# An Integrated Software-Hardware Exercise Encouraging System

**KONG SIBO**

**FACULTY OF COMPUTER SCIENCE AND**
**INFORMATION TECHNOLOGY**
**UNIVERSITI MALAYA**
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**FACULTY OF COMPUTER SCIENCE AND INFORMATION TECHNOLOGY**
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Matric No: 17198473/1

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# ABSTRACT

With the rapid development of technology, transportation, and urbanization, people's physical requirement is greatly reduced, and the mental load of many jobs is increased at the same time. Young people are now more likely to sit in front of a screen than go out for exercise. Lack of physical activity leads to an increased risk of a variety of chronic diseases, such as obesity, diabetes, and cardiovascular disease. This study proposed an integrated system for physical exercise, comprising an exercise monitoring wearable device and an exercise encouraging mobile application. The developed system captures the users' heart rate, blood oxygen and body temperature in real-time while the users are exercising. The STM32F103 board was used as the main control chip, the MAX30102 sensor for collecting users' heart rate and blood oxygen, whereas the MAX30205 sensor for collecting users' body temperature. Bluetooth low power module was chosen for communication with Android. Android Studio was used as the software development tool for the mobile application that receives sensor signals and records the signals as data. Analysis and visualization of data, as well as risk alerting, are among the functions of the mobile application. The application encourages exercise through exercise reminder, exercise goal setting, sign in, and other features. After implementing the system, 10 participants aged 18-30 years old were recruited for a six-week experiment using qualitative and quantitative methods. The study first assessed the effectiveness of the developed integrated system in encouraging exercise among the participants. Next, the importance of the exercise monitoring wearable device in encouraging exercise was studied. Finally, the effectiveness of the system in maintaining the participants' active lifestyle was studied. The results show that the system was effective in improving and maintaining participants' physical activity and the wearable device played a role in encouraging physical activity. The participants also reported little to no discomfort when using the system.

**Keywords:** wearable device, mobile application, encourage exercise, real-time system

# ABSTRAK

Dengan perkembangan teknologi, pengangkutan, dan pembandaran yang pesat, permintaan fizikal manusia banyak berkurang, dan beban mental bagi banyak pekerjaan meningkat pada waktu yang sama. Orang muda sekarang lebih cenderung duduk di depan skrin daripada bersenam. Kekurangan aktiviti fizikal menyebabkan peningkatan risiko pelbagai penyakit kronik, seperti obesiti, diabetes, dan penyakit kardiovaskular. Oleh itu, menggalakkan orang muda untuk melakukan lebih banyak senaman adalah cabaran mendesak di seluruh dunia. Kajian ini mencadangkan satu sistem latihan bersepadu untuk senaman yang selamat, merangkumi sebuah peranti boleh pakai untuk pemantauan senaman dan sebuah aplikasi mudah alih untuk penggalakan senaman. Sistem yang dibangunkan membaca kadar denyut jantung, oksigen darah dan suhu badan pengguna dalam waktu nyata semasa pengguna bersenam. Mengenai perkakasan peranti yang dipakai, papan STM32F103 digunakan sebagai cip kawalan utama, penderia MAX30102 untuk mengumpulkan kadar denyut jantung pengguna dan oksigen darah, sedangkan penderia MAX30205 untuk mengumpulkan suhu badan pengguna. Modul kuasa rendah Bluetooth dipilih untuk komunikasi dengan Android. Android Studio digunakan sebagai alat pembangunan perisian untuk membangunkan aplikasi mudah alih yang menerima isyarat penderia dan mencatatkan isyarat sebagai data. Analisis dan visualisasi data, serta peringatan risiko, adalah antara fungsi aplikasi. Aplikasi ini menggalakkan pengguna bersenam melalui mesej ingatan, penetapan matlamat senaman, rakaman masuk, dan ciri-ciri lain. Setelah pelaksanaan keseluruhan sistem, 10 peserta berumur 18-30 tahun direkrut secara rawak untuk mengambil bahagian dalam satu eksperimen selama enam minggu yang menggunakan kaedah kualitatif dan kuantitatif. Pada pemantauan, kajian ini meneliti keberkesanan sistem bersepadu yang dibangunkan dalam menggalakkan senaman yang selamat dalam kalangan peserta. Kemudian, kepentingan peranti boleh pakai untuk pemantauan senaman dalam menggalakkan senaman yang selamat dikaji. Akhirnya, keberkesanan sistem dalam mengekalkan gaya hidup aktif dalam kalangan peserta dikaji. Keputusan menunjukkan sistem yang dibangunkan adalah berkesan dalam meningkatkan dan mengekalkan aktiviti fizikal dalam kalangan peserta dan peranti boleh pakai berkenaan memainkan peranan dalam penggalakan aktiviti fizikal. Para peserta juga melaporkan sedikit atau tanpa ketidakselesaan semasa menggunakan sistem tersebut.

**Kata kunci:** peranti boleh pakai, aplikasi mudah alih, penggalakan senaman, sistem masa nyata

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# LIST OF SYMBOLS AND ABBREVIATIONS

AC : Alternating current

BLE : Bluetooth Low Energy

CPU : Central processing unit

DC : Direct current

EHS : Exertional heat stroke

FIFO : First-in-first-out

Hb : Hemoglobin

Hb02 : Oxygenated hemoglobin

IHS : Information Handling Services

MCU : Microcontroller unit

S01-S10 : Participant 1-Participant 10

STM32 : STM32F103

WHO : World Health Organization

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# CHAPTER 1: INTRODUCTION

## 1.1 Research Background and Motivation

Lack of physical activity is considered to be a major cause of reduced quality of life, multiple diseases and premature death (Booth et al., 2012). According to a study by the World Health Organization (WHO), deaths due to physical inactivity have surged globally from 1.9 million in 2002 to an average of 3.2 million in 2018 (Guthold, Stevens, Riley & Bull, 2020), equating to an increase of almost 69% in more than a decade.

Today's youth are more likely to sit in front of a screen than exercise, which poses a threat to their health (Guthold et al., 2020). Neglecting an active lifestyle is closely linked to the development of chronic diseases. Lack of physical activity leads to an increased risk of various chronic diseases such as cardiovascular disease (CVD), type 2 diabetes, various respiratory diseases and osteoarthritis (Owen, Healy, Matthews & Dunstan, 2010; Liu et al, 2015; Mandsager et al., 2018). Cardiovascular diseases alone cost trillions of dollars in healthcare costs each year (Rebolledo-Nandi, Chavez-Olivera, Cuevas-Valencia, Alarcon-Paredes & Alonso, 2015). The situation is so serious that urgent action must be taken to get youth moving. The key question is how to encourage inactive youth to exercise.

Experts believe that insufficient exercise will affect the health of young people in the future and emphasise the need for immediate measures to encourage them to exercise more (Guthold, Stevens, Riley & Bull, 2018). As a weekly exercise recommendation, WHO sets a minimum of 150 minutes of moderate exercise, such as walking and swimming, or 75 minutes of vigorous exercise, such as jogging and football (World Health Organization, 2010). Encouraging young people to be more physically active is therefore an urgent challenge worldwide. Malaysia's obesity and overweight population growth rate is the highest in Southeast Asia (Hassan, Sade, & Rahman, 2018). This is mainly due to unhealthy eating habits and dislike of exercise. Malaysia has also been identified as one of the least physically active countries in the world with over 60% of adults being essentially sedentary (Tam, Gregory, Yeoh, Yap & Wong, 2016).

To address this issue, technologies such as exercise monitoring devices and fitness apps have emerged to encourage young people to exercise to some extent, such as monitoring heart rate through Xiaomi's Mi Smart Band; and estimating daily walking steps using accelerometers. It is currently estimated that there are around 40,000 fitness and sports monitoring apps (Sullivan & Lachman, 2017). Today, people are becoming more and more dependent on the internet, using their computers or smartphones to deal with large and small matters at work or in their daily lives. These digital devices do make life more efficient and convenient, but they also bring with them a number of health problems, including lack of exercise due to prolonged sitting, which leads to obesity. These health issues have also caught the attention of many people, especially those who work, and apps for exercise and fitness are becoming increasingly popular.

Wearable sports monitoring devices and fitness mobile apps are two promising tools to engage and motivate users to participate in sports and fitness programmes. The use of apps to encourage people to engage in fitness and physical activity is becoming increasingly common, with people becoming more interested in the topic of exercise, fitness and health (Park, Yoo, Kim & Lee, 2018; Hamper, Wendt, Zagel & Bodendorf, 2016). Despite this, most of the current research on exercise apps focuses on pedometers, timers, and training posture instructions (Oyibo et al., 2019).

Market researcher Information Handling Services (IHS) has released a report saying that the number of app downloads will grow from 156 million in 2012 to 248 million in 2017, a growth rate of 63%. Shane Walker, senior manager, digital health unit at IHS is it with " More and more consumers are realising that fitness exercise is not just about going to the swimming pool exercising, it also includes recording a workout goal, investigating and understanding physical health enhancements". Currently, among millions of smartphone users, mobile apps for sports and fitness have long been an integral part of people's daily lives (Walker, 2013).

Popular fitness exercise systems include apps for mobile devices and wearables such as Fitbit and Garmin (MacDermott et al., 2019), Apple Watch and Polar heart rate monitors(Weaver et al., 2019). These apps and devices are designed to encourage healthy behaviour by promoting physical activity and monitoring progress towards health goals. Studies have found that the effectiveness of fitness trackers depends on the goals set by the user (Sullivan & Lachman, 2017).

At the same time, apps are a crowded marketplace, with many apps not downloaded and others downloaded and discarded after only a short period of time. According to a global study of over 300 fitness mobile apps and 300 million user profiles, only 25% of apps in all categories were used again after the first day and less than 10% continued to be used after 7 days (Vaghefi & Tulu, 2019). Therefore, developing an effective app to encourage exercise is essential.

The intention of this study is to design a system that encourages exercise using cost-effective records exercise frequency, logs exercise data, sets exercise goals, grades exercise intensity according to exercise (rewards), provides prompts for functions such as signing in, and exercise health monitoring and tailored to the individual exercise needs of sedentary youth. Participants frequently sedentary were selected. The criterion for sedentary was 8 hours of sitting per day, at least 5 days per week. The system includes a wearable device that can monitor exercise and an app that can encourage exercise. Some features of the app are exercise reminder, goal setting and real-time monitoring. This study will investigate whether the integrated hardware and software system can encourage young people to exercise more with increased confidence of exercise.

## 1.2 Problem Statement

mHealth, or sometimes known as mobile health or wireless health, is the use of portable internal and wearable sensors to monitor health (Dobkin & Dorsch, 2011). The sensor can combine biochemical (glucose, chemistry) and physiological data (EEG, blood pressure, heart rate, ECG, cardiac output and body weight). Exercise encouragement mHealth apps provide support to improve adherence to exercise and self-monitoring of exercise behaviour. mHealth studies' findings show increasing users' exercise behaviour with the aid of an app compared to a control condition without the app (Dobkin & Dorsch, 2011).

Research has shown that individual users of on-market fitness applications are only likely to be influenced by personal characteristics of the software features (goal setting/self-monitoring and rewards, etc.), following a survey of numerous on-market fitness encouragement software (Asimakopoulos, Asimakopoulos & Spillers, 2017). For Fitness applications in the market, there is more focused on user research on heart rate monitoring; Fitbit and Garmin focus more on the accuracy of data collection and different modes of exercise, data display and other aspects of research, and less on the design of methods to encourage exercise into the application (MacDermott et al., 2019).

