelines for the 6MWT. Secondly, the development of a monitoring web application dashboard that secures the patient data and allows the clinician to monitor the patient's progress. Besides, the project targets the development of a telehealth system for providing a video consultation portal for both patient and clinician. The telehealth system is targeted to utilize the WebRTC protocol to secure media transmission (audio, video, and messaging). The telehealth system will be integrated with the developed web dashboard, which allows the physiologist to get connected to the patient and provide feedback. All patient data will be securely transferred from his smartphone directly to the dashboard.

Both the smartphone and web applications utilize Google Firebase services. The authentication service is used to authenticate the user (sign up/log in) in the mobile application, where all the data are related to the user account. The Firestore database is a scalable NoSQL cloud database used in both applications for storing all details.

## 1.5 Project Significance

This project contributes to the clinical practice and research for 6MWT assessment. It improves the distance measurement approach using only a smartphone equipped with the necessary sensors, where a less computationally intensive implementation was made using only built-in Android sensors that can measure the distance to cm precision, utilizes Google Firebase provider for cloud services, better step counting implementation using step counter sensor, and less costly as no external hardware is required. It also provides a system for tracking and monitoring the 6MWT in a non-hospital environment using WebRTC technology that is secure and totally browser-based, and finally elaborates on how smartphone sensors can be used to provide meaningful information for biomedical applications.

## 1.6 Project Benefits

This project offers a more straightforward method for performing and monitoring the 6MWT for both patients and clinicians, in a way that the patient will perform the test in his preferred place and provide a transmission method for the clinician to review the result, as well as a method for both patient and clinician to make a further online consultation through the telehealth application. Moreover, this will reduce the time and cost for the patient and allow performing the 6MWT in a home-based environment.

# CHAPTER 2

# LITERATURE REVIEW

This chapter reviews the previous studies related to the usability of sensors in general, android devices embedded sensor and its framework, and specifically for assessing the 6MWT. In addition, WebRTC and its implementation using Peer-to-Peer (P2P) architecture in telehealth application to provide an easy to use and secure platform for video conferencing on the browser are also discussed.

## 2.1 Six-Minute Walk Test (6MWT)

The 6MWT is easy to perform, simple to administer, well-tolerated, and reflects daily living activities than other walking tests (Solway *et al.*, 2001). It has been widely used for measuring the response to therapeutic interventions for pulmonary and cardiac disease, is a walking test that primary measures the functional capacity from the total distance covered by the performer during the 6 minutes, known as 6-Minute Walk Distance (6MWD), on a stiff and straight corridor, under the supervision of a physician. It can also be used to measure functional status, fatigue and dyspnea (Enright, 2003). The primary purpose for the participant is to cover as much distance as possible during the time given without the need to rush as it is a self-based test.

The 6MWT provides meaningful and valuable information regarding most body systems by evaluating both integrated and global responses of systems involved in performing the test, including blood circulation, cardiovascular and pulmonary systems, body metabolism, and neuromuscular units (Crapo *et al.*, 2002). This test method can be applied for different patient conditions, including stroke, muscle disorder, arthritis, Parkinson's disease (*Six Minute Walk Test / 6 Minute Walk Test - Physiopedia*, no date), peripheral artery disease (Ata *et al.*, 2018), and chronic heart failure (Guyatt *et al.*, 1985). For example, the 6MWT is used to evaluate Chronic

Obstructive Pulmonary Disease (COPD) patients (Zeng *et al.*, 2019) due to their shortness of breath, frequent coughing, and chest tightness.

A study conducted on a number of 70 patients with stable COPD showed that the steps of 6MWT could help evaluate the functional status and life quality of COPD patients, which might be better in predicting lung hyperinflation in COPD (Zeng *et al.*, 2019). In another study (Chodór *et al.*, 2017), the 6MWT had been used as method to evaluate the patient's cardiovascular system efficiency for estimate whether there were improvement in the quality of patients life after the transcatheter aortic valve implantation procedure. The 6MWD can be influenced by many factors including height, age, gender, body weight, and corridor length, as varying them could lead to shorter distance (Enright, 2003). Walking is more efficient with taller height as it is associated with longer stride, resulting in longer distance walked (Enrichi and Sherrill, 1998). It can be also reduced by several types of diseases, including heart failures, obstructive lung diseases (Guyatt *et al.*, 1985). The 6MWT can be also used to assist healthy persons as shown in previous study (Enrichi and Sherrill, 1998), where it provided reference equations that allowed predicting the 6MWD in health subset of study participants, based on height, weight, body mass index (BMI), age and gender.

With considering limitations as long-distance travelling, time and cost consumed, and the need for a specialized application for 6MWT, previous studies proposed the idea of smartphone applications that allow the user to conduct the 6MWT in home in a straight hallway of knowns length, which utilized the smartphone sensors to track the steps and distance covered. This would provide a cost-effective and easy way of collecting data similarly collected by the 6MWT hospital supervisor, without the need to use any expensive hardware or require the patient to approach the hospital

### 2.1.1 6MWT Applications Related Work Discussion

A very knowledgeable approach to develop 6MWT distance tracking algorithm by (Capela *et al.*, 2015) was introduced by developing a calibrated-free 6MWT smartphone application that uses both accelerometer and gyroscope smartphone sensors to report the total distance walked, step timing, gait symmetry and walking changes over time by mainly counting the number of walkways completed by the patient after each turnaround point, where the pathway distance ends. His idea of calculating the distance based on body rotation seemed to be the best option for calculating the 6MWD. The body rotation will be a clear and solid proof for incrementing the distance as no matter how many steps are covered by the user, either walking fast or slow, the corridor distance is fixed, which means as body rotation is detected, it will tell that the user had fully finished walking the full corridor length from point A to B, and is heading in the opposite direction from B to A. Another study by (Salvi *et al.*, 2020) followed the same approach, using different sensors to detect U-turns taken by the patient and then computing the distance, relying on the median between the U-turns to calculate the residual distance remaining at the end of the test, and then send the patient results to a clinician application. This study suggested the usage of a different sensor for a better residual distance calculation.

Another study (Annegarn *et al.*, 2012) used an accelerometer to determine the walking patterns during the 6MWT for COPD patients healthy elderly subjects, which proved that COPD patients have different walking patterns compared to healthy subjects, which explains the lower 6MWD covered by COPD patients. In a different study (De Cannière *et al.*, 2020), Support Vector Machine (SVM) model was used to evaluate the functional capacity of a study conducted on 129 patients by assessing the 6MWD, where the patients were equipped with an accelerometer device and wearable ECG to extract the features. The study demonstrated that combining wearable monitoring with Machine Learning (ML) can objectively track clinical development in the cardiac rehabilitation population. ML models have been also used in a study by (Juen *et al.*, 2014) to determine the stride length from eight spatiotemporal parameters and four demographic parameters, and then use it to calculate the distance walked during the 6MWT by multiplying the strides by the strides length.

A study by (GC *et al.*, 2015), an iOS mobile application was developed and validated for self-administered 6MWT, which consisted of wireless data transmission to a central database, estimated distance travelled, record of step counts, heart rate, real-time self-administration of the 6MWT, and instructional video. The user is prompted to watch the test instructional video once the application is opened, where the app instructs the user to identify a place (such as a hallway) that can be used for walking back and forth, with landmarks as pivot points on either end. The application also prompts the user to key in the height, birth date, age, and weight. It also obtains the level of dyspnea using a virtual Borg dyspnea scale and records the pulse using photoplethysmography from the user's finger placed over the phone's camera. Not only that, but it also provides audible instructions that follow the ATS guideline script, delivered in an appropriate time during the test.

### 2.1.2 American Thoracic Society (ATS) Guidelines for 6MWT

The American Thoracic Society (Crapo *et al.*, 2002) has introduced guidelines for proper patient preparation and procedures for the 6MWT. Essential highlights to be mentioned is that physicians are not required to be present every time the test is conducted. Also, reasons to stop the 6MWT immediately could be chest pain, leg cramps, intolerable dyspnea. Besides, they highlighted that shorter pathway corridor length, high body weight, female sex, and shorter height would result in a less 6MWD (Crapo *et al.*, 2002). Some encouragement instructions were provided as well. Another study showed that the level of encouragement provided had shown a significant increase in the distance walked (Guyatt *et al.*, 1984).

## 2.2 Smartphone Embedded Sensors

Sensors, in general, are hardware components that measure a particular kind of physical quantity. Depending on the required application, this quantity can be force applied, light intensity, temperature, magnetic field, steps taken, or rotation rate. These sensors can be found as a functional external component required to be programmed and then used with suitable electrical connections. It can also be found integrated inside android smartphones that are ready to be used depending on the required application, with minimal programming required. The majority of sensors such as accelerometers and gyroscopes are classified as Micro Electro Mechanical Sensors

(MEMS), as they measure the change in electrical signal originating due to mechanical motion (*Android Sensor Programming By Example - Varun Nagpal - Google Books*, no date). Sensors are further divided into two categories: physical, which are actual hardware pieces of equipment that physically exist in the device, and synthetic, which are derived from one or more sensors, known as virtual, composite, or software sensors (*Android Sensor Programming By Example - Varun Nagpal - Google Books*, no date). Sensors can also help provide meaningful information to be interpreted for a particular application, which helps the user from painfully recording all of the data slowly and manually (*Professional Android Sensor Programming - Greg Milette, Adam Stroud - Google Books*, no date).

### 2.2.1 Android Sensors

Nowadays, smartphones contain hardware that can be used for wearable sensor applications and mobile data analysis, which for some applications can typically provide unavailable biomechanical information about the person's movement (Capela *et al.*, 2015). The android platform supports many types of motion sensors, which monitor the device movement and measure any possible force that could in any way create motion on the phone 3-axis coordinate system, such as accelerometer, gyroscope, step counter, step detector, and gravity sensor (*Android Sensor Programming By Example - Varun Nagpal - Google Books*, no date; *Motion sensors | Android Developers*, no date). As shown in Figure 2.1 below, the android smartphone can provide three different angular quantities, pitch, roll, and azimuth. Each quantity is measured relative to an axis of the coordinate system, where the pitch is around the x-axis, roll is around the y-axis, and azimuth is around the z-axis.

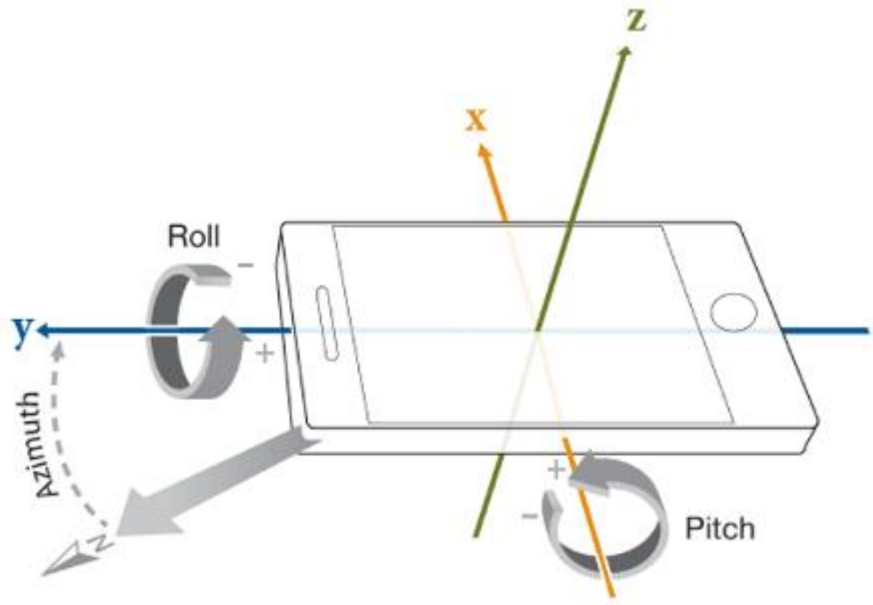



Figure 2.1 Reference equations for 6MWD in healthy adults (Enrichi and Sherrill, 1998)

Over the past years, Smartphone sensors had been utilized in many medical applications, such as using an accelerometer to track sleeping patterns by sensing the movement (Chaudhry, 2017) and using sensor fusion technique to acquire data from the gyroscope, magnetometer, and accelerometer sensors for human activity recognition (Chung *et al.*, 2019). They also have been used in other rehabilitation applications like detecting physical abilities (Whittington *et al.*, 2020).

#### 2.2.1.1 Accelerometer Sensor

Android sensor such as accelerometer, similar to others, can be accessed from the *Sensor* class (*Sensor | Android Developers*, no date). The sensor outputs a raw value measuring the acceleration along the x, y, and z axes, including gravity applied on the device with the most power-efficient and has minor battery consumption

(*Android Sensor Programming By Example - Varun Nagpal - Google Books*, no date). The unit of measurement in the SI unit is m/s$^2$. The output value is highly affected due to minor movements as experienced the application development process. A good practice is to filter the sensor signal before applying any computational calculations. As the sensor measures the acceleration applied to the device, it can be expressed by the following equation (2.1) (*SensorEvent | Android Developers*, no date).

$$Ad = -g - \frac{\sum F}{mass} \tag{2.1}$$

where, $Ad$ is the acceleration applied to the device, and $g$ is the gravity force, with a magnitude of 9.81 $m/s^2$.