There are many existing fitness systems consisting of wearables and apps in the market, where the impact of the whole system is more often studied. However, there is no study of what the respective effects of wearables (hardware) or app (software) are. The study aims to explore how much effect the software-only use has on encouraging exercise, and to explore how much effect it has on the overall system after the hardware was no longer use.

In light of these developments, this study combines the strengths of previous exercise and health software applications with the personal exercise needs of sedentary young people to create an exercise encouragement system based on an integrated Android-based mobile phone application and a wearable device. An experimental study is then designed to investigate the effectiveness of the developed system in encouraging exercise. Also, the importance of the wearable device (hardware) in the overall system is further explored, as well as the significance of an integrated system in encouraging participants to stay active.

## 1.3 Research Questions

This research examines the effectiveness of an integrated wearable system to encourage exercise in the hope that the intervention will encourage participants to do more exercise. The research questions are as follows:

**Research Question 1:** What is the efficacy of the integrated system in encouraging users to exercise?

**Research Question 2:** How important is the wearable (the hardware portion) in the overall system in encouraging users to exercise?

**Research Question 3:** What is the significance of a specially designed integrated system in encouraging participants to stay active?

## 1.4 Research Objectives

This research aims to build an exercise encouragement system comprising a custom-built wearable device and a corresponding mobile application. The effectiveness of the system as a whole and the individual sub-systems (the wearable device and mobile application) will be evaluated. Effectiveness of the whole system in maintaining exercise as a habit will be evaluated too. The four objectives of this research are described below.

1.To develop an integrated system comprising an exercise monitoring wearable device and an exercise encouraging mobile application.

2. To evaluate the effectiveness of the developed integrated system in encouraging exercise among young people.

3. To study the impact of the exercise monitoring wearable device in encouraging exercise.

4. To study the effectiveness of the integrated system in encouraging young people to maintain their active lifestyle in the absence of the system after the system had been used for a period of time.

## 1.5 Research Scope

This study focuses on the development of an exercise encouragement system consisting of a combination of software and hardware, and evaluates the effectiveness of the developed integrated system in encouraging youth to exercise. This study was conducted in the Malaysian region. A 42-day experiment was conducted after the system was developed to assess the effectiveness of the system in encouraging exercise. The study was limited to recruiting 10 sedentary youths between the ages of 18-30.

## 1.6 Significance of Research

Much research has been done on exercise encouragement systems. There are also many physical fitness apps on the market today. Many of the apps are downloaded but uninstalled or no longer used within a short period of time, making it essential to develop a targeted app that encourages exercise. Studies have shown that in order to make these applications more effective, designers need to tailor the applications to the target audience. Existing fitness apps, like FitBits (MacDermott et al., 2019) and Apple Band(Taylor, 2015), focuses on several simple exercise indices test, have few prompting features that encourage users to exercise. The system developed in this study records exercise frequency, logs exercise data, sets exercise goals, grades exercise intensity according to exercise (rewards), provides prompts for functions such as signing in, and exercise health monitoring.

## 1.7 Organisation of Dissertation

In Chapter 1 of this dissertation, the background and motivation of this research is analysed. The research questions are stated; the objectives, scope and significance of the study are identified. In Chapter 2, literature review is reported, providing an overview of the existing research in various areas such as adolescents and physical inactivity, physical activity monitoring systems and their accuracy, motivational techniques and monitoring of physiological parameters in wearable devices, encouraging exercise and maintaining physical activity levels. Chapter 3 describes of the research methodology, starting with the identification of key research questions, followed by an analysis of the research design and procedures. Chapter 4 explains the design of the integrated software-hardware system in detail, as well as testing and analyses of the developed system. Finally, the process of the experimental phase is described, as well as the data collection methods for both quantitative and qualitative analyses. Chapter 5 analyses the findings of the study, with the results of the quantitative and qualitative analyses presented. Chapter 6 discusses the research results, while Chapter 7 concludes this study, which summarises contribution of the research, as well as the achievement of the research objectives, research limitations and future work.

# CHAPTER 2: LITERATURE REVIEW

In this chapter, the following four aspects are reviewed. The first part defines "Youth" and lack of sports activities, and its impact. The second part is about the sports activity monitoring systems and their accuracy, and finds the advantages and limitations of the existing sports activity monitoring. The third part reviews the exercise encouragement methods in mobile applications, compares the existing applications, and reviews the methods of encouragement. The fourth part reviews the monitoring and measurement of physiological parameters during exercise using mobile applications, and identifies the specific unctions in the existing apps, as well as the importance of monitoring heart rate, blood oxygen and body temperature.

## 2.1 Youth and Physical Inactivity

With the rapid development of technology, transportation, and urbanization, people's physical exercise is greatly reduced, and the mental load of many jobs is increased at the same time. This phenomenon is leading to the increased risk of various chronic diseases, such as obesity, diabetes, and cardiovascular diseases (Owen, Healy, Matthews & Dunstan, 2010; Mandsager et al., 2018). Consequently, lack of physical activity has become a major cause of health issue(Booth et al., 2012).

According to WHO, about 31 percent of adults are under-exercise, and about 3.2 million die each year from under-exercise (Guthold, Stevens, Riley & Bull, 2018; Sims-Gould, Vazirian, Li, Remick & Khan, 2017). According to WHO, the total population of Malaysia in 2016 was approximately 31,187,000, and the total number of deaths in 2016 was approximately 154,000. Among them, the proportion of patients who died of chronic diseases was cardiovascular disease (35%), other non-communicable diseases (16%), chronic respiratory diseases (4%), diabetes (3%). Among physical inactivity is the fourth leading cause of death from chronic noncommunicable diseases(Lee et al., 2012).

In addition, the obesity rate of Malaysian population is also showing a not optimistic upward trend, and WHO predicts that if the Malaysian population persists in exercise and vigilance from now on, the obesity rate will remain stable and non-increasing; but if it is not controlled, the obesity rate will increase linearly (World Health Organization, 2018).

Malaysia’s obesity and overweight population growth rate is the highest in Southeast Asia (Hassan, Sade, & Rahman, 2018). This is mainly due to the unhealthy eating habits of the local people and their lack of preference for exercise. Due to lack of exercise, up to 52.3% of people suffering from non-communicable diseases (World Health Organization, 2018). In addition, the rates of hypertension, hyperglycemia, obesity, etc. are also higher than those of other ASEAN countries. There are related factors between inactivity and increased prevalence, which shows that Malaysians should face up to sports. The Malaysian Medical Journal pointed out that 43.7% of Malaysian adults are ‘physical inactive’, which means lack of exercise.

According to the Malaysian Bureau of Statistics, ischaemic heart disease was the number one killer of in 2017(You et al., 2019). Therefore, people who have no exercise habits or who do not exercise very much have a high chance of developing cardiovascular disease. As a recommendation for weekly exercise, WHO has set a minimum of 150 minutes of moderate exercise (e.g., walking and swimming) or 75 minutes of vigorous exercise (e.g., jogging and soccer) ( World Health Organization, 2010).

Experts believe that physical inactivity affects the health of future young people and emphasize the need for immediate measures to encourage them to be more active (Guthold, Stevens, Riley & Bull, 2018). The study also found that physical inactivity is a chronic and widespread phenomenon in all countries and regions under study. Therefore, encouraging youth to be more physically active is a pressing issue worldwide.

According to the World Programme of Action for Youth to the Year 2000 and Beyond, adopted by the United Nations General Assembly at its 50th session on 14

December 1995, the age range for the definition of youth is defined as the 15-24 age group. It is particularly noteworthy that, although the United Nations defines the age of youth as 15-24 years, it does not require that this definition be uniform across the world, and the World Programme of Action for Youth to the Year 2000 and Beyond specifically states: “In addition to the above-mentioned statistical definition of the term ‘youth’, beyond that, the meaning of the term ‘youth’ varies from society to society around the world. The definition of youth is constantly changing in response to fluctuating political, economic and socio-cultural circumstances.” It is true that countries all over the world set the age boundaries of their youth mainly based on their political, economic, and socio-cultural situations.

Since this study was conducted in the Malaysian region, according to the latest regulations of the Ministry of Youth and Sports, the age range of youth in Malaysia is 15-30 years old. Thus, this study has chosen the 18-30 years-old youth groups as the subject of study. This study did not manage to recruit participants aged between 15-17 years old.

Based on the above literature analysis, it is therefore very important to encourage sedentary young people to participate in more exercise.

## 2.2 Physical Activities Monitoring Systems and Their Accuracy

Existing motion detection and physical activity monitoring systems mainly use accelerometers to track the number of user steps (Jones, Seki & Mostul, 2017; Liu et al., 2015; Devoe, 2003; Audrey, Bell, Hughes & Campbell, 2013; Plasqui & Westerterp, 2007). Liu et al. (2015) designed and implemented a smart belt system using the three-axis accelerometer, which installs an alarm on the belt and the accelerometer is used to detect the daily walking steps of the user. The research focuses on the detection of the logarithmic step of the accelerometer (Liu et al., 2015).

There are also exercise monitoring equipment that monitors the real-time heart rate of users, which can adjust the current intensity of exercise according to the heart rate (Hamper, Wendt, Zagel & Bodendorf, 2016). The study monitored heart rate to measure the effectiveness of exercise and exercise intensity, but speedometer was not used to monitor the step strength. The rationale of monitoring heart rate is to prevent incorrect exercise mode or excessive exercise intensity which has caused sudden death and cardiac arrest (Mengelkoch, Martin & Lawler, 1994; Fukuda et al., 2010). The change of heart rate during exercise can be used to predict sudden death as heart rate increases with the increase of exercise intensity and oxygen uptake (Karvonen & Vuorimaa, 1988).

Nevertheless, most accelerometers used to measure the intensity of exercise were not accurate enough. In a study of comparing the accuracy of the RT3 three-axis accelerometer and ActiGraph single-axis accelerometer on the same side of the hip of 20 college students, Liu et al., (2015) showed that when measuring the energy consumption of walking or running at five different speeds and using a gas analyzer as a calibration standard, it was found that the RT3 three-axis accelerometer estimated energy consumption value higher than the actual measured value. On the contrary, the Actigraph estimated value less than the actual energy consumption. Therefore, it was concluded that RT3 three-axis accelerometer was more suitable for estimating the energy consumption of low-speed physical activity such as walking, while Actigraph was more suitable for fast running physical activity such as running at any speed (Alexander et al., 2016).

In addition, studies such as Devoe's showed that the R3D accelerometers tested on a treadmill had a correlation of 0.96 with the maximum oxygen consumption, compared with 0.59 for daily physical activity. Compared with the walking and running activities, the daily physical activity is highly irregular. This is due to daily physical activities come in many forms and the participation crowd is diverse while the participation environment is more complex. These are the difficulties of using triaxial accelerometers to measure the daily physical activities (Devoe, 2003).

Chen & Bassett (2005) pointed out that when a human runs, the frequency of body is less than 8Hz, but the upper limb exercise frequency can reach or even exceed 25Hz. However, at present, most accelerometers are filtered by 0.25-7Hz data, which is also the reason accelerometers cannot accurately measure the energy consumption of high-frequency motion. Howe, Staudenmayer & Freedson (2009) believed that the lack of energy consumption monitoring of upper limb activity caused some errors because accelerometers were only worn in the waist and back in most studies, but using a wrist-based heart rate sensor to judge the intensity of the exercise can well circumvent this problem. They also believed that wearing waist equipment for a long time was not comfortable or convenient, and similar problems were found in children and youth studies (Robertson, Stewart-Brown, Wilcock, Oldfield & Thorogood, 2011).

Plasqui & Westerterp (2007) pointed out that different types of motion and different accelerations are produced by different parts of the body. In practice, it is necessary to determine the wearing position of the accelerometer according to the type of exercise (Audrey, Bell, Hughes & Campbell, 2013). Therefore, the type of physical activity is an important factor in determining the wearing position of the accelerometer. However, there are few studies on the variability of different wearing positions on energy consumption. It was suggested that future studies should find out the best wearing position of different motion types to obtain more accurate data (Plasqui & Westerterp, 2007).

According to the above literature review, it can be found that the accelerometer is not accurate enough in measuring the motion intensity, and more studies are needed on the position of the accelerometer to be worn to improve the accuracy of measuring the motion intensity. This study, on the other hand, will follow recommendation by Howe, Staudenmayer & Freedson (2009) to use a wrist-based heart rate sensor to judge the intensity of the exercise. In addition, sensors for monitoring body temperature and blood oxygen will be included as parts of the proposed solution.

## 2.3 Exercise Encouragement Approaches in Mobile Applications

In terms of encouraging exercises, the existing research mainly focuses on the following three types of the research. The first aspect is the findings of Oyibo et al. (2019) on the different ways of encouraging sports by means of questionnaire and interview. Researchers used storyboard descriptions to simulate the plots of participants. Participants were asked to select each storyboard from three options for the question. This is done to ensure that participants understand each function and increase the reliability of the answer. To measure the participants' susceptibility to the six persuasive features described in the storyboard, the researchers adjusted the perceived persuasive power table according to the research background. The scale ranges from "strongly disagree (1)" to "strongly agree (7)". Finally, they suggested that persuasive message prompts, goal-setting, self-monitoring, and rewarding and cooperating are the most effective ways to encourage exercise (Oyibo & Vassileva, 2019). Nevertheless, this study is based on the results of a questionnaire analysis of hypothetical scenarios. The effectiveness of its practical applications requires further investigation.

The second types is the exploration of cooperative fitness to encourage office workers to engage in physical activities. The study of encouraging exercise used a two-person-one-match approach in the office, and the use of cooperation and sharing of daily walking data in the competition to motivate fitness. Although this approach can effectively encourage exercise, it requires encouraging exercise in a specific office environment and requires the cooperation of office colleagues to achieve good results (Ren, Yu, Lu & Brombacher, 2018). This may not be so effective when lone exercise is to be encouraged in a specific environment.

The third types is the use of message prompts and delivering of information to the users through their mobile devices or apps. There are many solutions fall into this category. The Android app by McShane & MacElhatton (2017) sends message prompts through the user's hand-set alarm sign. The application, which uses only persuasive message prompts still has much room for improvement in its effectiveness. Desk Job, an app that encourages health and fitness in the workplace and elsewhere, prompts users to break their sedentary habit by manually setting alarm breaks. When a break is due, the user is prompted to stretch or strengthen specific body parts pre-selected by the app, however, the function of the app to encourage exercise is relatively homogenous.

Jane APP is an exercise encouragement app that recommends to the users some nearby sports venues, to provide users with some sports venues, associating with coupons, to boost the enthusiasm of the users to go to the gym(Trainerize, 2020). In addition, Jane uploads coaches or sports courses on a regular basis, let users see the exercise status of others to stimulate the desire for exercise. However, this approach is far from enough to encourage exercise, because with the continuous development of many short video apps, such as YouTube and Tik Tok, where many sports experts upload their exercise videos, more and more people are inclined to watch various sports videos on these short video platforms. In addition, the simple exercise app does not have functions such as reminding exercise or recording exercise frequency.

Desk Job - an app that encourages health and fitness in the workplace and elsewhere - prompts users to break their sedentary habits by manually setting alarm breaks(McShane & MacElhatton, 2017). When a break is due, the user is prompted to stretch or strengthen specific body parts pre-selected by the app. However, the function of the app to encourage exercise is relatively homogenous in this app.

Fitness Recorder mainly records data of each exercise, such as how many times each group exercised, how they felt after exercise, etc. The users need to fill in the exercise process and feeling after each exercise. However, the app does not provide enough exercise encouragement features and in terms of the usability the operation is relatively complex. On the contrary, the system developed in this research can automatically detect, record and display the exercise data as well as give feedback based on evaluation of the data.

Popular running apps on the market such as Joyrun app, encourage exercises mainly through voice prompt to alert users to exercise, but the function is relatively monotonous, without personalised functions such as goal setting and real-time monitoring(Wang et al., 2019). Specialised hardware devices such as Fitbit and Garmin focus more on the accuracy of data collection and different modes of exercise, and data display, less on the design of methods to encourage exercise into their corresponding apps. Fitbit can track basic information of exercise, including steps, distance, calories burnt, and floor climbed. FitBits, just like Apple Band, does not provide enough exercise encouragement features from software requirements points of view.

There was a study suggested that in order to make these apps more effective, designers need to tailor them to their target audience (McCurdie et al., 2012). Research has shown that individualistic users of on-market fitness applications are only likely to be influenced by personal characteristics (goal setting/self-monitoring and rewards), following a survey of numerous on-market fitness encouragement software.

The application of sports monitoring system is becoming more extensive, but it is challenging to influence the sustainable change of adolescent's behaviour only through the tracking of their exercises. Appropriate training, personnel support, technology acquisition, and incentives may be more conducive for continuous engagement in exercise (Sullivan & Lachman, 2017). Some studies recommended a broader intervention for health tracking to promote and motivate sustained participation (Schaefer, Ching, Breen & German, 2016).

Based on the above review of the literature, it is challenging to encourage and sustain change in adolescent behaviour through exercise monitoring devices alone. Increasing incentives appropriately may be more conducive to sustained exercise participation. In addition, encouraging participants to monitor their weekly exercise frequency (i.e., register the number of workouts in the app), giving persuasive informational cues, goal setting, self-monitoring, and rewards are the most effective ways for encouraging individuals to exercise. From the review, this research incorporates exercise reminder, goal setting, exercise monitoring, exercise data, exercise evaluation, safety reminder and sign in the proposed solution.

## 2.4 Exercise Monitoring and Measurement of Physiological Parameters in Mobile Applications

Apart from exercise encouragement, monitoring is another important feature of exercise mobile application. Vaghefi & Tulu (2019) provide some support with self-monitoring to improve adherence to exercise and self-monitoring of exercise behaviour. Participants were also encouraged to monitor weekly exercise frequency (i.e., check-in workouts in the app) and planned non-exercise days were personalised in the app based on the number of workouts planned per week. mHealth's findings provide initial support for a theory-based app that increases users' exercise behaviour compared to a control condition without the app(McCurdie et al., 2012). Providing viable support for future research, the theoretical structure of self-monitoring could be integrated into exercise apps (McCurdie et al., 2012).

A fitness app in theXiaomi App Store, Fitness Recorder is an app that records exercise data such as how much weight, how many times in each exercise group, and the feeling after exercise, but the operation is relatively complex (Xiaomi App Store, 2020). The users need to fill in the exercise process after each exercise and their feelings, and while using the monitoring features, the users do not receive various indexes of monitoring and feedback from the app.

The existing studies on human health monitoring using wearable device mainly focus on the collection of physiological parameters such as heart rate, blood pressure, blood oxygen, and body temperature (Rebolledo-Nandi, Chavez-Olivera, Cuevas-Valencia, Alarcon-Paredes & Alonso, 2015; Higgins, 2016). The parameters are collected using the wearable device to understand the physical condition of the users in a timely manner (Wannenburg & Malekian, 2015; Sullivan & Lachman, 2017).

Trivedi & Cheeran (2017) used monitoring devices to monitor heart rate, blood oxygen and body temperature, and uploaded the monitored data to the cloud. Doctors can access the monitored data remotely. The study of mini-family vital signs monitor by Yusof & Wen Hau (2018) aimed at monitoring the elderly’s heart rate, body temperature, and blood oxygen, and sending the elderly’s data and location to the doctor when the monitored parameters were abnormal (Yusof & Wen Hau, 2018). The study concluded that monitoring of human heart rate, blood oxygen, body temperature and other physiological parameters can be very useful to understand a person’s current health.

The study by Xiao, Yu & Han (2020) is a relatively simple exercise app which measures heart rate, but it does not prompt for exercise, record exercise frequency, support goal setting, give advice according to the exercise intensity, allow sign in, monitor exercise parameters. More importantly, most existing apps on the market lack of corresponding professional hardware devices to match each other. The heart rate data, for example, can only be simply measured by the sensor of the mobile phone, which will affect the accuracy of the measurement.

## 2.5 Summary

After reviewing research on exercise monitoring devices and the collection of physiological parameters of human health and encouragement techniques in mobile applications, it is evident that the effectiveness of using a single exercise monitoring application to encourage users to do more exercise could be improved (Li et al., 2019). The strengths and limitations of the past studies are summarized in Table 2.1.

**Table 2.1: Summary of advantages and disadvantages of literature review**

| | Advantages | Limitations |
|---|---|---|
| Exercise monitoring equipment - accelerometer | Better for measuring daily steps. | Most accelerometers used to measure exercise intensity are not accurate enough. |
| | | Accelerators need to be worn around the waist and back, making it uncomfortable or inconvenient to wear for long periods of time. |
| | Suitable for estimating energy consumption | There are few studies on the variation of energy consumption in different wearing positions. |
| Exercise monitoring equipment - heart rate, blood oxygen, temperature | Changes in heart rate during exercise can be used to predict sudden death. | Accuracy needs to be improved for low intensity exercise (walking). |
| | Heart rate was monitored to measure the effectiveness and intensity of exercise. | |

| | | |
|---|---|---|
| | The position of wearing is convenient and comfortable. | |
| | Wearable devices collect parameters to timely understand the user's physical condition. | |
| Exercise encouragement methods in mobile applications. | Persuasive messaging, goal setting, self-monitoring/rewards and cooperation are the most effective ways to encourage exercise individually. | Collaboration and sharing motivate users toexercise but needs to be done in a specific office environment where individual exercise is not appropriate. |
| | Tailor-made requirements for target users, the effect is obvious | Single function, encouraging effect is not good. |
| | Monitor how often they exercise each week (i.e. how many times they sign in to exercise) | |

In view of these circumstances, this study developed an exercise encouragement system based on an integrated Android mobile phone application and a wearable device, taking into account the advantages of previous exercise and health software applications and the personal exercise needs of sedentary young people. Users can have a clear grasp of their exercise intensity, exercise goals, exercise frequency, exercise results and health data, allowing them to get a timely and realistic picture of their workouts and to make rational planning based on the exercise evaluation provided by the system. It is expected that young people will be encouraged to exercise more as a result.

# CHAPTER 3: RESEARCH METHODOLOGY

This research examines the effectiveness of an integrated system with a wearable device and a mobile app to encourage exercise in the hope that the intervention will encourage participants to do more exercise. This research concentrates on the development of the system and examine the effectiveness of the system through experimentation.

## 3.1 Research Design

This study is developmental and experimental in nature. The solution is designed as a combination of a wearable monitoring device and a corresponding mobile application that captures the users' heart rate, blood oxygen, and body temperature in real-time while the users are exercising. Regarding the hardware of the wearable device, the STM32F103 board is used as the main control chip, the MAX30102 sensor for collecting users' heart rate and blood oxygen, whereas the MAX30205 sensor for collecting users' body temperature. Bluetooth low power module is chosen for communication with Android. Android Studio was used as the software development tool to develop the mobile application that receives sensor signals and records the signals as data. Analysis and visualization of data as well as risk alerting are among the functions of the application. Iterative and incremental process model with prototyping was adopted to guide the development of the mobile application.