#### 2.2.1.2 Step Counter Sensor

The step counter sensor is used to track the number of steps taken by the user since the last device reboot (power on) while the sensor was activated. Once the phone is restarted, the value is set to zero. It also keeps track of steps taken by the user per day by relying on the accelerometer sensor to give the calibrated values as an output (*Android Sensor Programming By Example - Varun Nagpal - Google Books*, no date). Like the accelerometer, it consumes a low amount of power. One disadvantage for the step counter sensor is the latency between the event sensed and event-triggered, which can be up to 10 seconds (*Motion sensors | Android Developers*, no date). However, it is more accurate than the step detector sensor. As this sensor tracks the steps taken since the device reboot, the sensor data should be handled wisely with an accurate approach to restart the steps tracking every time the user starts conducting the 6MWT. This is implemented by triggering certain functions and events flags in the 6MWT algorithm, as explained in chapter 3.

#### 2.2.1.3 Android Orientation Angles

The orientation angles (azimuth, pitch, and roll) can be measured by computing both accelerometer and magnetometer sensors readings. By using *getRotationMatrix* method, which returns a rotation matrix array holding 9 floats. Then using the *getOrientation* method, the resulted *rotationMatrix* is converted to the three types of orientation angles. The output after computing the orientation angles generates the three different types of angles (azimuth, pitch, and roll), indexed from 0 to 2 accordingly. By default, the azimuth, which the developed algorithm relays on, is provided in radian. A sample raw output value in radian from the azimuth angle is shown in Figure 2.2 below.

$$[1.7414459, 1.7551138, 1.7719693, 1.8240068, 1.7987447, \dots]$$

Figure 2.2 Raw azimuth signal output in radian

To make it more meaningful, it can be transformed to degree using basic math and logic, the resulted equivalent degree output is shown in Figure 2.3.

$$[99.7775, 100.56061, 101.52637, 104.507904, 103.060486, \dots]$$

Figure 2.3 Raw azimuth signal output in degree

The azimuth angle in degree can be used to identify certain user behaviour done while holding the phone, such as rotating or detecting a full U-turn. User rotation, no matter what direction is the user pointing to, will have two different point values before and after rotation. Taking the difference between two values, with delayed time difference between them, which is the duration of rotation, can identify the degree of rotation the user had taken.

To visualize the azimuth signal, the *orientationAngles[0]*, pointing to the azimuth signal values, were converted to degrees. Then, the 6MWT was performed indoor on a fixed hallway, with storing and logging all the sensor data during the test period. The signal shape is visualized as in Figure 2.4, where the data falls between the range of 0 ° to 360 °. Each slope change indicates that a U-turn had been made at the end of the hallway. The difference between any two points, before and after the slope, can indicate the amount of rotation taken by the user, thus can easily identify if the user had made a U-turn and finished a certain distance.

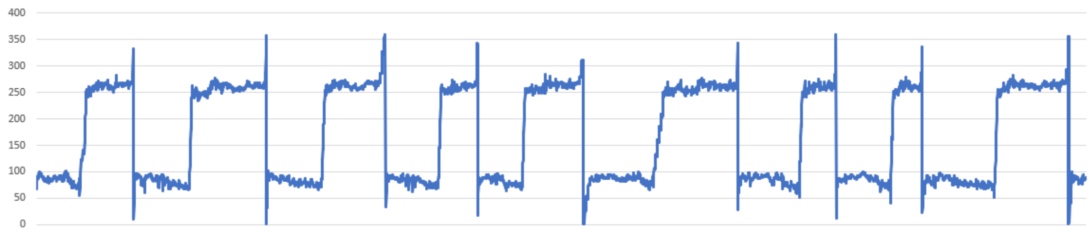



Figure 2.4 Sample from the azimuth computed signal while performing 6MWT

## 2.3 Web Real-Time Communications (WebRTC)

As a result of the increase in the availability of computational power as well as the internet connectivity, video conferencing is rapidly gaining prominence and becoming a more common mode of communication. Web Real-Time Communications (WebRTC) is one of the commonly used open-source frameworks for developing real-time web-based communication applications, as it allows web browsers to exchange video and audio with other browsers (Fowdur *et al.*, 2020) without any external plugins required (Edan and Abdullah, 2020), or additional software to be installed as it is a set of APIs on both mobile and desktop browsers, that allows the setup of a connection of two peers and control media source devices (Antunes *et al.*, 2016). WebRTC has been used widely in many different applications, including telemedicine as proposed by (Antunes *et al.*, 2016). WebRTC allows web browsers to exchange streams using Peer-to-Peer (P2P) architecture. Besides, WebRTC encrypts media communications using the AES-256 algorithm (Santos-González *et al.*, 2017), both video and audio between two users automatically (Sime, 2016), making it so attractive to be used for telehealth applications.

WebRTC lies on the TCP/IP application layer; it transmits communication details by relying on what is called a “signalling” server, which exchanges the session control messages implemented by Session Description Protocol (SDP) (Antunes *et al.*, 2016). SDP provides a standard representation for other description metadata, transport addresses, as well as media details (*hjp: doc: RFC 4566: SDP: Session Description Protocol*, no date).

WebRTC APIs are designed around three main concepts, which are (a) *MediaStream*, (b) *RTCPeerConnection*, and (c) *RTCDataChannel* (Fowdur *et al.*, 2020). Additional component was found in (Santos-González *et al.*, 2017) to be *geoStats* which is responsible for retrieving different statistics about a WebRTC session. The *MediaStream* has three main functionalities, such as prompting a request every time a stream is fetched, manages input devices if multiple sources of video or audio are found, and enable entry to a stream object that constitutes both video and audio streams (Fowdur *et al.*, 2020). The *RTCPeerConnection*, which was found in (Antunes *et al.*, 2016) with a name of *PeerConnection* represents the WebRTC connection between both clients (local and remote), by providing a method to connect to a remote peer, maintain and monitor the connection, and shut it down once it is no longer in use. Finally, the *RTCDataChannel* allows the exchange of data between the two peers (Fowdur *et al.*, 2020).

There are challenges that are closely related to video conferencing, where they rely more on the environment and kid of device being used. As mentioned by (Rodríguez *et al.*, 2012), screen size, CPU, bandwidth availability and latency, as well as session recording. Those challenges are more tightly close to the type of the device being used as explained by the author; for instance, video conferencing requires processing power to decode, encode and distribute video and audio in real time. Mobile systems CPU power tends to impose a limitation in this area. Also, smaller screen size tends to lose much of the information being transmitted compared to large screen performance.

### 2.3.1 WebRTC Related Work Discussion

Few different techniques for the signalling mechanism were proposed by (Edan and Abdullah, 2020); which are (a) JavaScript language for useful content of video conferencing through HTML5, and (b) Secure Socket Layer (SSL) to encrypt connection between users and control the connection to different sessions, as well as other meeting room real-time features, (c) ASP.net for developing a dynamic HTML page and ensure flexibility and reliability, (d) C# as a core programming language, and finally (e) SQL hash table for participants database. The authors included in their application flow a secure approach for allowing users to join calls, where the room creator will assign a "user-id" for other participants, which only users with the identical key can access the same room session and participate. Their implementation, with relying on WebRTC Application Programming Interfaces (APIs) did not require any external software (plugins), hardware, cloud, or commercial servers, which had also been applied and tested on different browsers such as Google Chrome, Safari, Explorer, and Firefox, and on different operating systems.

In another web-based telemedicine solution introduced by (Antunes *et al.*, 2016) using WebRTC API to transmit both video and audio in a real-time over the internet, where the client connects to an HTTP server through a web browser and access to the main HTML page that also uses JavaScript and CSS. The JavaScript takes the role in enabling the connection to a second signalling server, in which the author relayed on public servers both for TURN and STUN to maintain the clients' connection. Another WebRTC client server implementation by (Fowdur *et al.*, 2020) was found to be using JavaScript for the client-side, and Node.js for implementing the signalling server to allow video conferencing; both HTML and JavaScript codes as well were used to implement most of the functions.

## 2.4 Chapter Summary

Based on the discussed literature, the 6MWT algorithms introduced by (Capela *et al.*, 2015; Salvi *et al.*, 2020) are considered the best approach for measuring the distance walked during the 6MWT. Comparing the algorithm methodology, to the other machine learning models approaches, those machine learning approaches, although they had high accuracy, rely primarily on the training data and types of data acquired, with the amount of data collected, and from which group or race of people. If the data did not include various patients' records, it will be biased to a particular group, with low accuracy to others. The first two works of literatures mentioned utilized other parameters like the body rotation to indicate that the user had covered a certain amount of distance. This is important, as different patients with different diseases and from different places worldwide have different abilities in walking; thus, the stride distance or any other parameters will vary a lot, and it will be challenging to train a machine learning model on all those scenarios. However, body rotation is a solid indication of a certain activity to trigger the distance calculation, as rotation is as simple as a change in rotation degree value. Once a user sets a hallway distance and then rotates at the end of the hallway, this indicates that he entirely covered the hallway distance and is returning in the opposite direction.

The algorithm will be developed based on the previous research idea using android accelerometer and magnetometer sensors to compute the azimuth signal angle to track the body rotation and adding on that the step counter to calculate the user's number of steps, with improving the test experience by audible instructions and other necessary features. The phone step counter sensor will be used as suggested to calculate the number of steps and the average distance covered per step. Once an average distance per step value is calculated, it will then be multiplied with only the number of steps covered at the last hallway round, adding it to the total distance calculated earlier, and then outputting the 6MWD to the user.

Referring the telehealth, WebRTC implementation seemed to be the ideal way for building one-to-one video calls on the browser, with no download and video server required after setting up necessary connections and a secure method to transfer data between two browsers.

# CHAPTER 3

# RESEARCH METHODOLOGY

This chapter discusses the methodology applied in this project, including the project flow chart, development methodology and tools.

## 3.1 Project Workflow

The project began by identifying the scope of study and understanding the current issue being solved. Both literature review and logbook documentation were carried out constantly, followed by programming languages and smartphone sensors exploration. The project development was decoupled into different stages. Each stage was elaborated in detail in a separate section. The stages were mobile application development, and web application development. The android application development stage included the 6MWT application and algorithm development, and telehealth booking system development. Next, the clinician dashboard, which started by developing the backend server logic as well as database connection with the android application. The final stage, the telehealth development started by integrating WebSocket into the earlier developed server. Then, the WebRTC application development will proceed after.

The system validation was divided into two separate stages, specifically for the Six-Minute Walk Test (6MWT) accuracy. The 6MWT validation must meet high accuracy during the testing phase, comparing it to other applications and other researchers' approaches and results. The overall system validation must ensure that all stages mentioned earlier must work fluently without any issues. The diagram below describes the flow of conducting and developing this project to achieve all specified objectives.

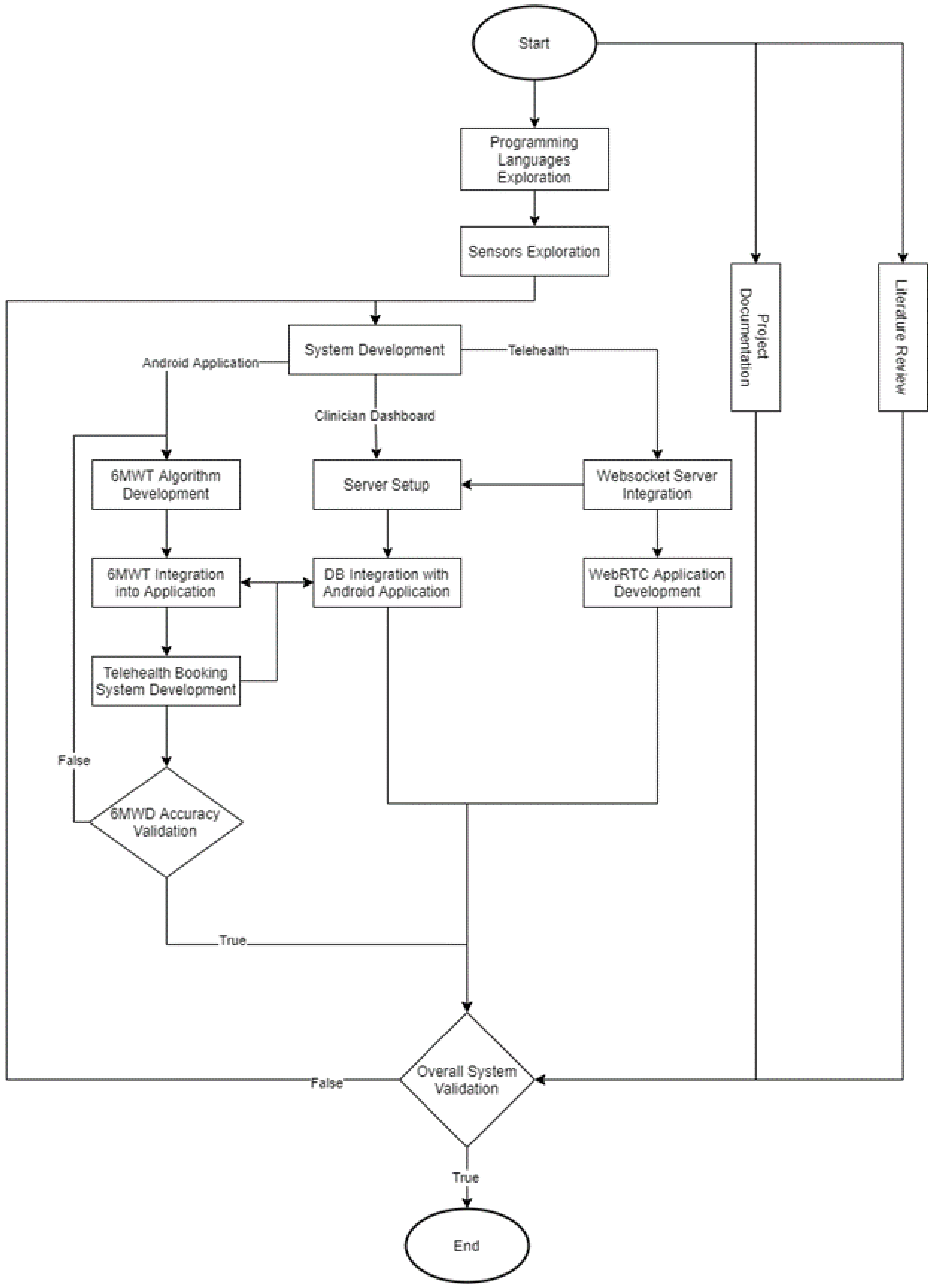



Figure 3.1 Overall Project Workflow

### 3.2 Mobile Application Development

The Android application was developed using Java programming language. It includes mainly authentication, 6MWT educational page, 6MWT tracking, and telehealth booking. Each of the following sections will describe the development methodology and structure for the application.

#### 3.2.1 Smartphone Application Structure

The Android application was developed using multiple screens. Each screen is known as an *Activity*. An activity is one screen of the application user interface. The application starts by authenticating the user who will be using the application, as it will hold personal and health information related to the user. The android layout was developed using Extensible Markup Language (XML). The layout was designed to handle the main functionality, where each will be demonstrated in detail. The authentication which is divided into two main parts, login and signup is shown in Figure 3.2.


Figure 3.2 Layouts for authentication flow.

The main activity layout XML have two main buttons, where the *Login* button user interface will direct the use to *activity_login.xml*, while the second button user interface *Sign Up* will direct to *activity_sign_up.xml* as shown in Figure 3.2. The *activity_login.xml* will take the registered user email and password for validation and directing the user to the next activity. The *activity_sign_up.xml* will have edit text fields for taking the user information and registering it using the cloud provider authentication service.

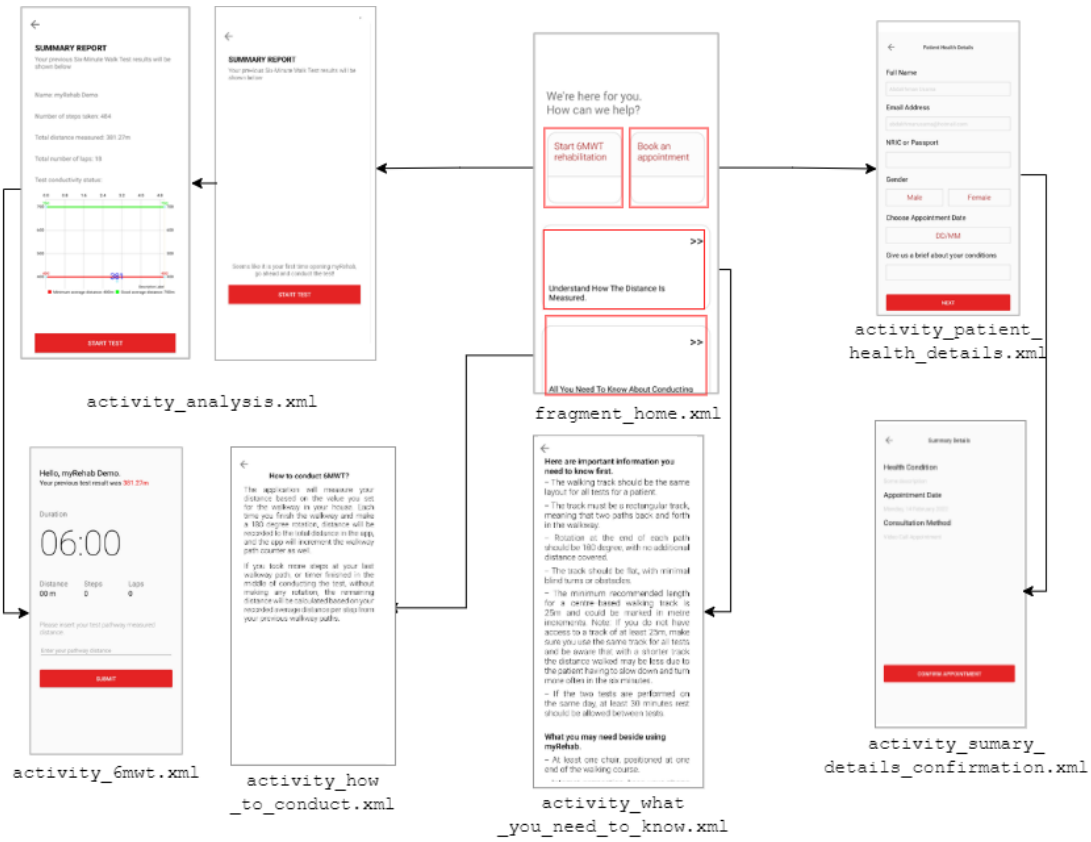



Figure 3.3 Layouts for the flow after authentication.

Once authenticated, the user will be directed to the home activity for accessing all other activities. Figure 3.3 demonstrates the flow from the home activity to the remaining activities. For the 6MWT flow, the user will be directed to landing screen for first time using the application with the test and summary report if it is not his first time to perform the test. Once the 6MWT is finished, the user will be redirected automatically to a summary report page to view his test results, which is *activity_analysis.xml*. Every time the user joins to perform the test again, he will view his last test history results before performing the test.

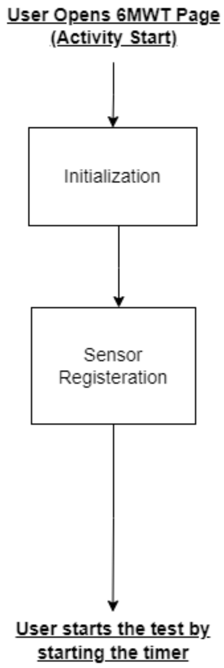
Two activities were used to deliver educational information about the test, where they can be accessed using the buttons in *fragment_home.xml*. Those activities are *activity_how_to_conduct.xml* and a*ctivity_wgat_you_need_to_know.xml*. Finally, the telehealth booking, which is mainly done by *activity_patient_health_details.xml* will have input fields to collect user information and then summarize them before confirmation in the last activity of its flow.

### 3.2.2 Algorithm Development

Developing the 6MWT distance measurement algorithm will be using the same concept introduced by earlier studies (Capela *et al.*, 2015; Salvi *et al.*, 2020) by detecting U-turns at the end of test hallway. Following the same guidelines from the American Thoracic Society (Crapo *et al.*, 2002), where the patient will be asked to walk on a straight hallway with a known fixed distance, which is then keyed in the smart phone application. The developed algorithm will utilize both accelerometer and magnetometer with the step counter sensor for processing the user activity and calculating the distance covered, steps taken, and rotations count.

To be able to access the sensor data, the sensors must be registered, with guaranteeing the access by the phone. Once they are registered, all sensor data can be accessed through the *onSensorChanged* method, which is called when there is a new sensor event or when there is a new reading from the sensor. The code fragment for the sensor registration can be seen in the following Figure 3.4. The registration is done directly after the *onCreate()* method is called following the Android activity life cycle.

After the registration, the application is ready to measure the test parameters once the timer starts. The *onCreate()* method will initialize all view components on the screen, variables that are used to for computation, as well as set the timer to 6-minutes period. The remaining of the process is continued once the user starts the test. One important code block is the sensor availability checking which is also done inside the *onCreate()* to check if sensors exist or not. The *onResume()* is called after the *onCreate()* method, which handles the three sensor registration as explained in the previous paragraphs.




**Android Code Fragment**

```
....

@Override
protected void onCreate(Bundle savedInstanceState) {
  // Function will be called to initialize the activity views,
  // variables, update 6-minute timer, and check sensor
  // availability.

}

...

@Override
protected void onResume() {
super.onResume();

  // Registering Sensors
  mSensorManager.registerListener(this,
        mAccelerometerSensor,SensorManager.SENSOR_DELAY_GAME);
  mSensorManager.registerListener(this,
        mMagnetometerSensor,SensorManager.SENSOR_DELAY_GAME);
  mSensorManager.registerListener(this,
        mStepCounter,SensorManager.SENSOR_DELAY_UI);
}

...
```

Figure 3.4 Code fragment that highlights the sensor registration process made once activity starts.

After the timer starts, the counter flag is set to true, and step counter sensor is reset to zero based on the previous history saved in the *SharedPreferences*. Then, the timer counter starts counting down from six minutes till it ends. The *updateTimer()* is called on every second to update the timer, and validate the audible instruction timing to be triggered during the test. The azimuth signal is processed from both accelerometer and magnetometer sensors only when the counter flag is set to true, where the values are stored in *azimuthInDegrees* variable, that is later used in processing and rotation logic.

The developed algorithm aims to detect the rapid change of the azimuth signal amplitude, which is then used to count the number of rotations, to compute the distance covered during the test. Figure 3.5 demonstrated the overall algorithm flow in detecting U-turns. Once the azimuth signal is computed, next stage is to apply a delay operation to each signal value as shown in Figure 3.5(c) with a window of 25 milliseconds. The delay operation will produce a new delayed azimuth signal, in which its values are updated from the raw azimuth, making the signal repeat its values for a period, and become smoother. This delayed signal is essential to segment the signal slopes (U-turns) from the other activities done such as walking or running during the 6MWT. Figure 3.6 demonstrates the code block for the initial steps after the test starts and process of converting the raw data to the azimuth values in degree.

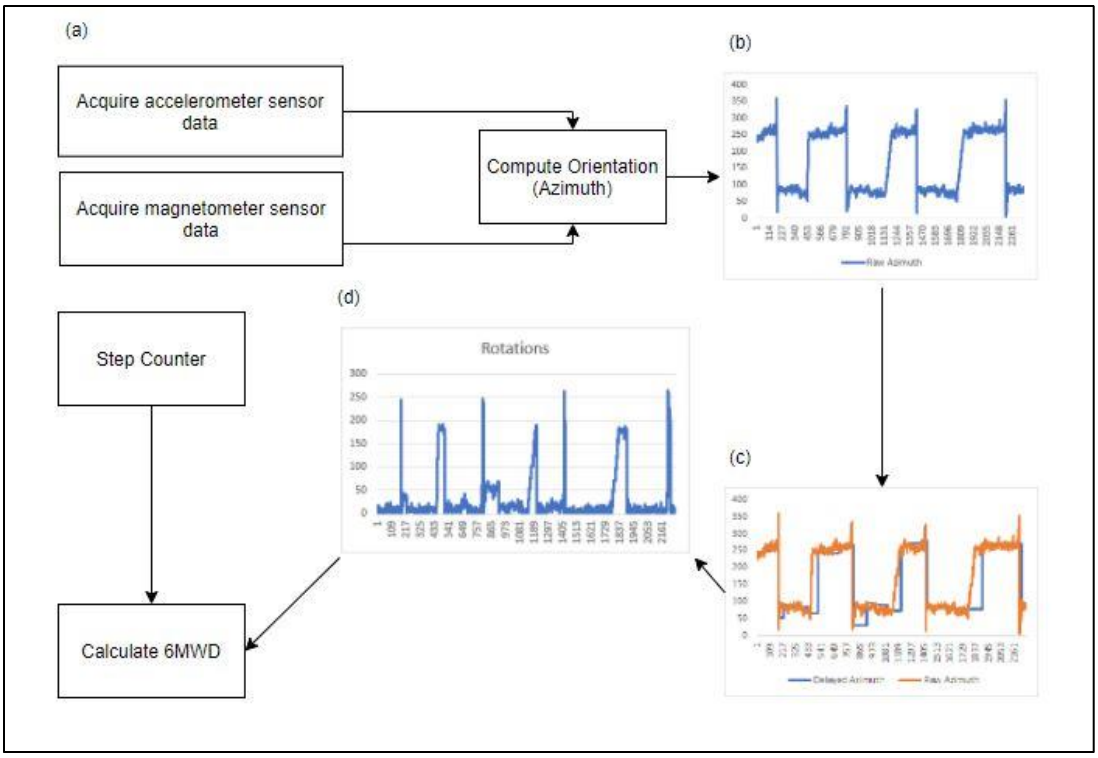
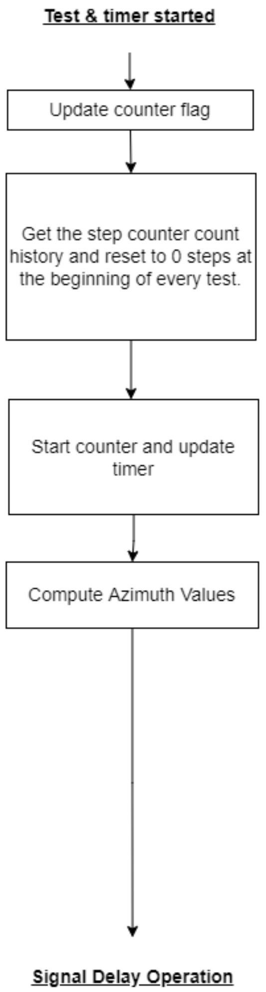



Figure 3.5 6MWT algorithm for calculating the distance taken by user during the test. (a) Acquiring sensor values to compute the azimuth values. (b) Raw azimuth signal after computing it from both accelerometer and magnetometer. (c) Blue signal is the delayed azimuth signal, with a delay factor of 3 seconds per value. (d) U-turns that are computed by calculating the absolute difference from both raw and delayed signals




**Android Code Fragment**

```
...

counterIsActive = true;

...


SharedPreferences.Editor editor = prefs.edit();
editor.putInt(Initial_Count_Key, stepCounterEvent);
editor.commit();

...

countDownTimer = new CountDownTimer(timeRemaining, 1000) {

  // Will contain the code for the audible instructions
  updateTimer((int) millisUntilFinished / 1000);
}

...

@Override
public void onSensorChanged(SensorEvent event) {

  if (counterIsActive){
    // Using accelerometer and magnetometer for
        processing
    rotateUsingOrientationAPI(event);
  }
}

// Inside rotateUsingOrientationAPI
SensorManager.getRotationMatrix(mRotationMatrix,
        null,mLastAccelerometer,
        mLastMagnetometer);
SensorManager.getOrientation(mRotationMatrix,
        mOrientation);
float azimuthInRadians = mOrientation[0];
azimuthInDegress = (float)
        (Math.toDegrees(azimuthInRadians) + 360) % 360;
```

Figure 3.6 Code fragment that highlights the process after the user starts the test, which includes starting counter and computing azimuth values.