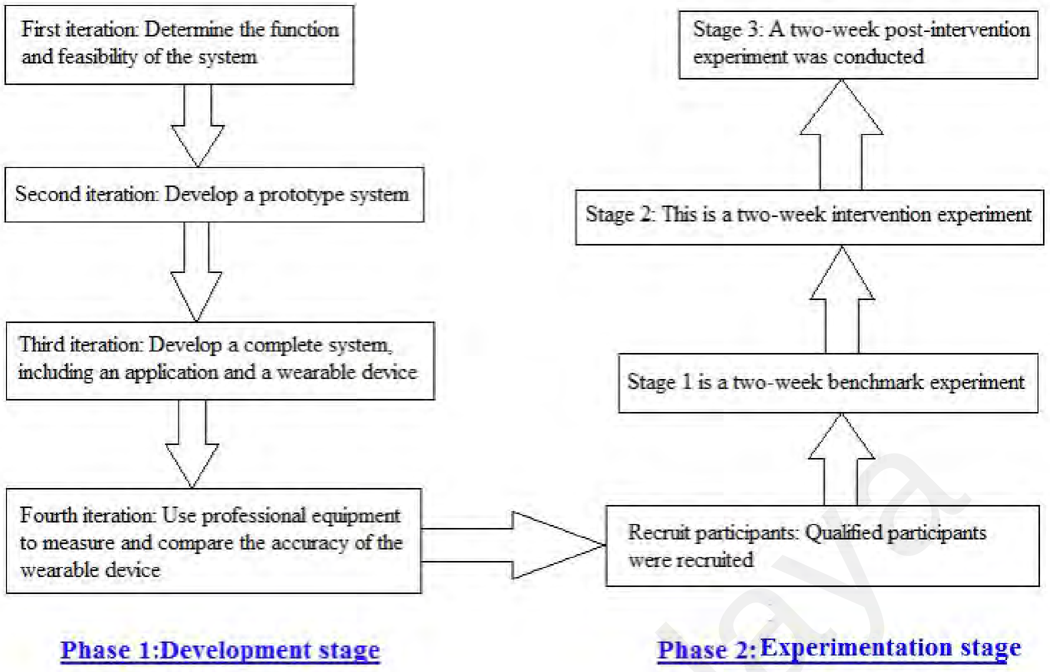


**Figure 3.1: Overall process of the research.**

The study was conducted in two phases as depicted in Figure 3.1. The first phase was further divided into four iterations. In the first iteration of the first phase, 10 stakeholders, including 4 sports psychologists and 6 potential users, were interviewed about their expectations of this integrated (hardware and software) system to promote exercise. After analyzing the answers of the 10 respondents, the words and fuctions that appear with high frequency in the functional requirements of potential users were used as functional requirements. The functional requirements of the system were determined through interviews prior to performing more costly development tasks.

In the second iteration, a prototype system based on the interview results was developed. The stakeholders could see the specific functions of encouraging exercise through the prototype system, although the ideas they put forward during the interview have not been fully implemented yet. The prototype system was used as a confirmation of the interview results.

The third iteration developed a complete system for exercise encouragement. In addition to the app, a wearable device that captures the user's heart rate, blood oxygen and body temperature during exercise was included. In addition, users can set their weekly exercise goals in the application. The application can also prompt for exercise and allow an exercise rating at the end of each exercise. After meeting each of their goals, the users can sign in and complete their weekly exercise goals. At the same time, the stakeholders tested the system again in the third iteration. In the fourth iteration, measurements from the wearable device were compared with measurements made using specialized devices such as oximeters and thermometers to assess accuracy of the measurements.

The first phase is the development phase. After the completion of the first phase, the second phase of experimentation was started. The experimentation was conducted in three stages: baseline week, intervention week, and post-intervention week. Using the developed wearable system for encouraging exercise as the research tool, exercise data were collected and the intervention was implemented. The purpose of comparing data from the three stages was to assess the effectiveness of the system in encouraging exercise. In this study, 10 participants were recruited using convenience sampling technique (Stratton, 2021). The participants were randomly selected from a group of young people between the ages of 18 and 30, as the primary focus of this study was to encourage youth to do more exercise. Data were collected on the participants' daily exercise schedule and weekly exercise frequency. Then, the data were analyzed using a combination of quantitative and qualitative methods. Qualitative data were collected from the interviews to supplement the quantitative data and better understand the effectiveness of the system as a whole and the wearable device individually in encouraging participants to exercise and stay active.

## 3.2 Research Procedures

### 3.2.1 Procedures for the Experimental Phase

After completing the development and testing of the wearable device and the app, the experimental phase started. The effectiveness of the entire system was analyzed using empirical evidence. Ten participants were recruited using convenience sampling technique and the participants further recruited their acquaintances for the study. The participants were selected from a group of young people (5 males, 5 females) between the ages of 18 and 30 years old, as the main focus of this study was to encourage youth to be more physically active. The 10 participants were labelled as S01, S02... S10. Table 3.1 is participant information.

**Table 3.1: Participant Information Table.**

| Subject | Gender | Age | Subject | Gender | Age |
|---|---|---|---|---|---|
| S01 | Female | 18 | S06 | Female | 25 |
| S02 | Male | 20 | S07 | Female | 26 |
| S03 | Male | 21 | S08 | Male | 27 |
| S04 | Female | 22 | S09 | Male | 28 |
| S05 | Male | 24 | S10 | Female | 30 |

The recruitment process was based on the following criteria. First, sedentary participants were selected. The criterion for sedentary was 8 hours of sitting per day, at least 5 days per week. Second, recruited participants were interested in engaging in physical activity and changing their sedentary behaviour. An individual’s readiness to engage in health-related behaviour change was categorized into the following five stages: pre-contemplation, consideration, preparation, action, and maintenance (Prochaska, 1991). By having potential participants complete a physical activity questionnaire regarding the stages of change, their category can be determined. Candidates in the pre-consideration stage were excluded because they were not considering any behavioural changes. Finally, those who were physically unwell were excluded, as these individuals may face risks with physical activity during the study.

After ethical approval was obtained from the University of Malaya Research Ethics Committee (UM.TNC2/UMREC-933e), the experimental study started but the participants could withdraw from the study at any time. However, in the course of this study, none of the participants withdrew from this study.

The experimental study lasted for six weeks and the timeline is shown in Figure 3.2. The six weeks were divided into three stages. The first stage was a two-week baseline week. The participants were contacted daily by telephone to collect information about their daily exercise schedule and weekly exercise frequency without any intervention. At the end of the two-week, each participant received the wearable device and installed the app on their phones. This was followed by a two-week intervention week. During this stage, the participants used the installed app as well as the wearable device to track their daily exercise, and the app recorded data related to the participants' daily exercise.

At the end of the two-week intervention, each participant was interviewed, which included interview questions about health tracking using the system, and its impact on physical activity and their experience with the system. Usability of the system was investigated by asking questions such as, "Can you look at the recorded exercise data and interpret which exercises relate to that data?" All interviews were recorded and qualitatively analyzed. Then the exercise data recorded by the application were quantitatively analyzed to examine the effectiveness of the integrated system in encouraging exercise.

The third stage was the two-week post-intervention. In this stage, the participants were divided into an experimental and a control group, with five participants in each group. During this stage, the experimental group used only the mobile app without the wearable device, while the control group used nothing. After the two weeks, the experimental group was interviewed. The results of the interviews and the associated data (number and frequency of exercises recorded by the app) were then analyzed qualitatively and quantitatively. On the contrary, the control group was take notes daily via text message and phone calls, and their exercise data were recorded for two weeks to examine whether they maintained their exercise levels (met their goals).

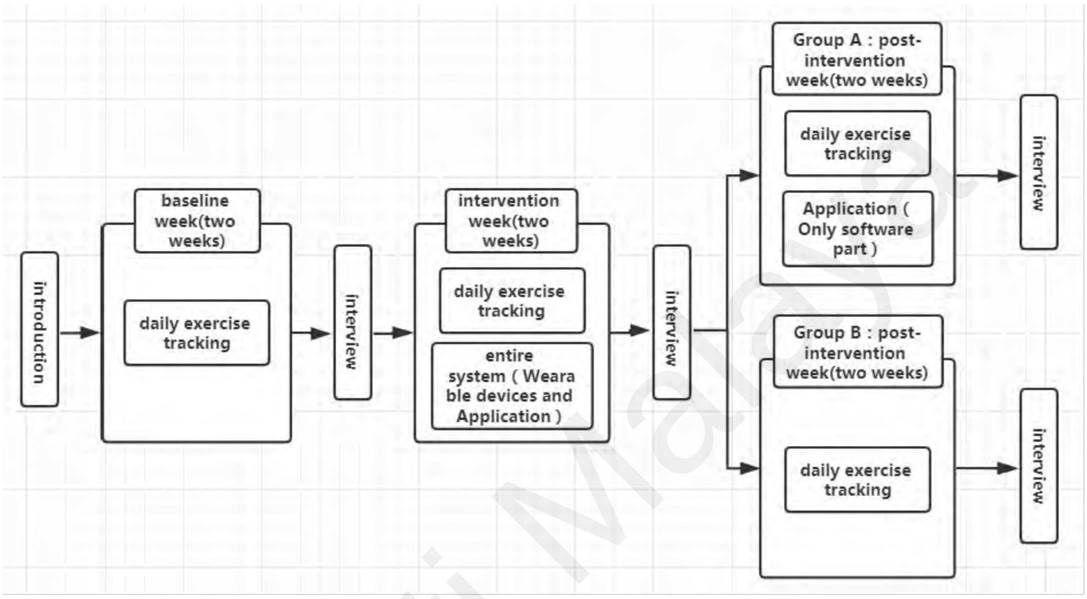


Figure 3.2: The flow of experimental phase.

## 3.3 Quantitative Methods

### 3.3.1 Quantitative Data Collection

Quantitative data can be easily converted to numerical form to get the useful information needed. This information is usually expressed in the statistical form. The quantitative data collected in this study were about the participants' exercise frequency (time) and duration (min), recorded by the app and collected through surveys. Analysis of the quantitative data collected evaluates the effectiveness of the system.

### 3.3.2 Quantitative Data Analysis

The method of quantitative research involves statistical analysis. The basic statistical analysis methods use arithmetic methods such as mean, median, mode, range, and variance to find the presence of regular pattern in the data. This study used SPSS software to analyze the quantitative data and LSD for post-hoc analysis tests. The method of data analysis was mainly one-factor analysis of variance, to check the effectiveness of the system in encouraging exercise interventions.

## 3.4 Qualitative Methods

### 3.4.1 Qualitative Data Collection Methods

Qualitative data collection methods focus on non-institutional methods and instruments. Examples include face-to-face personal interviews, focus groups, or observation methods. Considering the smaller sample size for the quantitative analysis of this study, qualitative analysis was chosen as a supplement to the research data as a way of exploring the effectiveness of the system in more depth. Telephone interview was the chosen qualitative data collection method for this study. The interviewer collected data through one-on-one interaction.

Interviews are informal, haphazard, and even conversational, and some questions may be unplanned and spontaneous. However, to obtain data that can be more easily analysed, the data can be standardised to some extent by conducting semi-structured interview where the same open-ended questions based on some themes are asked, and then some spontaneous questions are asked based on the answers. At the end of each research week, the researcher interviewed each participant. The interviews followed a pre-determined protocol and included open-ended questions about health tracking and its impact on participants' physical activity.

First, the participants were asked to explain their activity data by answering questions such as, "Can you look at your exercise data and explain what physical activity was associated with that data?" The participants then elaborated on their experiences with exercise tracking in the past week by answering this question, "Can you share some of your experiences related to exercise tracking in the past week?"

Participants were also asked to explain some interesting statements that emerged during the interviews. All interviews were recorded and transcribed for qualitative analysis. Based on the results of the interviews, qualitative data were analysed using NVIVO software. The aim of this qualitative research was to gain a deeper understanding of the effectiveness of the system in encouraging exercise.