To segment the rotations, the absolute difference is computed between both raw and delayed azimuth signals, as shown in Figure 3.5(d), which will then provide a signal that indicates the number of rotations taken by the user, thus the number of laps covered in the hallway, as each U-turn indicates that the user had finished a certain distance, from the start to the end of the hallway.

(a)

[54.26059, 53.58499, 78.64368, 77.738464, 94.949615, .. , 92.61438, 91.14404, 88.20001, 84.56903, ..]

(b)

[54.26059, 54.26059, 54.26059, 54.26059, 54.26059, .. ,92.61438, 92.61438, 92.61438, 92.61438, .. ]

Figure 3.7 Comparison between both raw and delayed signals used to segment the rotations from sensor data. (a) Raw azimuth data. (b) Delayed azimuth data.

A sample of both raw and delayed signals from the same timestamp is shown in Figure 3.7. As shown from Figure 3.7(a) and (b), the first value from (a) will be repeated for 25 milliseconds creating the new delayed azimuth signal (b). Thus, when calculating the absolute difference, the new signal peaks should be also in the same range of time. To identify whether a user had made a rotation or not, the rotation signal values are compared to a threshold of 130-degree value. Once it exceeds the threshold, a rotation is detected. The flowchart below highlights the key code blocks for detecting the rotations made using both raw and delayed azimuth.

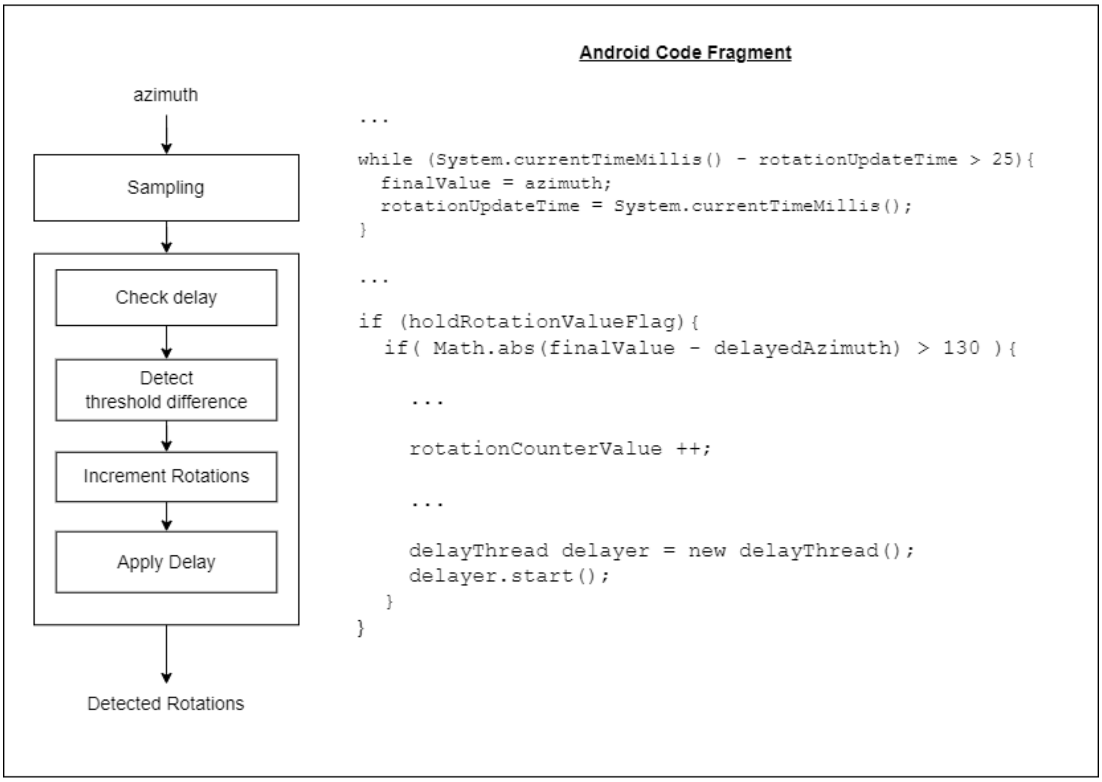



Figure 3.8 Flowchart for rotation detection process.

One important consideration is how fast the signal values are updated and changed, and it is very possible to have multiple values satisfy the thresholding condition directly after each other. This will cause false rotation detection, as once a rotation is performed, it is important to stop computing the values for a certain period, thus making sure that there is at least a minimum time difference between two rotations. As every person will have different ability to walk during the 6MWT, and the time between two rotations will vary depending on every person and hallway distance, the delay locking period needs to be calculated dynamically based on every user.

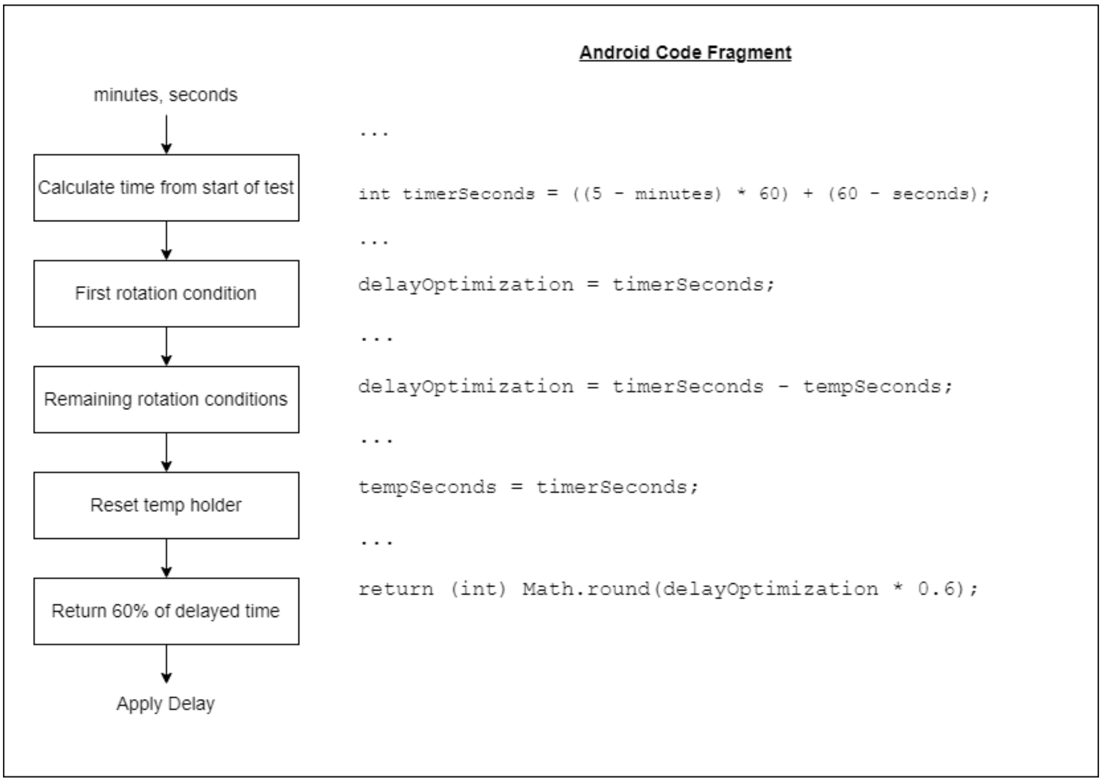



Figure 3.9 Flowchart for calculating the optimization delay process.

Once the rotation is detected, a delay locking period is introduced to hold computing other values, which is equal to sixty percent (60%) of the time difference between the first rotation and start of test, if it is the case of first rotation detected, or between two rotations otherwise. This to ensure that the signal values are set to normal walking behaviour and not meeting the rotation detection condition, thus making it more accurate and reduce the false detected rotations during performing the 6MWT. The flowchart for optimization calculation process is show in Figure 3.9.

At the end of the test, the user may not finish the last lap as the time may finish in the middle of the hallway. This is handled by using the step counter sensor as recommended in a previous study by (Salvi *et al.*, 2020). While performing the 6MWT, the number of steps is calculated and stored with the number of rotations covered back and forth in the corridor to calculate the average distance per step value. As for the final lap, in which the user did not cover all the hallway distance, will have some steps, those final lap steps taken are not used to calculate the average distance per step. Once the average distance per step is calculated at the end of the test, it is then used to find the residual distance by multiplying the average distance per step with the last lap step values.

The distance covered is calculated by multiplying the number of U-turns by the hallway distance set at the beginning of the test, with adding the residual distance calculated between the last U-turn and end of the test by multiplying the average distance per step by the number of steps only covered at this last amount of distance.

$$\begin{aligned} &Total\ Distance\ Covered \\ &\quad = (Number\ of\ Rotations\ Detected \\ &\quad * Hallway\ Distance) \\ &\quad + (Average\ Distance\ per\ Step \\ &\quad * Last\ Lap\ Steps\ Count)\ meters \end{aligned} \tag{3.1}$$

Figure 3.10 Final equation for calculating the measured distance by the algorithm

### 3.2.3 Step Counting Using Step Counter Sensor

The steps taken is a secondary parameter in the 6MWT algorithm as it is only used to calculate the residual distance covered by the user at the end of the test, only for the condition where some distance is covered at the end of the test, and not counted by the rotation detection section. The step counter sensor tracks the number of steps since last device reboot, the sensor output values should be processed and handled before being used as a part of the developed algorithm.

To reset the sensor values to zero value, the algorithm utilizes the *SharedPreferences* APIs, where it allows storing and retrieving data stored as a key-value pairs to and from a file on the device storage. The algorithm stores the sensor values at multiple stages. These values are used later to reset the step counter sensor variable value to zero every time the user starts the 6MWT.

## 3.3 Web Application Development

This section describes the tools and methods used for developing the dashboard as well as the telehealth system. The application is built using Nodejs framework and express server for the backend. The front end is built using HTML, CSS, JavaScript. It also uses Embedded JavaScript Templates (EJS) for an effective, optimized, and less repetitive code possible during the development process.

### 3.3.1 Clinician Dashboard Development

This dashboard contains four main pages; connected to a database for querying data. The pages are patient test results, registered users, telehealth bookings requests, and a page for manually creating a telehealth video call. Firebase provide a cloud-hosted database service known as Firestore, which is used in this project across both android and web applications. Three out of four pages are sharing the same database collections for storing the data between the android application as well as the web application. The application is built using an Express server with Nodejs framework to enable backend communication with the frontend dashboard. The dashboard workflow is explained in the Figure 3.11.