### 3.4.2 Methods of Qualitative Data Analysis

With the development of qualitative research techniques, there are many tools available and this study used NVIVO software to analyze the qualitative data. All interviews were recorded and systematically and rigorously analyzed. The semi-structured interviews were analysed using ‘subject analysis’. Subject analysis is a method of identifying, analysing and reporting patterns in a set of data (V. Braun & Clarke, 2006). The coding process was checked for generalizability as suggested by Gibson & Brown (2009). This process consisted of pooling the data into two specific themes. Searching and reviewing themes - the researcher completed this process manually, where NVIVO generated a large number of codes. These were modified repeatedly until the researcher grouped all of the transcribed text into related themes and performed a thematic analysis. Following the qualitative analysis, the quotations were grouped into two themes, with a total of 20 codings: the impact of the whole system in encouraging exercise, and the significance of the whole system in maintain healthy exercise for the participants.

## 3.5 Summary

This chapter begins by presenting the key research questions and outlining the research process in detail. The entire study is divided into two phases. The first phase is the development phase, which is further divided into four iterations. Based on the results of interviews with potential users, the functionality of the system was determined.

Hardware sensors were compared and selected based on functional requirements. The best system development solution and measurement method was designed. It was determined that the STM32F103 motherboard was used as the main control chip, the MAX30102 sensor was used to collect the users' heart rate and blood oxygen, and the MAX30205 sensor was used to collect the users body temperature. A Bluetooth low-power module was selected to communicate with Android. Android Studio was used as the software development tool to develop the mobile application that receives the sensor signals and records the signals as data. Once the system has been developed, the system was tested and the errors analyzed and fixed.

In the second phase, an experimental programme was designed based on a baseline week, an intervention week, and a post-intervention week. Relevant data were collected during the experimental period and subsequently empirical evidence is used to analyse the effectiveness of the system as a whole. It was also determined that a combination of quantitative and qualitative methods would be used to analyse the data. The study used SPSS software to analyse the quantitative data and LSD for post-hoc analysis. The qualitative data was analysed using NVIVO software and the qualitative analysis was chosen to complement the research data to explore in more depth the effectiveness of the system in encouraging exercise as well as to provide answers to the research questions posed.

# CHAPTER 4: DEVELOPMENT OF THE PROPOSED SOLUTION

## 4.1 Functional Requirements of the Entire System

The complete system to encourage exercise includes a mobile app and a wearable device that captures the user’s heart rate, blood oxygen, and body temperature while exercising. In addition, users can use the app to encourage exercise with features that prompt for exercise, goal setting, real-time monitoring of exercise, exercise ratings, and sign in.

### 4.1.1 Mobile app requirements analysis

The target group of the users in this research is the sedentary youth. It is hoped that by wearing the device developed in this research and using the encouragement exercise app, it can improve their motivation to exercise and motivate them to develop good exercise habits and improve their health level.

The functional requirements of the system developed in this study are analysed as follows. The functional requirements of the exercise encouragement app and the wearable device developed in this study are mainly derived from the findings of previous studies, the recommendations of sports psychologists and the needs of sedentary young people.

In the requirements analysis, the needs of sports psychologists and sedentary young people were summarised into seven main requirements as shown in Figure 4.1. The exercise encouragement application and the wearable device developed in this study have the following user requirements in addition to the basic functions such as user registration: exercise reminder, recording exercise data, setting exercise goals, exercise evaluation and giving advice on next exercise, signing in, monitoring the exercise health index, and exercise safety alerts. This section will analyse in detail the target group and the functional requirements of the complete system developed in this study.

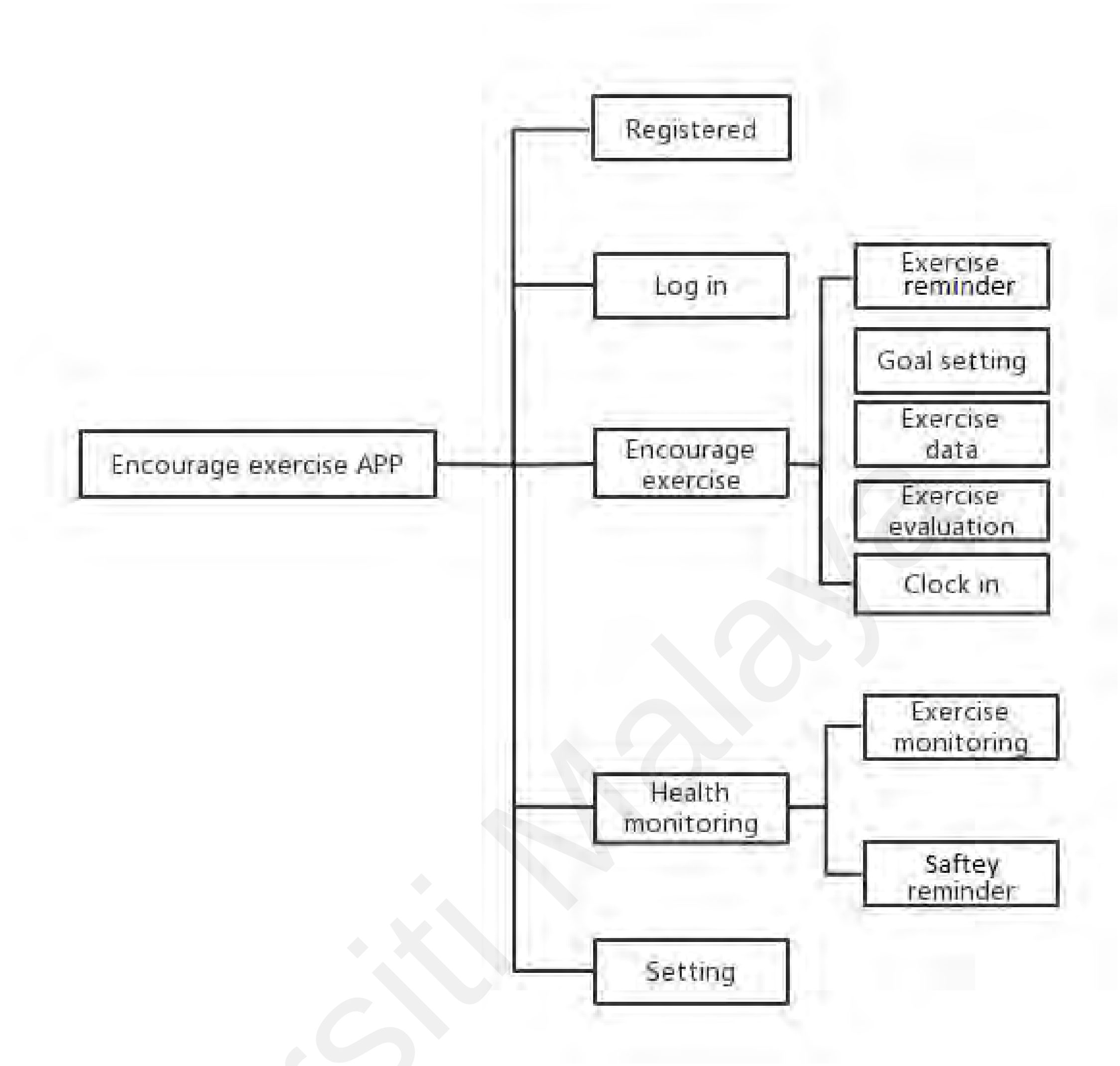


Figure 4.1: System functional requirements decomposition.

The following discusses the rationale for the system functional requirements.

(1) User Interface

It is important that the user can clearly see their health index during the exercise process. The system developed in this study needs to have a user-friendly interface and be easy to understand, as this is the only way to meet the user's need to monitor their own health indicators anytime and anywhere during exercise, and if the interface is too complex, it will jeopardise the user's experience.

(2) Cueing the needs of exercise

Almost every sedentary young person tester says that it is essential to have a system that prompts them to exercise, as they agree that exercise can improve their mood and help them burn off excess energy. The brain produces a lot of pleasant chemicals (hormone) during exercise, reducing anxiety and so on. However, few people actually do it on their own, so it is important to be reminded to exercise.

(3) Record exercise frequency and record exercise time

Potential users think that exercise is boring, they think it is tiring and they feel bored no matter how long they have been exercising. Some people even want to give up after a few minutes of running. On the contrary, if they find that their exercise data is not satisfactory, they will try to improve themselves as much as possible.

(4) Exercise ratings and exercise reviews

Most people who love to exercise do so because they believe it is conducive to the health. Sedentary young people, on the other hand, say that they do not realise that exercise can be meaningful and fun, so it makes sense to rate the level of exercise at the end of the day. If this is accompanied by a rating, it can stimulate their desire to exercise. To stimulate users to exercise in the long term and help them to develop good exercise habits, suggestions for the next exercise will be given and encourage them to improve further the next time they exercise.

## 4.2 Detailed functions

There are seven functions of the system, which are shown in Table 4.1.

**Table 4.1 Seven Functions of the System**

| Feature | Function |
|---|---|
| Exercise reminder | Use persuasive reminder to encourage exercise. |

| | |
|---|---|
| Goal setting | Set the appropriate exercise time and frequency. |
| | View exercise goals. |
| Exercise data | Check the exercise time. |
| | When the goal is not completed, prompt to continue to practice. |
| Exercise evaluation | Rating exercise. |
| | Giving advice on next exercise. |
| Safety reminder | View risk level. |
| | Safety alert. |
| Sign in | Record the frequency of exercise. |
| Exercise monitoring | Real time monitoring of body health index. |
| | Including heart rate, blood oxygen and body temperature. |

## 4.3 Security of Mobile App

To improve the security and reliability of the system, the following were implemented.

(1) Login authentication security

The login account is used to authenticate the user’s identity and improve the security of the system. The user account authentication is realised through static password that is encrypted in the process of transmission to avoid disclosing the user’s information. The system adopts unified account management and users use unified access control interface to meet their login requirements. Authentication log audit is used to protect the system against illegal login.

Users need to first register an account and set a password before they can use the system. The system's backend validates the username and password. If it is invalid, or the password filled in does not meet the system registration requirements, the system prompts the user to modify the username or password according to the type of error. After successful registration, the user is considered to be a legitimate user of the system and can edit information such as username, name, gender and weight.

(2) Application security

At the application level, the system controls the security of data to ensure user privacy.  The system encrypts and stores users' personal data to prevent unauthorized users from stealing or accessing the data.

## 4.4 SQLite Database Design and Interface

The storage of user exercise data needs to have good performance for the system and the database server should have a high level of stability and reliability to ensure the system runs properly. The use of SQLite databases for the system has the advantage of being efficient, as it only uses a small amount of memory to have good performance. The SQLite engine is connected to the program through direct API calls within the programming language. This has a positive effect in terms of energy consumption, latency and overall simplicity. The entire database (definitions, tables, indexes and the data itself) is stored in a single file on the host device.

(1) Data sending interface

The system data consists of the app and wearable device data, and communication between the two parts is achieved through a data interface that links the two parts closely together. The design of the system data interface is an important part of the system and determines the data transfer capability of the system.

(2) Health monitoring data interface

The system provides users with real-time exercise data, including heart rate, blood oxygen, body temperature and other personal exercise information at the same time. The system calculates the user’s exercise data based on the data stored in the database and displays the user’s heart rate, blood oxygen and body temperature for the day. The database stores the user’s exercise data in real time. Table 4.2 shows the health monitoring data stored.

**Table 4.2: Health monitoring data stored.**

| Field | Type | Default value | Empty or not | Description |
|---|---|---|---|---|
| id | long | | N | Record id |
| content | string | | N | Heart rate, temperature, oxygen values |
| craete_time | datetime | now | N | Creation time |
| create_id | long | | N | Created by ID |

## 4.5 Mobile App’s Architecture and Implementation

### 4.5.1 Overall software architecture

The system architecture is based on the analysis of the identified requirements, combining the functional settings, technical feasibility and implementation of the system. The system architecture is divided into three layers, as shown in Figure 4.2.

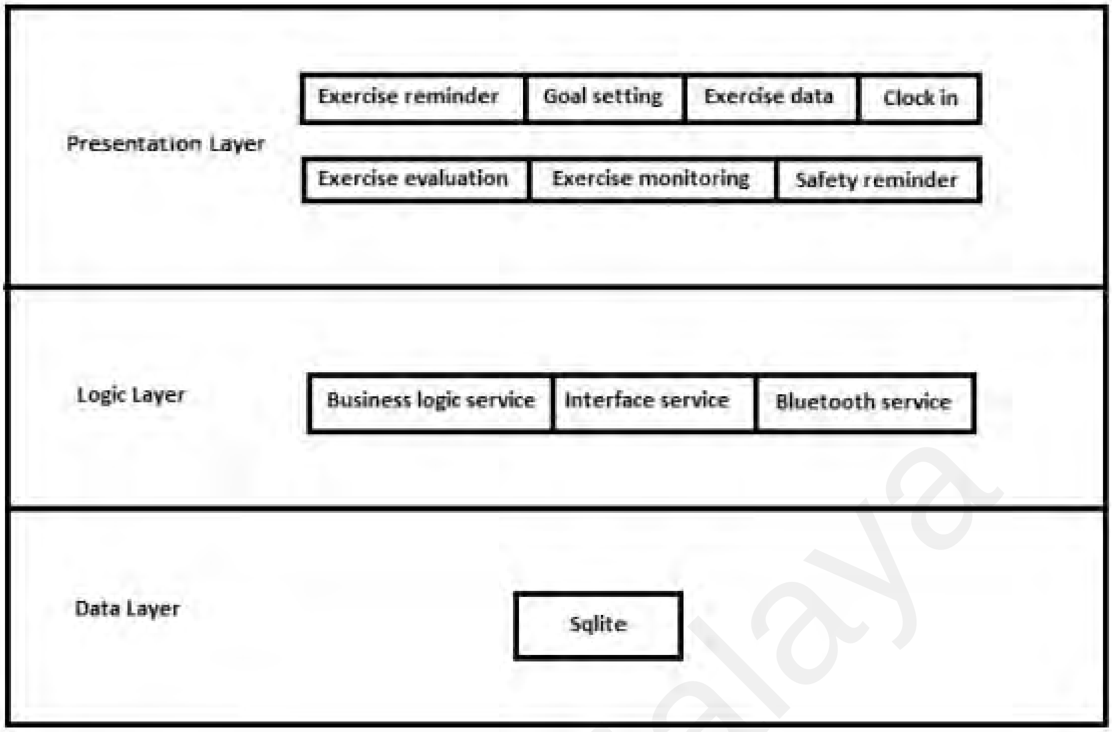


**Figure 4.2: System architecture diagram.**

(a) Presentation layer: The representation layer of the system is the most direct level at which the app connects with the user, and is mainly used for the presentation of the app's interface on mobile devices. Users log in the app to view various exercise data, including exercise frequency, exercise time and exercise goal.

(b) Logic layer: The logic layer of the system is responsible for performing the task of processing the business logic of the data. The user realises the data communication between the system and the front-end through the interface service to ensure the smooth operation of the system functions. The logic layer can temporarily store data received by the system in real time, and the Bluetooth service is used to transmit motion data. The app can search the Bluetooth device and send a connection request to the Bluetooth device. After the connection is established, the app communicates with the Bluetooth device. Figure 3.4 shows how the data is transmitted from the wearable device to the app and then stored , analysed and displayed in the app.

(c) Data layer: The data layer of the system is used for the management of exercise data. The system uses SQLite database for data storage. The study used Android phones as a tool to encourage safe exercise. It was developed using Android Studio. According to the requirements of this system, the main function of the Android application is to encourage users to exercise. The application can search the Bluetooth device and send a connection request to the Bluetooth device. After the connection is established, the app communicates with the Bluetooth device. The controls, layouts, events, special classes, and mechanisms used are button controls, checkedTextView controls, ListView controls, custom view controls, LinearLayout layouts, click message response events, collection classes, interface classes, activity interface classes, intent classes, inheritance mechanisms, multithreading mechanisms, processor message mechanisms, and Bluetooth communication mechanisms.

### 4.5.2 Detailed design and implementation of the system

Figure 4.3 shows how real-time data is transmitted from the wearable device to the app, and then stored, analysed and displayed in the app.

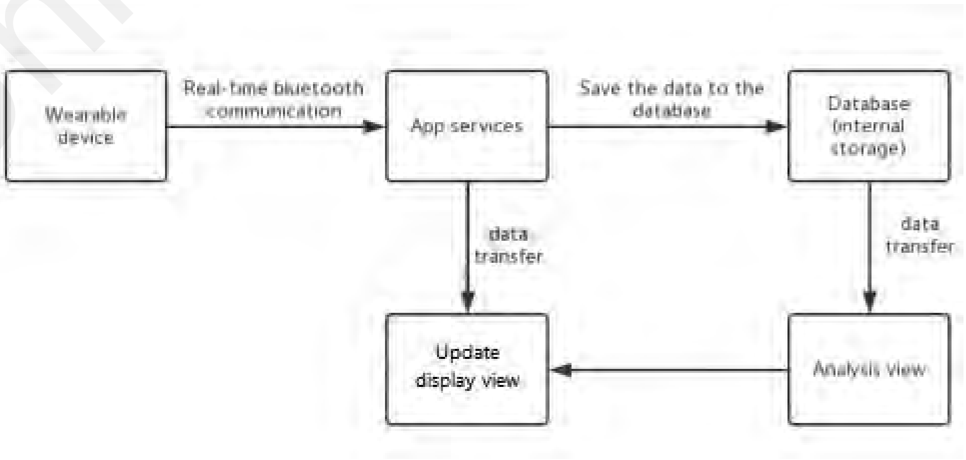


**Figure 4.3: Handling of monitoring data.**

In terms of features of the app, the users can use the exercise encouragement module to set exercise goals, view the exercise data, see the exercise assessment, give ratings and sign in. The system will give evaluation and rating based on the duration and intensity of the user's exercise, encourage the user to exercise, record and display the exercise data, and calculate the user's exercise frequency.

### 4.5.3 User registration and login function

The user needs to register before using the app for the first time. To register, users first need to enter a username and password, then click "Register Now". The system will get the username and query it in the user database.The username must not exist in the user database yet. Then, the system will verify the username and password. Both username and password cannot be empty, or otherwise a popup will appear with the message "User name cannot be empty", or "Password cannot be empty", respectively. If the user inputs an invalid password, the app will prompt the user to set the password according to the requirements. Figure 4.4 shows the user login page.

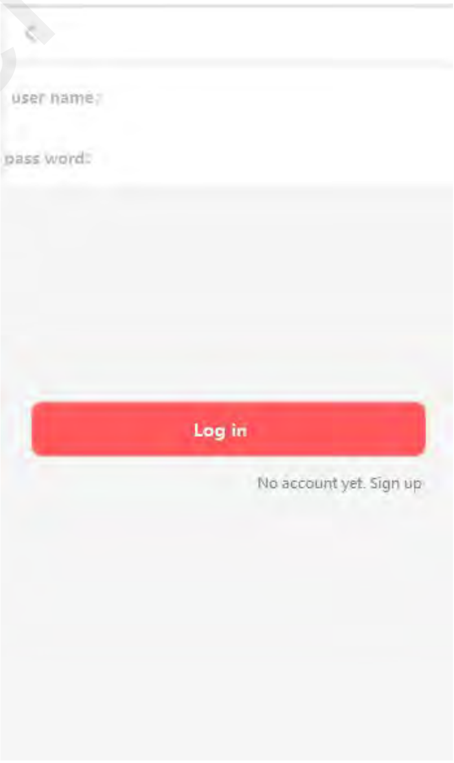
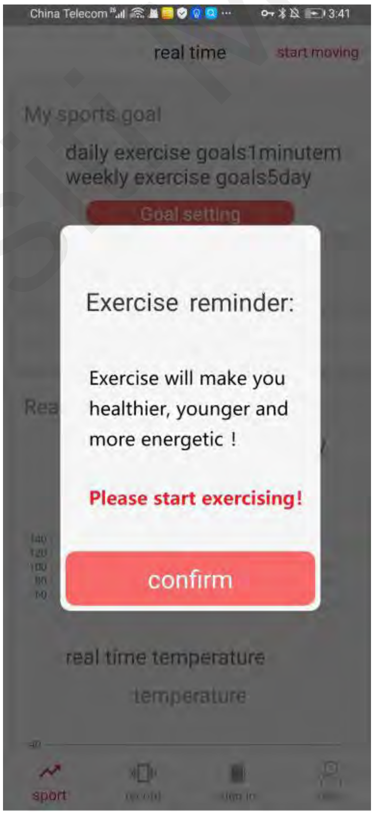


Figure 4.4: User login page.

### 4.5.4 Exercise reminder function

After the user logs in successfully, the exercise prompt interface will pop up, prompting a persuasive message “exercise will make you healthier, younger and more energetic! Please start exercising!” When the user clicks the start exercise button, the exercise reminder will not be prompted. Otherwise, the same interface will pop up every 3 hours to remind the user to exercise. If the user wants to close the prompt, they can click the “confirm" button. The button will disappear temporarily. The pop-up time period is from 8 a.m. to 11 p.m. Figure 4.5 shows the exercise reminder function diagram.



Exercise reminder:

Exercise will make you healthier, younger and more energetic !

Please start exercising!

Figure 4.5: Exercise reminder function.

### 4.5.5 Exercise goal setting function

Users can set their daily and weekly exercise goal according to their condition and check their exercise goal at any time. The logic about the daily exercise time is that if it is greater than 24*60, an alert box pops up “Time out of range!” . If the weekly exercise time is greater than 7, an alert box pops up “Days out of range!” . . If the user sets a valid goal and then clicks on Save Settings, a pop-up box will appear saying “Save Settings Successful!”. Figure 4.6 shows the user interface for exercise goal setting.

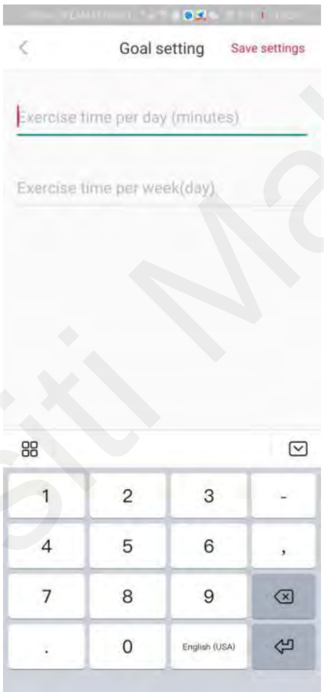


Figure 4.6: User interface for exercise goal setting.