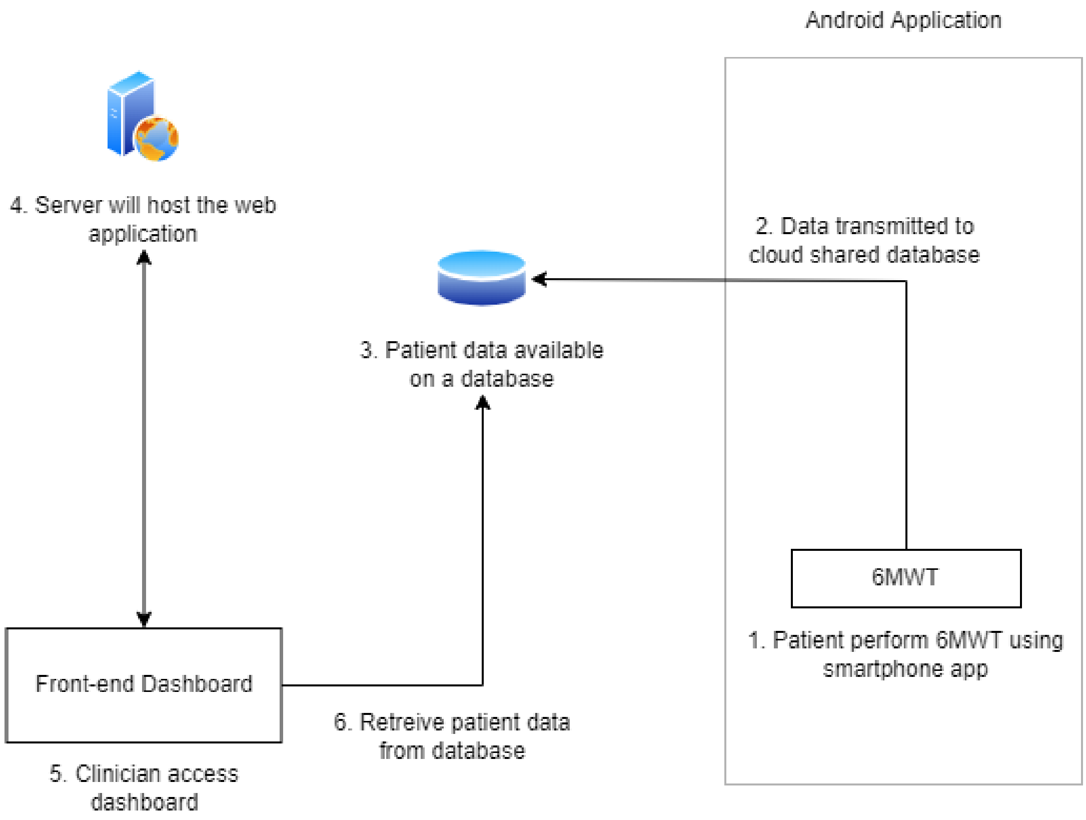



Figure 3.11 Web application dashboard flowchart

### 3.3.2 Video Conferencing (Telehealth) System Development

#### 3.3.2.1 System Design and Implementation

The system was implemented using WebRTC JavaScript APIs as was found to be the ideal method used by previous literature. WebSocket protocols were used as well to allow full-duplex communication channels compared to the popular HTTP protocol, which is known to provide half-duplex communication. The WebSocket (using socket.io library) was implemented with a Node.js server for serving the static client pages as well as handle the signalling concept for WebRTC. HTML, CSS, as well as JavaScript programming languages have been used to develop the front-end (client side) application. Public STUN servers were used in the implementation, which is responsible for obtaining the public IP and the port to send the video streaming (Santos-González *et al.*, 2017). For the real-time chatting, WebRTC data channels are used to provide peer-to-peer real-time data exchange between the two peers. The overall WebRTC application implementation flowchart design is shown in the Figure 3.12 below.

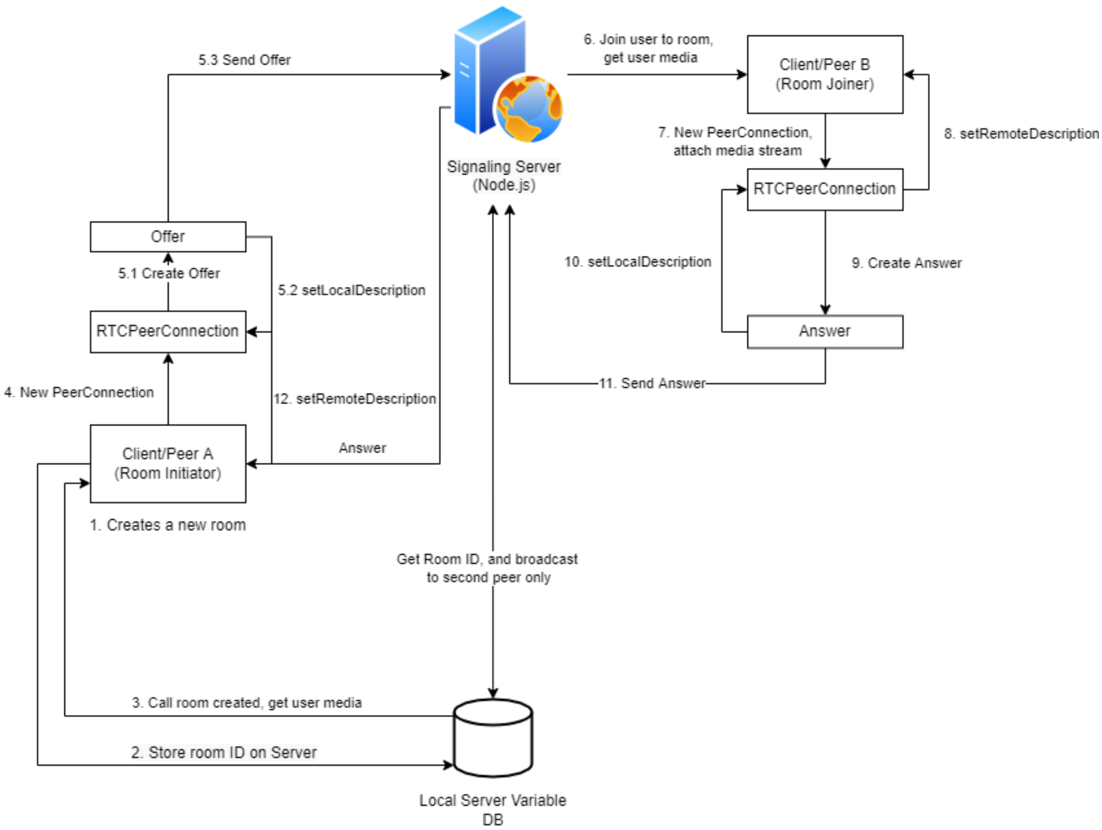



Figure 3.12 WebRTC System Implementation Design

### 3.3.2.2 Telehealth System Development

To be more detailed, the process starts when one user (known as a peer or a client) creates a room (URL link) to initiate the call, each room is given automatically a unique ID that represents the call room. Figure 3.13 show the user interface responsible for creating the call with the unique ID.

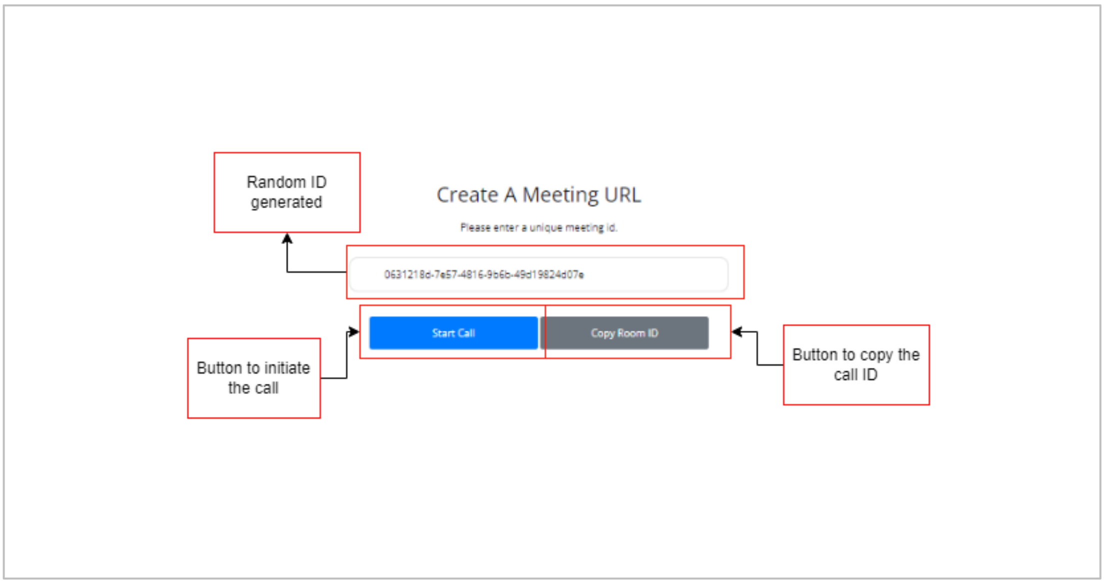



Figure 3.13    Create a call page UI

The WebRTC process from this point can be divided into two parts. One which represents the flow of the APIs for the room creator, and another which will represent the flow for the room joiner (second user to join the room). The user firstly will insert his name or any related information, that will be used in the real-time chatting. The name will be transmitted through data channels with the messages.

As for the room creator, once a new room is created, a socket event called *join* is emitted to the server using socket.io library. This variable will be used to store all the data and make further connection to other users. Then, once the room ID is stored in the variable, a *create_room_event* is emitted back from the server to the same room to notify the client with the room being created. This will prompt the user with the media access request for allowing the browser to capture his camera and microphone stream, for both video and audio. This process is done using *getUserMedia()* API. This API takes the media configurations, which highlights that both audio and video are requested to be accessed. Figure 3.14 demonstrates the request prompt shown for accessing the user media. Once a request is granted, a local client variable for the room creator will hold the stream values for it to be transmitted later once a user joins the call. At this stage, the process is on hold until a second user joins the same room URL.

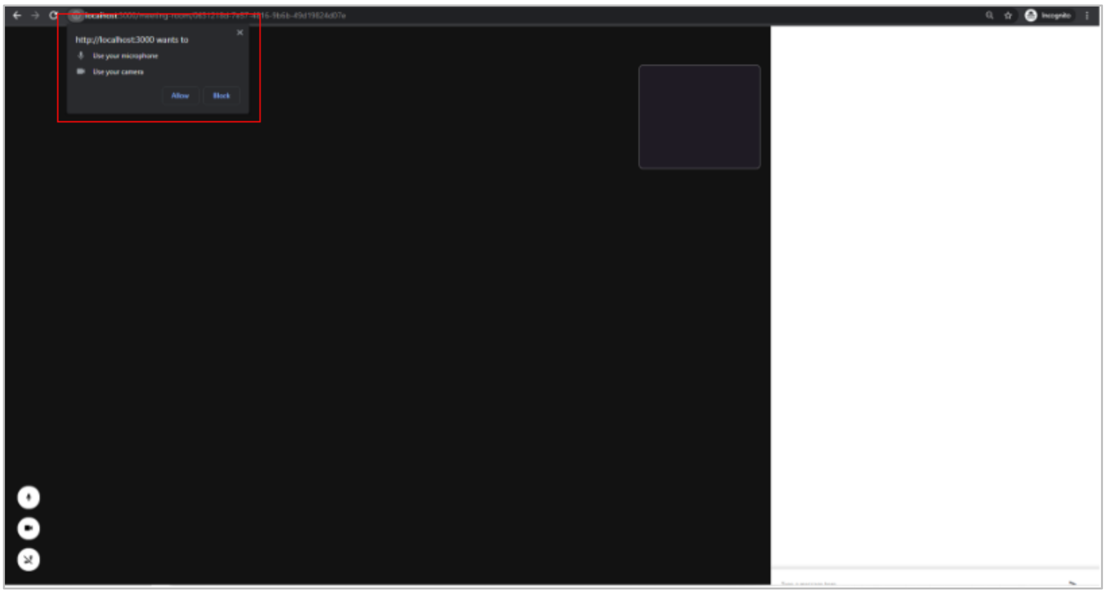



Figure 3.14 User media access request prompt to access audio and video.

Once a second user joins a room from a second browser, a *join* event is emitted again similarly to the room creator. The process onward will be different, as this will result in a *join_room_event* emitted from the server to the client. As this application is developed to handle peer-to-peer video calls, only two users are allowed to join a single room, thus any other join request onward will deny the access to the calls. This will also help in identifying the room creator from the second room joiner. The *join_room_event* will similarly result in requesting the user stream as well as saving it to a local client variable.

Now as both users are in the same room on the server, the *join_room_event* will also result in emitting a *start_call_event* from the room joiner to the server to inform about starting the call with the room creator. This will broadcast the same event to the second peer on the room, which is the room creator. On listening to this event, a new *RTCPeerConnection* is created to represent the connection between the two clients as discussed in the literature section. The client stream will be added to the created variable that represents the *RTCPeerConnection* using the *addTrack()* function for it to be streamed to the other user. Then, a new WebRTC offer is created by the room creator to the second peer. Once an offer is created, the first user emits emits a *webrtc_offer* event with the *sessionDescription* to the server, which then is broadcasted to the second peer who joined the room. This will perform the same process of creating an *RTCPeerConnection*, add local tracks to the connection, and then create an answer to the received offer. Before an answer is created to the room creator offer, the transmitted *sessionDescription* of the first user will be set as the remote description on the second user, as a part of peer connection process. After creating the offer answer by the room joiner, who is the second user, a *webrtc_answer* event is emitted from the second user to the room creator with his session description, through the server, which is then set on the first user as the remote description for the *RTCPeerConnection*. ICE candidates are transmitted back and forth between the two users during the process of offer and answer creation and transmission.