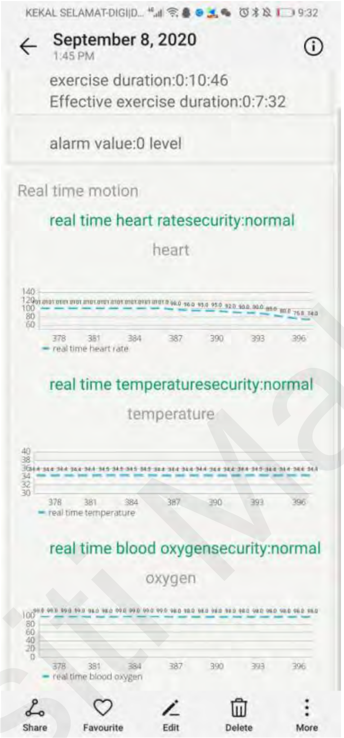
### 4.5.6 View real-time exercise parameters function

The real-time exercise monitoring page displays the start exercise button, the exercise time, the effective exercise time, the alert level, as well as the real-time heart rate, blood oxygen and body temperature. When the user clicks start exercise, the exercise time will start to be counted. In order to identify the quality and intensity of exercise, when the heart rate is greater than 120, the exercise time will be automatically counted into the effective exercise time. Research shows that the physical benefits of exercise can only be produced when the heart rate is greater than 120 beats per minute (Wright et al., 2016).

Alert level is defined to enable monitoring of exercise safety. The default alert level is 0. If blood oxygen is consistently below 90, heart rate is consistently above 190 and body temperature is consistently above 39.5, the alert level will change to 1, while the green text will turn red and the phone will vibrate to alert the user. The thresholds are determined based on past studies and existing recommendations:

- Studies have shown that blood oxygen saturation during exercise of less than 90% is considered an abnormal response, which may reflect damage to the lung, heart or circulatory system (Ruf & Hebestreit, 2009), Another study also showed that if SpO2 is less than 90%, it is suggested that activity intensity should be limited (Washington et al., 1994).
- Research shows that the maximum range of exercise average heart rate between the ages of 20 and 30 is 190-200 beats per minute (Rubin & Permanente, 2000).
- Research on exertional heat stroke (EHS) shows that participants with their body temperature not exceeding 39.5 degrees Celsius rarely experinced EHS. Five studies averaged 39 degrees Celsius as the limit, and only a few participants exceeded 39.5 degrees Celsius (Haskell, Montoye, & Orenstein, 1985). Another study showed that the level associated with fever and high fever was 39.5 degrees Celsius (Walsh & Whitham, 2006).

Te system is set to update the data of real-time heart rate, blood oxygen and body temperature every 3 seconds, which is displayed in the form of a graph for the user to view. When the user has completed the set exercise target, he/she can click the end exercise button to end the exercise. If the exercise target has not been reached, the user will be prompted to select "Today's exercise target has not been reached, do you want to continue exercising". Figure 4.7 shows the view real-time exercise parameters.



exercise duration:0:10:46
Effective exercise duration:0:7:32

alarm value:0 level

Figure 4.7: View real-time exercise parameters.

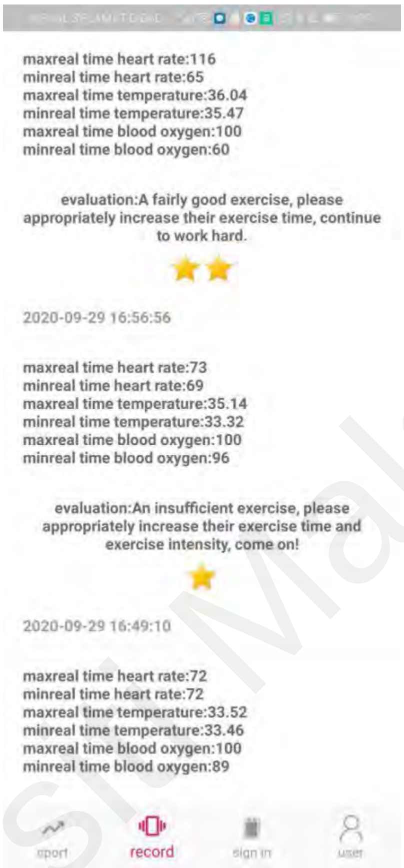
### 4.5.7 Exercise evaluation and rating function

The ratings page shows maximum heart rate, minimum heart rate, maximum body temperature, minimum body temperature, maximum blood oxygen, minimum blood oxygen, ratings and comments. Rating is automatically available when the user clicks the End Exercise button. The rating page keeps a record of the maximum and minimum heart rate, blood oxygen and body temperature parameters in order for the user to see the body parameters in a clear and concise manner. The rating is calculated as one star if the effective workout is under 8 minutes, two stars if it is between 8-15 minutes, three stars if it is between 15-22 minutes, four stars if it is between 22-30 minutes and five stars if it is above 30 minutes. The ranges were set based on a study on physical health and exercise goals which showed that through moderate intensity endurance exercise for 30 minutes or more, at least three times a week, health change will occur (Emerson, Chen, Kelly, Parnell, & Torres-McGehee, 2021). Therefore, the system encourages participants to exercise for more than 30 minutes each time. Meanwhile, a study show that 74.4% of people reported more than 15 minutes of exercise as the appropriate exercise duration (Caspersen, Christenson, & Pollard, 1986). Another study on sedentary showed that compared with inactive individuals, exercising for 15 minutes a day reduced the risk of all-cause death by 14%. Every additional 15 minutes of daily exercise can further reduce the all-cause mortality by 4% (Lavie, Ozemek, Carbone, Katzmarzyk, & Blair, 2019). Thus, the developed system takes 15 minutes as the boundary of sedentary and non-sedentary. The 0-15 minutes range is divided into two levels of low exercise level; the 15-30 minutes range is divided into two moderate exercise levels; while above 30 minutes as high exercise level. Depending on the levl of exercise, different messages are given to encourage the user to exercise. Table 4.3 lists down different time ranges and the corresponding messages.

**Table 4.3: Time ranges and the corresponding messages.**

| Rating | Time range | Message |
|---|---|---|
| 1 | <8min | An insufficient exercise, please appropriately increase your exercise time and exercise intensity, come on! |
| 2 | 8-15min | A fairly good exercise, please appropriately increase your exercise time, continue to work hard! |
| 3 | 15-22min | A good exercise, you can still be better, keep up the good work! |
| 4 | 22-30min | A very good exercise, please keep it, you will be healthier and healthier! |
| 5 | >30min | A perfect exercise, please keep it up, you are the best! |

Figure 4.8 shows the exercise data evaluation and rating.



maxreal time heart rate:116
minreal time heart rate:65
maxreal time temperature:36.04
minreal time temperature:35.47
maxreal time blood oxygen:100
minreal time blood oxygen:60

evaluation:A fairly good exercise, please appropriately increase their exercise time, continue to work hard.

★★

2020-09-29 16:56:56

maxreal time heart rate:73
minreal time heart rate:69
maxreal time temperature:35.14
minreal time temperature:33.32
maxreal time blood oxygen:100
minreal time blood oxygen:96

evaluation:An insufficient exercise, please appropriately increase their exercise time and exercise intensity, come on!

★

2020-09-29 16:49:10

maxreal time heart rate:72
minreal time heart rate:72
maxreal time temperature:33.52
minreal time temperature:33.46
maxreal time blood oxygen:100
minreal time blood oxygen:89

Figure 4.8: Exercise data evaluation and rating.

### 4.5.8 Sign in function

After the daily goal has been completed, a sign in record can be made to record the exact time and date of the exercise. Detailed exercise parameters can be viewed for the most recent exercise, including trend graphs of heart rate, blood oxygen and body temperature. Figure 4.9 shows the sign in function.

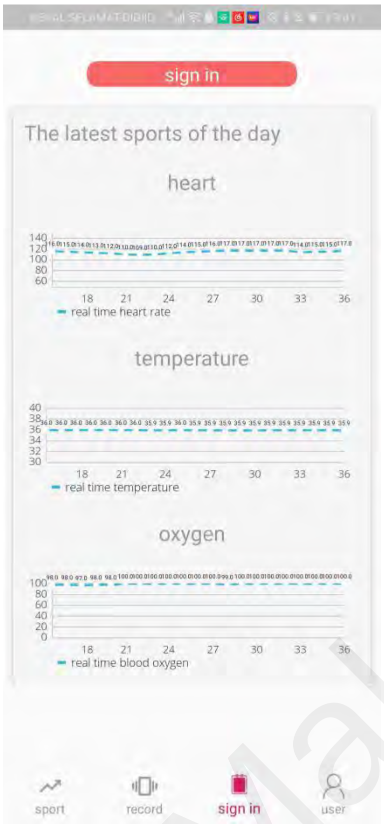


Figure 4.9: Sign in function.

### 4.5.9 Bluetooth communication function

The app uses the BLE Bluetooth technology to discover devices, query services, and read and write functions. Compared to the traditional Bluetooth technology, BLE is known for its low power consumption. This module calls the Low Power Bluetooth API and starts the services separately to perform a series of Bluetooth scanning, connecting, sending and receiving data operations. Firstly, the Bluetooth transmitter module of the wearable is switched on. Then the Bluetooth switch is turned on in the Android settings, and the corresponding wearable can be selected to connect, listen and send data by clicking the Find Bluetooth Device button in the app. Figure 4.10 shows the bluetooth communication user interface.

Figure 4.10: Bluetooth communication user interface.

## 4.6 Wearable devices key technologies and implementation

### 4.6.1 Microcontroller unit

As mentioned in Section 3.2, STM32F103 that supports Cortex-M3 was chosen as the microcontroller chip, which is connected to each sensor module. The STM32F103 microcontroller unit (MCU) is the core of the entire system. MCU is the appropriate reduction of the specifications of the central processing unit (CPU), a collection of memory, A/D conversion, UART, GPIO, timer and other units on a chip. As the core of the whole system, the microcontroller module controls each module and performs functions such as data transmission, signal processing and data storage.

The selection of the microcontroller in the system is critical, in addition to considering the performance, cost, power consumption and storage capacity, but also consider the computing power of the microprocessor, dormancy time and integration. Performance directly affects the implementation of functions and operating speed. The low cost can reduce the cost of the entire system, while its working power consumption directly affects the power consumption of the entire system. Memory capacity directly determines the system's data and program sizes. Integration level directly affects the size of the system. Therefore, the STM32F103 is chosen as the microcontroller for wearable devices among many microcontrollers, mainly because of its advantages of high performance, rich hardware resources, high integration level, large memory capacity, few peripheral circuits, and fast operation speed.

Each sensor module (MAX30102 and MAX30205) and STM32F103 microcontroller is supplied with 3.3 V supply voltage, so there is no need for level conversion. Considering the portability of wearable devices and the requirement of small size and low power consumption, Bluetooth technology was chosen as the data transmission means of this system.

The hardware block diagram of the wearable device designed is shown in Figure 4.11.

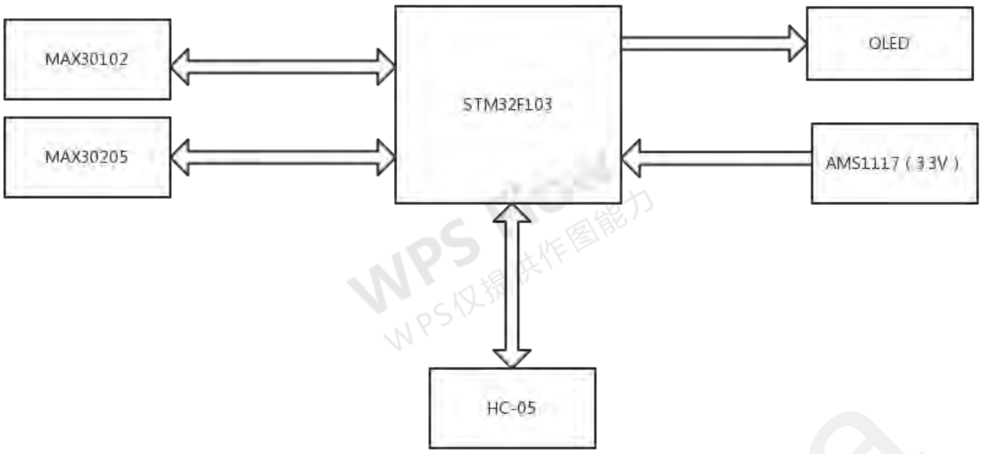


Figure 4.11: Wearable device block diagram.