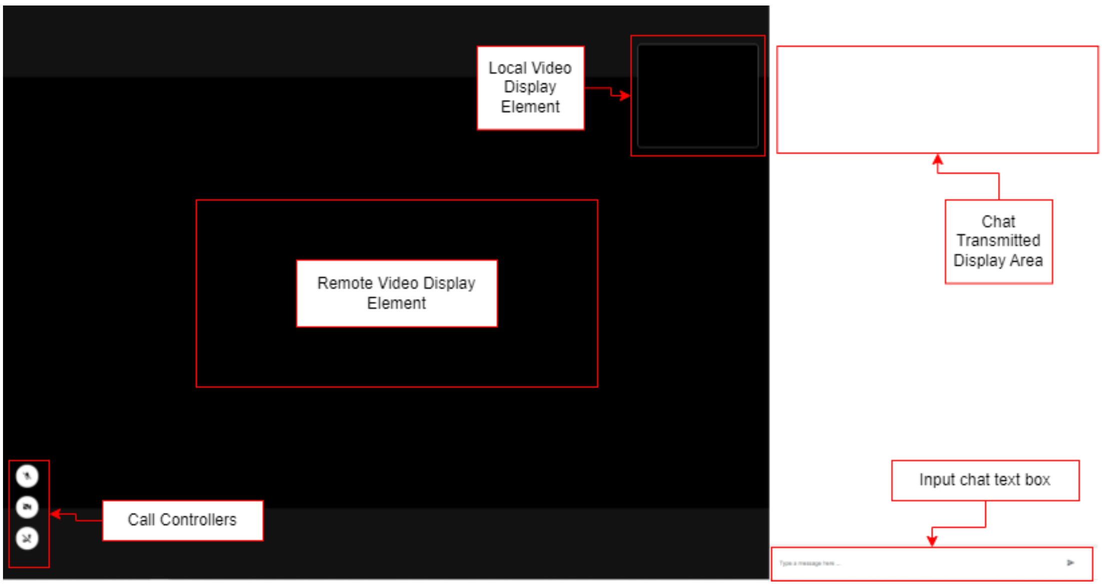



Figure 3.15 Telehealth application Interface.

At this point, a successful WebRTC connection is established, and both users can access to others streams on the browser. The remote stream for both users is added on the HTML video element to be displayed, and both users can see others' video streams. Figure 3.15 demonstrates the application user interface with its main components. The real-time chatting is implemented using the RTCPeerConnection *createDataChannel* API for both room initiator and second joiner before creating a new offer and an answer. This creates a new channel linked to the other remote peer, where any kind of data may be transmitted. All APIs were implemented inside separate functions for the purpose of reusability, which is summarized in the table below.

Table 3.1 Functions with their description for handling WebRTC implementation process.

| Function | Function Arguments | Description |
|---|---|---|
| *setLocalStream* | mediaConstraints | Responsible for accessing the user media and adding it to the video element on the front-end. |
| *addLocalTracks* | rtcPeerConnection; socketId | Adds the track captured to the RTCPeerConnection object for it to be transmitted. Handles also creating the data channels. |
| *createOffer* | rtcPeerConnection | Responsible for creating a new offer by the room creator for it to be transmitted to the second peer. It also handles setting the local description once the session description arrives. |
| *createAnswer* | rtcPeerConnection | Responsible for creating a new answer by the second peer as a response to the received offer. It also handles setting the local description once the session description arrives. |
| *setRemoteStream* | Event | The event holds the remote stream transmitted through the connection, which then adds it to the video element on the front-end. |
| *sendIceCandidate* | Event | This function is called before creating both offer and answer to start emitting ICE candidates through the socket event. |

| Function | Function Arguments | Description |
|---|---|---|
| *Logger* | Log message; Function name; Error flag | Helper function to log some information while the process is being done. |
| *addMessageToScreen* | Message input, Message owner flag | Helper function to append message data received from the data channel. |
| *LeaveCall* | | Helper function that ends the call. |
| *muteMicrophone* | | Helper function to mute the audio source of the stream for the peer who called it. |
| *pauseVideo* | | Helper function to pause the video source of the stream for the peer who called it. |
| *joinCall* | | Helper function to start the call after receiving the peer information and emits the first join event. |

### 3.4 Cloud Services Providers

Different cloud services providers had been used for this project implementation. Initially, Amazon Web Services (AWS) had been used for the purpose of web-application deployment on and Elastic Compute Cloud (EC2) instance, shared database deployment as parse server on another EC2 instance, and finally AWS amplify framework for the android application authentication (also with using AWS Cognito service). AWS is undeniably a powerful cloud services provider, but considering the long-term aspect for the project, in term of development and deployment to the market, there could be some drawbacks for relying mainly on AWS. One main potential issue is the pricing, as AWS provides only 1-year free tier with certain limit and services, the expected monthly bill for hosting the services on a small, scaled project would still be costly. Another issue faced was the documentation complexity, as most of the documentation is either way too advanced to be implemented or requires a certain framework or programming language for it to be used, which was an issue during the development process.

Alternatively, google provides a simpler, free for long-term services, called Firebase, which is currently being used by both web and android applications. Google Firebase provides authentication, as well as database which were used during the development. It also provides a lot of other services with a very easy documentation to follow that could potentially ease the future development with a low cost and had been proved to run on a production environment with a high performance. Firebase doesn't limit the free service usage to only one year as well as experienced during the project development, which is a key advantage for any project specially during the development stage.

## 3.5 Development Tools and Platforms

This section will list the developments tools, development platforms, and cloud services providers used for the development of this project.

### 3.5.1 Integrated Development Environments (IDEs)

#### 3.5.1.1 Android Studio IDE

Android Studio is an official Integrated Development Environment (IDE) for Google's Android operating system, which will be used to develop the Android application for conducting the 6MWT. Java programming language was used for developing a native application that will allow the user to conduct the 6MWT, book an online consultation, and send data and booking information securely to a database.

#### 3.5.1.2 Visual Studio Code

Visual Studio Code is a Microsoft free source code editor that was used to develop the dashboard web application, telehealth application, as well as server-side logic. JavaScript, HTML, CSS, NodeJS, Express, and EJS were used to develop all required applications. Socket.io, as well as WebRTC, were used for real-time data and media transmission.

### 3.5.2 Development Platforms

This project had been developed using a Windows 10 operating system on HP Pavilion Notebook. As for the development tools, Visual Studio Code was installed to the latest version by the time this report is written, where Android Studio version was 4.1.1. An Android device version 11 was used as the emulator for building the android application.

## 3.6 Chapter Summary

To sum up, three sensors were used to acquire the signal and data during the 6MWT, which are accelerometer, magnetometer, and step counter. They were used to process the azimuth signal which represents the degree of rotation, which is then used to identify whether a patient had done a U-turn while performing the test and calculate the distance. Step counter sensor also played a role in calculating the steps by counting the steps taken and identifying any residual distance at the end of the test. The web application which consists of a dashboard and a telehealth application was developed on a single server to host the application as well as performs the signalling operation for WebRTC implementation. The web application dashboard was mainly displaying the user related information, and the telehealth application will allow peer-to-peer video calling through a unique generated room URL.

# CHAPTER 4

# RESULTS AND DISCUSSION

This chapter discusses the overall research and validation results of the proposed technique for 6-Minute Walk Test (6MWT) implemented on Android devices using embedded sensors as well as the telehealth implementation using WebRTC.

## 4.1 Introduction

All system components, including the mobile application algorithm for self-administered 6MWT and web application for clinical video conferencing were successfully developed and satisfied the research objectives. The algorithm was implemented based on literature finding using three embedded sensors from smartphone devices with Android operating system. Both accelerometer and magnetometer were used for processing the azimuth signal, for the purpose of rotation detection while performing the test. Step counter sensor was used to count the steps taken during the test. Test results are then transmitted to a cloud database for it to be accessed by the web application for the monitoring purpose. The web application includes a logging dashboard for the results to be displayed, and a telehealth application implemented using WebRTC for peer-to-peer media transmission.

Besides the main 6MWT distance tracking functionality by the smartphone application, the application does provide authentication, audible test instructions during the test, educational information page, and telehealth booking. As for the telehealth application, the clinician will be able to access all patient data from his created account as well as test results, and finally create remote consultation rooms.

## 4.2 Functional Validation and Performance Measurement Procedure

The functionally validation and performance measurement procedure was divided into two steps mainly for validating the 6MWT application accuracy as per research objective. The distance measurement accuracy mainly relies on how accurate rotations were detected by the patient while performing the test, while holding the phone with the application running. Thus, two validation procedures were performed on: (i) validating rotation detection accuracy, and (ii) validating the overall distance measured.

During validation, the 6MWT was performed both indoor and outdoor environments where a relevant hallway distance was found, by a healthy participant, following the guidelines provided by the American Thoracic Society. Different walking styles were simulated during estimating algorithm performance as mentioned by other study (Salvi *et al.*, 2020), from slow to fast walking styles, straight to U-turns, and different hand shakiness levels. For the rotation validation, the rotations were counted using a physical counter, and then compared to the measured rotation count by the application. As for the distance validation, the actual distance measured was compared to the overall estimated distance by the application. All results were collected and analyzed for validation and considering any future improvements. The validation was done on a hallway with different distance ranges, for ten trials per each validation procedure.

During all validation trails, the smartphone device was held tightly using the right hand with the screen facing upward. This placement will reduce any potential false detection or calculation for any of the test parameters, as placing the phone in the pocket could potentially increase the error rate due to the high movement and loose grip. Also, the participant is given the free decision in determining the rotation direction as the application can detect either rotating toward right or left.

For the rotation detection validation results demonstrated in the section below, the measured rotations are the number of rotations counted by the application; the actual rotations are the number of rotations made by the participant; the missed rotations count is the difference between the actual and measured as described above, and finally the hallway distance is the distance set by the participant for the walking pathway. As for the distance measurement validation results, the actual distance covered is the real total distance covered by the participant during the test; the measured distance covered the estimated distance resulted by the application at the end of the test.

The rotation detection procedure showed that the algorithm can capture the rotations successfully for many of the cases, with a total average accuracy of 89.2%. For most of the cases where a pause was taken while performing the test was made, many rotations were not detected successfully. This has to do with the way it eliminates any non-ideal behaviour made during the test. In other words, one part of the algorithm validates the rotation by applying a delay locking period after each detected as explained in the methodology chapter. This delay period was found to significantly remove a lot of false detected rotations, due to the behaviour of rapid sensor values change, which could potentially pass the thresholding logic that identifies the detection.

The delay period as explained previously is calculated dynamically based on the duration between two rotations, which is equal to 60% of the time between two rotations, or the time from the beginning of the test to the first rotation. In the case of pausing during the test, the time between two rotations will significantly increase more than the previous history rotation period, which means more delay before counting the next rotation. Thus, after a long pausing period, a long locking delay is applied, which is mainly to reduce false detection, resulting in missing counting the rotations even if the thresholding condition is satisfied. Another condition that was also found to affect the detection is hand shaking; where rapid shaking could cause change to the azimuth signal, which could result in satisfying the rotation detection condition. This, however, was less affecting the result compared to the pausing as explained previously.

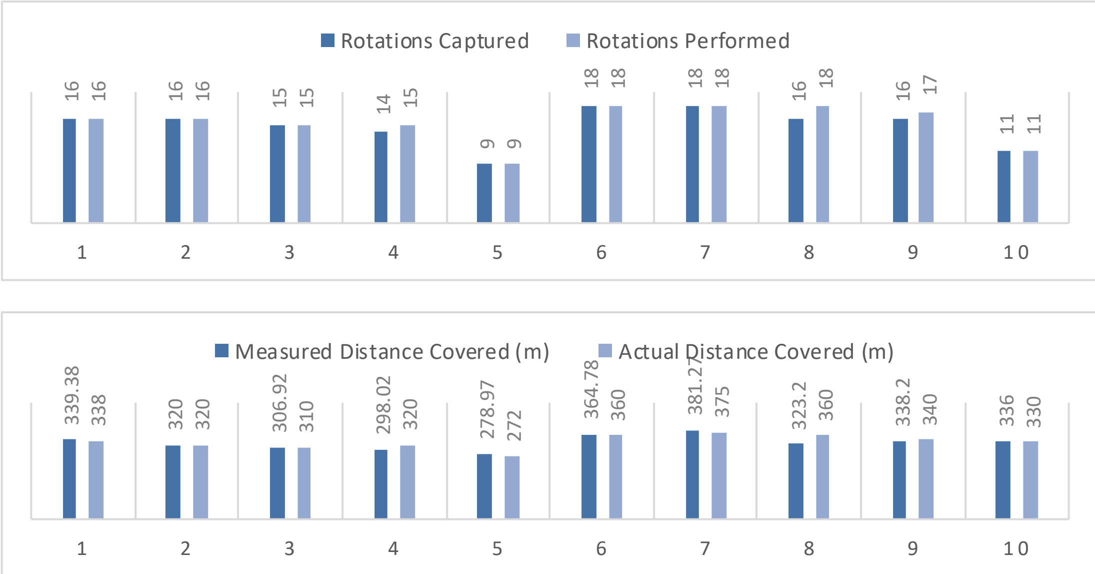



Figure 4.1 Relation between distance to rotations detected.

The missed rotations can result in a significant difference in the measured distance by application as seen in the distance validation table. A single rotation missed or over counted could result in a minimum distance difference equal to the hallway distance, due to the way the application measures the distance. Most of the distance validation on the other hand had satisfying results, as the algorithm is able to measure the distance to cm precision and to a near estimation. In the condition that the application had detected all rotations successfully, there measured distance was in a near margin to the actual distance measured during the test. This relation can be seen in Figure 4.1 chart, where missed rotations contribute to the missed distance measurement. One condition when the participant finished exactly on the starting point had exactly accurate distance measurement as no residual distance was calculated as seen from the distance validation table, while some others were either over or underestimated due to approximation made by the residual distance measured after the test is finished.

Table 4.1 Rotation Detection Validation Results.

| No. | Measured Rotations | Actual Rotations | Missed Rotations Count | Accuracy (%) | Hallway Distance (m) | Additional Notes | Phone Placement |
|---|---|---|---|---|---|---|---|
| 1 | 27 | 29 | 2 | 93.10 | 15 | Moderate pace walking; more like a healthy person | Ideal placement as found through previous testing (Held on right hand, facing upward, and always screen on for checking values) |
| 2 | 11 | 15 | 4 | 73.33 | | Very slow-paced walking; small steps; a lot of pauses; Noticed some rotations not detected when rotating in left direction | |
| 3 | 14 | 16 | 2 | 87.50 | | Very slow-paced walking; small steps; a lot of pauses; Noticed some rotations not detected when rotating in left direction | |
| 4 | 17 | 18 | 1 | 94.44 | | Very slow-paced walking; small steps; Rotation only in left direction | |
| 5 | 20 | 20 | 0 | 100.00 | | Very slow-paced walking; small steps; Rotation only in right direction | |
| 6 | 19 | 22 | 3 | 86.36 | | Very slow-paced walking; small steps; Minor hand shaking while holding the phone | |
| 7 | 12 | 16 | 4 | 75.00 | | Very slow-paced walking; small steps; paused multiple times during the test; long pauses miss one count ahead | |
| 8 | 14 | 17 | 3 | 82.35 | | Very slow-paced walking; small steps; paused multiple times during the test; long pauses miss one count ahead | |
| 9 | 8 | 8 | 0 | 100.00 | | No pauses; Not complete full 6-minute walk test | |
| 10 | 8 | 8 | 0 | 100.00 | | No pauses; Not complete full 6- minute walk test | |

Table 4.2 Distance Measurement Validation Results.

| No. | Hallway Distance (m) | Actual Distance Covered (m) | Measured Distance Covered (m) | Rotations Captured | Walking Speed | Additional Notes |
|---|---|---|---|---|---|---|
| 1 | 20 | 338.00 | 339.38 | 16 / 16 | Slow paced walking | All rotations were captured successfully. Did not stop exactly on either hallway ends, and algorithm was able to successfully calculate a good estimation of the hallway distance |
| 2 | 20 | 320.00 | 320.00 | 16 / 16 | Slow paced walking | All rotations were captured successfully. Stopped exactly on the starting point, thus there were no residual distance calculated, therefore the final distance is exactly similar to the measured distance |
| 3 | 20 | 310.00 | 306.92 | 15 / 15 | Slow paced walking | All rotations were captured successfully. Residual distance is approximated to a good range, as last rotation was not counted, and last meters were averaged |
| 4 | 20 | 320.00 | 298.02 | 14 / 15 | Slow paced walking | Missed a single rotation, which lead to a significant difference between the actual distance covered and measured distance by device |
| 5 | 30 | 272.00 | 278.97 | 9 / 9 | Slow paced walking | All rotations were captured successfully on a 30m hallway. Few meters were averaged by the residual distance calculation. |
| 6 | 20 | 360.00 | 364.78 | 18 / 18 | Normal paced walking | All rotations were captured successfully; took only few steps after the last rotation, but it overestimated to few meters |

| No. | Hallway Distance (m) | Actual Distance Covered (m) | Measured Distance Covered (m) | Rotations Captured | Walking Speed | Additional Notes |
|---|---|---|---|---|---|---|
| 7 | 20 | 375.00 | 381.27 | 18 / 18 | Normal paced walking | All rotations were captured successfully; took one last round without rotating, but it overestimated to few meters |
| 8 | 20 | 360.00 | 323.20 | 16 / 18 | Normal paced walking | Two rotations were missed resulting in a large distance difference. |
| 9 | 20 | 340.00 | 338.20 | 16 / 17 | Normal paced walking | Missed a single rotation, which lead to a significant difference between the actual distance covered and measured distance by device |
| 10 | 30 | 330.00 | 336.00 | 11 / 11 | Normal paced walking | All rotations were captured successfully on a 30m hallway. Few meters were overestimated by the residual distance calculation. |

## 4.3 Smartphone Application User Interface

The 6MWT algorithm had been proven to successfully work on an android smartphone application. Figure 4.2 demonstrates the main screens that the patient will have access to, which are authentication, telehealth booking, dashboard, testing page and summary results.

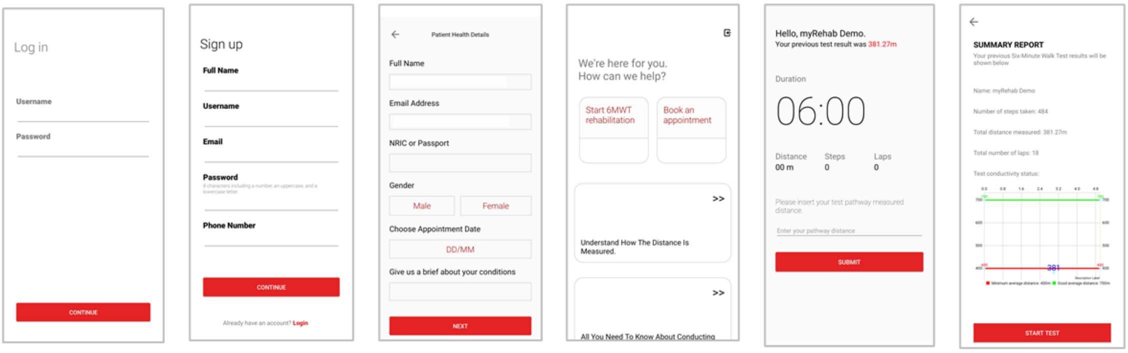



Figure 4.2 Smartphone application user interface

To use the application, the patient is required to create a new account or sign in first. This is followed up by directing the user to the main activity dashboard, which he is then given the option to start the test or book an appointment. In the case of booking the appointment, the patient is required to fill his health application record, which will be passed to the clinician on the dashboard and stored on the cloud database. As for the 6MWT, the patient will be able to see his previous summary report, which is always updated after performing the test.

## 4.4 Web Application User Interface

The web application, which contains both patient data report logging, and telehealth application have been successfully developed. The figures below highlight the main pages for the clinician to go through. Figure 4.3 below illustrates the main page for clinicians to create a video call URL with the patient.

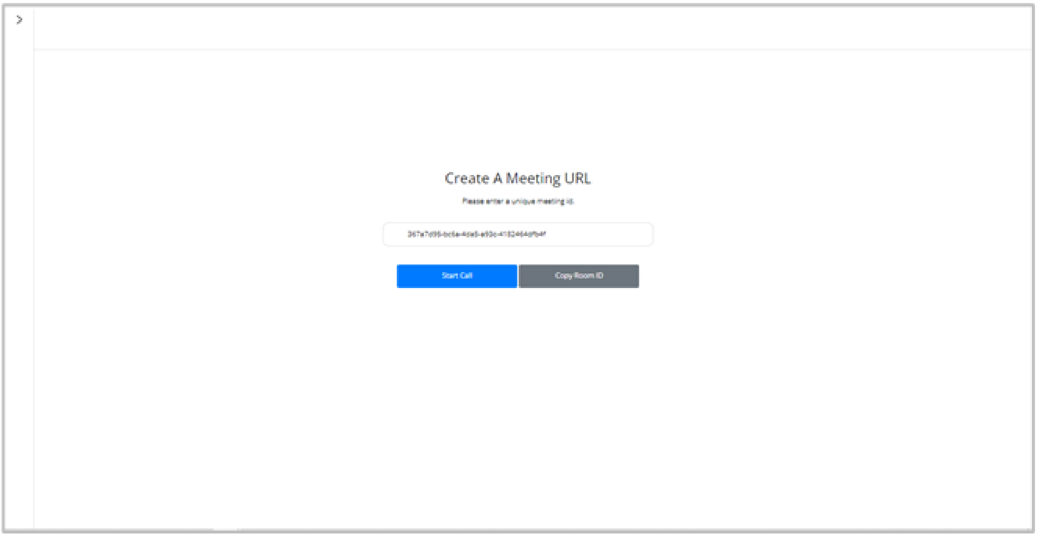



Figure 4.3 Web application telehealth page for creating new consultation rooms

This will redirect the clinician to the call URL/room created, which can be seen in Figure 4.4 below.

Figure 4.4 Web application telehealth rooms

Besides, the clinician will have an access the registered user's detail, test results, and finally the telehealth bookings. This can be seen in Figure 4.5.

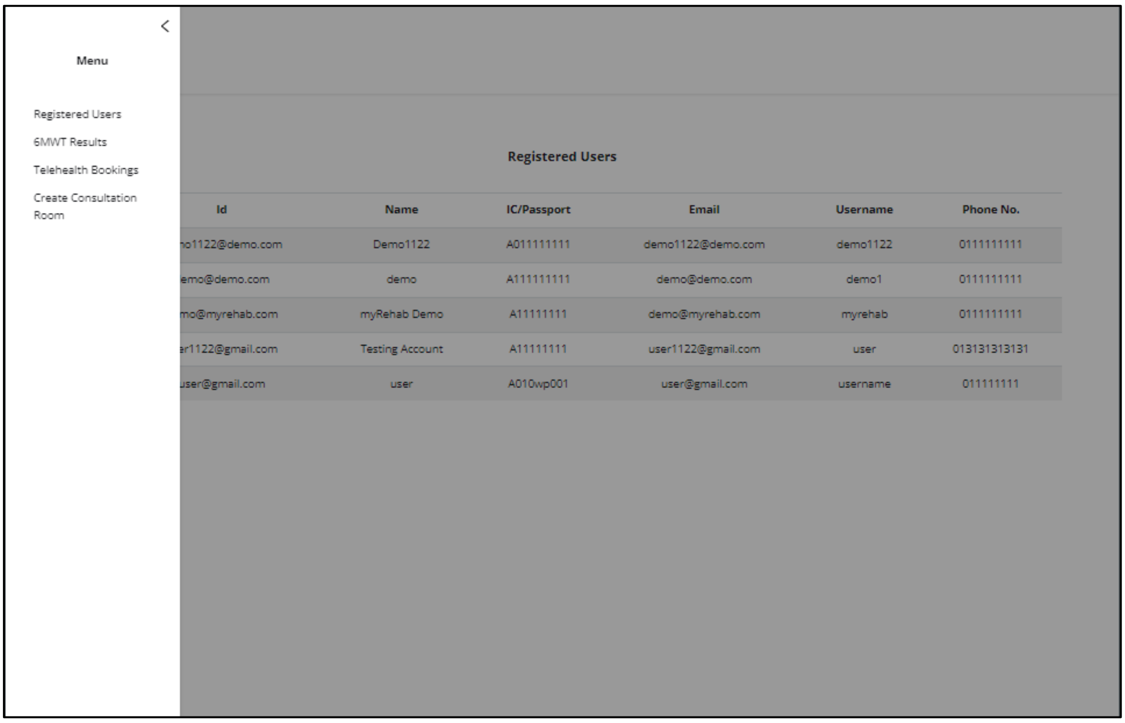



Figure 4.5 Web application clinician pages for patient details

## 4.5 Chapter Summary

In conclusion, this chapter showed that the research project objectives have been successfully achieved by proving both smartphone android application for the 6MWT, clinician dashboard for remote monitoring and consultation, and finally performance validation.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

This chapter discusses the project conclusion and provide some suggestions for future work that could be improved.

## 5.1 Conclusion

In conclusion, different smartphone embedded sensors have been used in the purpose of developing a U-turn detection algorithm and step counting for the purpose of 6MWT distance measurement. Two validation procedures were performed to measure the performance and validate accuracy. This provides a simple and accurate tool for 6MWT measurement that will allow the test to be performed in a non-hospital environment. The use of WebRTC for telehealth applications is very promising due to the capabilities and features it provide with no cost accumulated, and with the help of Firebase cloud services, this system is expected to improve and ease the clinical as well as patient procedure for performing and monitoring the test. This project contributes to improving clinical practice and elaborates on smartphone sensor processing in providing meaningful biomedical applications. The developed approach improved in the distance measurement with having step counter built-in sensor integrated with a simple rotation detection mechanism thus resulting in a less computationally intensive implementation. The use of Firebase allows scalability to this project with the help of its services. It also provides a secure browser-based telehealth video call platform that relies on Web Real-Time Communication (WebRTC) technology.

## 5.2 Future Works Recommendation

One key aspect for further improving this project is to validate it on real patients who are in need for the 6MWT, as by the time of this thesis, there was no access to clinics and patients. This will not only provide more information on the application drawback and areas for improvements but will other researchers to consider handling more use-cases so that the algorithm is able to perform under any condition or movement by the patient. Also, making the developed system more scalable, it is recommended to deploy the developed web application using any cloud provider, where Google Firebase is recommended as other services are already used from the same provider. This will make the web application more usable as currently it only runs using local machine server.

Moreover, in term of 6MWT algorithm, the algorithm had been validated on a single mobile device placement, which is by holding it on the right hand, facing upward. This could be further improved by tuning the algorithm to be able to attach the smartphone to the leg while walking, so less effort will be made during the test. In addition to that, the current algorithm utilizes the step counter sensor for the purpose of counting the steps while walking during the test; this can be improved by implementing the step counting using other sensors signals, as the step counter have latency between the event sensed and event-triggered, thus causes some steps to be missed.

## REFERENCES


*Android Sensor Programming By Example - Varun Nagpal - Google Books* (no date).

Annegarn, J., Spruit, M. A., Savelberg, H. H. C. M., Willems, P. J. B., Bool, C. van de, Schols, A. M. W. J., Wouters, E. F. M. and Meijer, K. (2012) 'Differences in Walking Pattern during 6-Min Walk Test between Patients with COPD and Healthy Subjects', *PLoS ONE*. Edited by C. Taube. Public Library of Science, 7(5), p. e37329.

Antunes, M., Silva, C. and Barranca, J. (2016) 'A Telemedicine Application Using WebRTC', *Procedia Computer Science*. Elsevier B.V., 100, pp. 414–420.

Ata, R., Gandhi, N., Rasmussen, H., El-Gabalawy, O., Gutierrez, S., Ahmad, A., Suresh, S., Ravi, R., Rothenberg, K. and Aalami, O. (2018) 'Clinical validation of smartphone-based activity tracking in peripheral artery disease patients', *npj Digital Medicine*. Nature Publishing Group, 1(1), pp. 1–8.

De Cannière, H., Corradi, F., Smeets, C. J. P., Schoutteten, M., Varon, C., Van Hoof, C., Van Huffel, S., Groenendaal, W. and Vandervoort, P. (2020) 'Wearable monitoring and interpretable machine learning can objectively track progression in patients during cardiac rehabilitation', *Sensors (Switzerland)*. MDPI AG, 20(12), pp. 1–15.

Capela, N. A., Lemaire, E. D. and Baddour, N. (2015) 'Novel algorithm for a smartphone-based 6-minute walk test application: Algorithm, application development, and evaluation', *Journal of NeuroEngineering and Rehabilitation*, 12(1), pp. 1–13.

Casillas, J. M., Hannequin, A., Besson, D., Benaïm, S., Krawcow, C., Laurent, Y. and Gremeaux, V. (2013) 'Walking tests during the exercise training: Specific use for the cardiac rehabilitation', *Annals of Physical and Rehabilitation Medicine*. Elsevier Masson, 56(7–8), pp. 561–575.

Chaudhry, B. M. (2017) 'Sleeping with an Android', *mHealth*. AME Publishing Company, 3, pp. 7–7.

Chodór, P., Wilczek, K., Zielińska, T., Przybylski, R., Głowacki, J., Włoch, Ł., Zembala, M. and Kalarus, Z. (2017) 'Assessment of cardiovascular function following transcatheter aortic valve implantation based on six-minute walk test',

*Cardiology Journal*. Via Medica, 24(2), pp. 167–175.
Chung, S., Lim, J., Noh, K. J., Kim, G. and Jeong, H. (2019) 'Sensor data acquisition and multimodal sensor fusion for human activity recognition using deep learning', *Sensors (Switzerland)*. MDPI AG, 19(7).
Crapo, R. O., Casaburi, R., Coates, A. L., Enright, P. L., MacIntyre, N. R., McKay, R. T., Johnson, D., Wanger, J. S., Zeballos, R. J., Bittner, V. and Mottram, C. (2002) 'ATS statement: Guidelines for the six-minute walk test', *American Journal of Respiratory and Critical Care Medicine*. Am J Respir Crit Care Med, 166(1), pp. 111–117.
CURCI, C., PISANO, F., BONACCI, E., CAMOZZI, D. M., CERAVOLO, C., BERGONZI, R., DE FRANCESCHI, S., MORO, P., GUARNIERI, R., FERRILLO, M., NEGRINI, F. and De SIRE, A. (2020) 'Early rehabilitation in post-acute COVID-19 patients: Data from an Italian COVID-19 Rehabilitation Unit and proposal of a treatment protocol', *European Journal of Physical and Rehabilitation Medicine*. Edizioni Minerva Medica, 56(5), pp. 633–641.
Edan, N. and Abdullah, E. Y. (2020) 'Design and implementation of a novel secured and wide WebRTC signalling mechanism for multimedia over internet Related papers Design and implementation of a novel secured and wide WebRTC signalling mechanism for multimedia over internet', *International Journal of Electrical and Computer Engineering (IJECE) International Journal of Electrical and Computer Engineering (IJECE) International Journal of Electrical and Computer Engineering (IJECE)*, 10(5), pp. 5430–5435.
Enrichi, P. L. and Sherrill, D. L. (1998) 'Reference equations for the six-minute walk in healthy adults', *American Journal of Respiratory and Critical Care Medicine*. American Lung Association, 158(5 PART I), pp. 1384–1387.
Enright, P. L. (2003) 'The Six-Minute Walk Test', *Respiratory Care*, 48(8).
Fowdur, T. P., Ramkorun, N. and Chiniah, P. K. (2020) 'Performance Analysis of WebRTC and SIP-based Audio and Video Communication Systems', *SN Computer Science 2020 1:6*. Springer, 1(6), pp. 1–22.
Gaziano, T., Reddy, K. S., Paccaud, F., Horton, S. and Chaturvedi, V. (2006) 'Cardiovascular Disease'. The International Bank for Reconstruction and Development / The World Bank.
GC, B., E, V., S, I., D, T., P, K., KA, M., GM, M., MJ, P. and JE, O. (2015) 'Accuracy and Usability of a Self-Administered 6-Minute Walk Test Smartphone

Application', *Circulation. Heart failure*. Circ Heart Fail, 8(5), pp. 905–913.
Guyatt, G. H., Pugsley, S. O., Sullivan, M. J., Thompson, P. J., Berman, L. B., Jones, N. L., Fallen, E. L. and Taylor, D. W. (1984) 'Effect of encouragement on walking test performance', *Thorax*. BMJ Publishing Group, 39(11), pp. 818–822.
Guyatt, G. H., Sullivan, M. J., Thompson, P. J., Fallen, E. L., Pugsley, S. O., Taylor, D. W. and Berman, L. B. (1985) 'The 6-minute walk: A new measure of exercise capacity in patients with chronic heart failure', *Canadian Medical Association Journal*. Canadian Medical Association, 132(8), pp. 919–921.
*hjp: doc: RFC 4566: SDP: Session Description Protocol* (no date).
Holland, A. E., Spruit, M. A., Troosters, T., Puhan, M. A., Pepin, V., Saey, D., McCormack, M. C., Carlin, B. W., Sciurba, F. C., Pitta, F., Wanger, J., MacIntyre, N., Kaminsky, D. A., Culver, B. H., Revill, S. M., Hernandes, N. A., Andrianopoulos, V., Camillo, C. A., Mitchell, K. E., Lee, A. L., Hill, C. J. and Singh, S. J. (2014) 'An official European Respiratory Society/American Thoracic Society technical standard: field walking tests in chronic respiratory disease', *The European respiratory journal*. Eur Respir J, 44(6), pp. 1428–1446.
Juen, J., Cheng, Q., Prieto-Centurion, V., Krishnan, J. A. and Schatz, B. (2014) 'Health monitors for chronic disease by gait analysis with mobile phones', *Telemedicine journal and e-health : the official journal of the American Telemedicine Association*. Mary Ann Liebert, Inc., 20(11), pp. 1035–1041.
Morgan, A. D., Zakeri, R. and Quint, J. K. (2018) 'Defining the relationship between COPD and CVD: what are the implications for clinical practice?', *Therapeutic Advances in Respiratory Disease*. SAGE Publications Ltd, 12.
*Motion sensors | Android Developers* (no date).
Nag, T. and Ghosh, A. (2013) 'Cardiovascular disease risk factors in Asian Indian population: A systematic review', *Journal of Cardiovascular Disease Research*. No longer published by Elsevier, 4(4), pp. 222–228.
Park, Y. R., Lee, Y., Lee, G., Lee, J. H. and Shin, S. Y. (2015) 'Smartphone applications with sensors used in a tertiary hospital-current status and future challenges', *Sensors (Basel, Switzerland)*. Sensors (Basel), 15(5), pp. 9854–9869.
Polinski, J. M., Barker, T., Gagliano, N., Sussman, A., Brennan, T. A. and Shrank, W. H. (2016) 'Patients' Satisfaction with and Preference for Telehealth Visits', *Journal of General Internal Medicine*. Springer New York LLC, 31(3), pp. 269–275.
*Professional Android Sensor Programming - Greg Milette, Adam Stroud - Google*

*Books* (no date).
Rodríguez, P., Cerviño, J., Trajkovska, I. and Salvachúa, J. (2012) *ADVANCED VIDEOCONFERENCING SERVICES BASED ON WEBRTC*. Edited by P. Kommers, P. Isaías, N. Bessis, and L. Rodrigues. IADIS Press.
Salvi, D., Poffley, E., Orchard, E. and Tarassenko, L. (2020) 'The mobile-based 6-minute walk test: Usability study and algorithm development and validation', *JMIR mHealth and uHealth*. JMIR Publications Inc., 8(1), p. e13756.
Santos-González, I., Rivero-García, A., Molina-Gil, J. and Caballero-Gil, P. (2017) 'Implementation and analysis of real-time streaming protocols', *Sensors (Switzerland)*. MDPI AG, 17(4).
Sattar, Y., Ullah, W., Rauf, H., Virk, H. ul H., Yadav, S., Chowdhury, M., Connerney, M., Mamtani, S., Pahuja, M., Patel, R. D., Mir, T., Almas, T., Moussa Pacha, H. and Chadi Alraies, M. (2020) 'COVID-19 cardiovascular epidemiology, cellular pathogenesis, clinical manifestations and management', *IJC Heart & Vasculature*. Elsevier, 29, p. 100589.
*Sensor | Android Developers* (no date).
*SensorEvent | Android Developers* (no date).
Sime, A. W. (2016) 'WebRTC: delivering telehealth in the browser', *mHealth*. AME Publishing Company, 2, pp. 11–11.
*Six Minute Walk Test / 6 Minute Walk Test - Physiopedia* (no date).
Solway, S., Brooks, D., Lacasse, Y. and Thomas, S. (2001) 'A qualitative systematic overview of the measurement properties of functional walk tests used in the cardiorespiratory domain', *Chest*. Chest, pp. 256–270.
Tsai, L. L. Y., McNamara, R. J., Moddel, C., Alison, J. A., McKenzie, D. K. and McKeough, Z. J. (2017) 'Home-based telerehabilitation via real-time videoconferencing improves endurance exercise capacity in patients with COPD: The randomized controlled TeleR Study', *Respirology*. Blackwell Publishing, 22(4), pp. 699–707.
Whittington, P., Dogan, H., Phalp, K. and Jiang, N. (2020) 'Detecting physical abilities through smartphone sensors: an assistive technology application', *Disability and Rehabilitation: Assistive Technology*. Taylor and Francis Ltd.
Zeng, G. S., Chen, L. C., Fan, H. Z., Wu, L. L., Wu, X. P., Fang, Z. K., He, X. and Yu, H. P. (2019) 'The relationship between steps of 6MWT and COPD severity: A cross-sectional study', *International Journal of COPD*. Dove Medical Press Ltd., 14,

pp. 141–148.

# ABSTRAK

The 6-Minute Walk Test (6MWT) is a walking test that measures exercise capacity for assessing various types of diseases. The primary goal of the test is to measure the distance covered during the 6 minutes. Current method of conducting the test have difficulties for long-term rehabilitation such as cost of transportation and long waiting hours. Meanwhile, fitness mobile applications might not be suitable for the 6MWT indoor due to the large scale of distance measurement. Previous studies found in literature have room of improvements in their approach. Indoor measurement for body activity could be more complicated with smartphone sensors due to high sensitivity to movement. This study aims to develop a 6MWT monitoring platform and tracking Android application that assists in conducting the test in home-based environment as an alternative approach. The developed algorithm utilizes Android smartphone sensors as accelerometer and magnetometer for processing the azimuth angle to detect body rotation at the end of the hallway, and step counter sensor for counting the steps and residual distance calculation. The patient data are transmitted to a web dashboard for clinicians to view the results. A telehealth application is developed using WebRTC to allow post-test consultation and remote monitoring. The algorithm accuracy was validated using for rotation detection and distance measurement by a healthy participant. The average accuracy for rotation detection is 89.2% while performing the test using the application. This accuracy reflected precise distance measurement for most of the trails during the validation, where the distance was estimated to cm precision. The smartphone application also provides audible instructions and test educational information. This study will improve the clinical practice by providing an application for 6MWT measurement and tracking in a non-hospital environment and improve in the method of distance measurement for 6MWT from previous literature. This will benefit the public by providing a simple solution for performing the test by using smartphone, and to clinicians by providing a monitoring dashboard and telehealth applications.