### 4.6.2 Design of wireless communication technologies

Wireless communication technologies such as Zigbee, WiFi, and Bluetooth have their own unique characteristics, with respective advantages and disadvantages. The advantage of WiFi is its easy implementation and wide range, while the disadvantage is its high power consumption and large size. Bluetooth has the advantage of small size and wide range, and the disadvantage of limited connectivity. For the wearable device designed in this research, it is mainly used for real-time monitoring of the participants' basic physiological indicators, which requires small size and low power consumption. Thus, the Bluetooth technology was chosen.

This study uses the Bluetooth Low Energy (BLE) Bluetooth technology (Mackensen et al., 2012). Compared with traditional Bluetooth technologies, BLE is more notable for its low power consumption. This module calls the API of low-power Bluetooth and starts Service separately to carry out a series of operations such as Bluetooth scanning, connection, sending and receiving data.

### 4.6.3 Measurement of heart rate and blood oxygen and sensor selection

The most accurate measurement of oxygen saturation is still through collecting and analyzing blood with professional equipment to obtain the oxygen value. However, this method can cause pain to the users. A non-invasive, convenient collection of oxygen measurement method, such as using a specialized sensor, has become the direction of research. The measurement of blood oxygen content can also be obtained by analyzing the returned signal after irradiation by a light source. Since oxygenated haemoglobin (Hb02) and reduced haemoglobin (Hb) absorb different wavelengths of light differently, the measurement of blood oxygen saturation requires different wavelengths of light as the incident light. Figure 4.12 shows the absorption coefficient curves of oxygenated haemoglobin and reduced oxygenated haemoglobin for different wavelengths of light. The wavelength of the incident light source was chosen to be 660mm and 940mm (Sineka & Mythili, 2019).

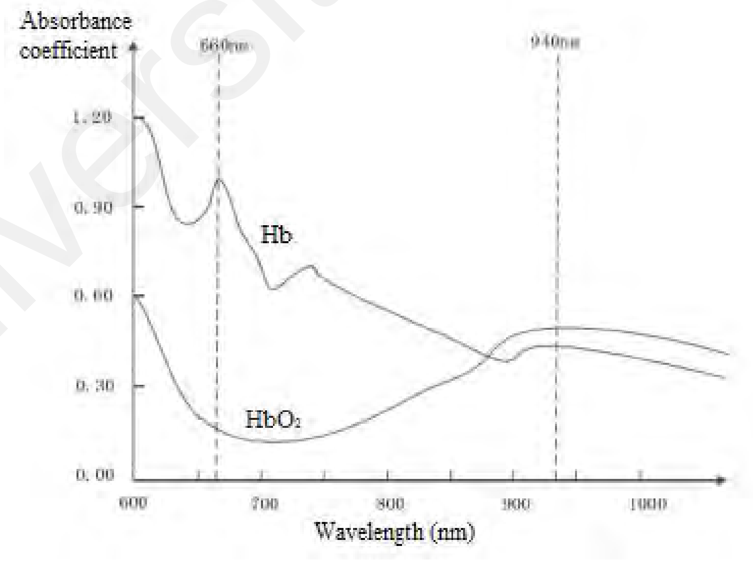


**Figure 4.12: Absorption coefficient curve of different wavelength light.**

The measurement of heart rate and blood oxygen is based on the principle of PPG (Photo Plethysmo Graphy), which is a pulse signal obtained by photoelectric volumetric pulse wave tracing (Yang, Zhu & Zhu, 2015). The basic principle of the photoelectric volumetric method is to use the difference in light transmission caused by human tissue when the blood vessels are pulsating to make heart rate and oxygen saturation measurements. The traditional method of measuring heart rate, which involves placing a finger on the wrist pulse to sense the arterial pulse and estimate the beats per minute (BPM), is inaccurate and unreliable and is more prone to error when the pulse rate is high or irregular.

The PPG signal is detected by emitting a light source, and when the incident light is shone on tissue containing blood vessels, the light range of the incident light penetrating the vessels should change periodically for the diameter of the vessels (Moço, Stuijk & de Haan, 2018). When the heart is contracting, the blood volume in the vessel becomes smaller, the light absorption becomes smaller and the detected light intensity is maximum. On the contrary, when the heart is diastolic, the blood volume in the blood light becomes larger, the light absorption becomes larger and the detected light intensity is minimum. The pulsation period of the heart depends on the periodicity of the light intensity.

In order to achieve miniaturization and wearability of the wearable device, this design uses an integrated circuit chip MAX30102 as the oxygen saturation and heart rate monitoring sensor (Shruthi & Resmi, 2019). MAX30102 was designed and developed for wearable devices by MAXIM and launched in 2016. It has high cost-effectiveness and high integration. MAX30102 uses the human tissue in the blood vessels pulses caused by the different light transmission rate to carry out pulse and blood oxygen concentration saturation measurement. With this measurement method, the user only needs to place the sensor on the finger, wrist, or ear lobe to measure the data using the PPG signal detection method.

In this study, when heart rate and blood oxygen were measured using the photo volumetric method, the signal reflected back from the light was composed of two components, the direct current (DC) component and the alternating current (AC) component, as shown in Figure 4.13. The source of the DC component is venous blood, no fluctuating components and muscles in arterial blood while the AC component reflects the absorption of arterial blood, which is synchronized with the pulsatile cycle. In general, the value of the AC component of the light signal is much smaller than the value of the DC component. The heart rate is calculated in relation to the AC component of the optical signal and PPG calculates heart rate by detecting the peak in a cycle. The heart rate is determined by the time difference between two adjacent wave crests. The ratio of the DC component to the AC component is calculated to obtain the blood oxygen value.

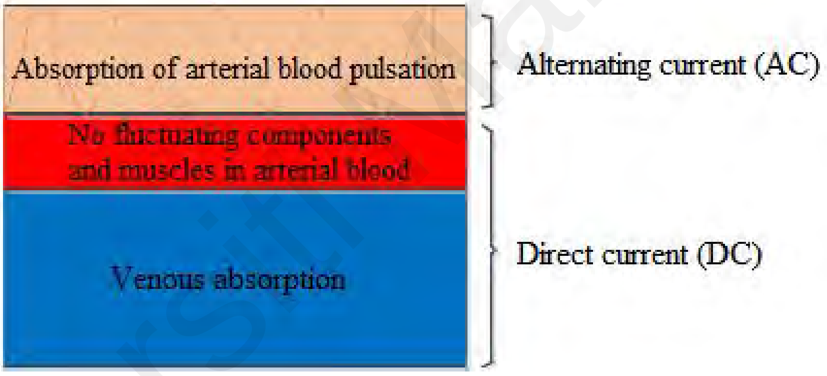


**Figure 4.13: The main components of the optical signal.**

In this study, the heart rate and blood oxygen signals are obtained by reflection. The transmitter and receiver of MAX30102 are on the same side. The light source on the epidermal tissue side emits red light (660mm) and infrared light (940mm). The light receiver on the same side will receive the scattered light after blood absorption. The receiver device is a high sensitivity phototransistor. The received signal is amplified, analogue filtered and digitally filtered. Finally, the measurement data is stored in an internal first-in-first-out (FIFO) memory for reading by an external controller. The emitted power of the light source is increased in this study to improve the reflection of the signal strength.

### 4.6.4 Measurement of body temperature and sensor selection

The measurement of body temperature is based on the principle of the temperature-dependent characteristics of the current and voltage of the semiconductor PN junction. The MAX30205 integrated temperature sensor integrates temperature-sensitive devices and circuits for amplification, operation, and compensation on the same chip, which has the advantages of good output linearity, small size, accurate temperature measurement and a small error range. The sensor has good linear output and high accuracy temperature characteristics. That can sensor accurately measures temperature and provides an over-temperature alarm/interrupt/shutdown output. The sensor has in the temperature range of 0℃ to 50 ℃, with the accuracy of 0.1℃ (Sudha et al., 2018).

The MAX30205 sensor has a supply voltage range of 2.7V to 3.3V, a low supply current of 600uA and an IIC-compatible interface with lockout protection, making it a desirable choice for the wearable device. When the host computer transmits the start signal through the PC interface, the MAX30205's clock transmission line SCL will generate a clock with the same frequency as the host computer. When the sensor is close to the human skin, it will sense the skin temperature. The skin temperature signal first goes through the 16-bit digital-to-analog converter. This digital-to-analog converter comes in the form of a binary complementary code. After the completion of the digital-to-analog conversion, the data is passed to the data registers. Finally, the main processor reads the data in the temperature registers to complete the acquisition of human body temperature.

## 4.7 Overall System Testing

In the fourth iteration, the wearable device was compared with specialized devices such as oximeters and thermometers for accuracy of measurement values. The YK81D finger clip medical pulse detector was selected for comparison of heart rate and blood oxygen measurements (Figure 4.14). Microlife thermometer was selected for comparing body temperature.

Six test subjects were selected for the heart rate, blood oxygen and body temperature testing experiment, including three males and three females, aged between 18-30. Each test subject used and tested the integrated system three times with an interval of 10 minutes between tests.

**Figure 4.14: Comparing measurements of the wearable device and YK81D.**

The results of the 3 tests for each tester with the wearable device developed, and YK81D finger clip detector and Microlife thermometer were compared. The mean error results are shown as absolute values, as shown in Tables 4.4 to 4.10.

**Table 4.4: Participant Information for Accuracy Testing.**

| Participant Information for Accuracy Testing | | | | | | |
|---|---|---|---|---|---|---|
| No. | 1 | 2 | 3 | 4 | 5 | 6 |
| GENDER | Female | Female | Female | Male | Male | Male |
| AGE | 21 | 25 | 30 | 23 | 27 | 28 |

**Table 4.5: Heart rates measured by the wearable device.**

| Results of heart rate measured by the wearable device | | | |
|---|---|---|---|
| Tester | Heart rate (beats/min) | | |
| Male 1 | 82 | 86 | 79 |
| Male 2 | 76 | 78 | 81 |
| Male 3 | 78 | 74 | 75 |
| Female 1 | 89 | 85 | 88 |
| Female 2 | 80 | 82 | 78 |
| Female 3 | 79 | 84 | 81 |

**Table 4.6: Heart rates measured by YK81D detector.**

| Heart rates measured by YK81D | | | |
|---|---|---|---|
| Tester | Heart rate (beats/min) | | |
| Male 1 | 88 | 80 | 85 |
| Male 2 | 72 | 82 | 76 |
| Male 3 | 73 | 79 | 82 |
| Female 1 | 82 | 92 | 95 |
| Female 2 | 84 | 88 | 84 |
| Female 3 | 75 | 78 | 86 |

**Table 4.7: Blood oxygen measured by the wearable device.**

| Blood oxygen measured by the wearable device | | | |
|---|---|---|---|
| Tester | Oximetry value % | | |
| Male 1 | 99 | 100 | 99 |
| Male 2 | 98 | 99 | 100 |
| Male 3 | 98 | 100 | 98 |
| Female 1 | 99 | 99 | 100 |
| Female 2 | 100 | 100 | 96 |
| Female 3 | 98 | 98 | 99 |

**Table 4.8: Blood oxygen measured by YK81D detector.**

| Blood oxygen measured by YK81D | | | |
|---|---|---|---|
| Tester | Oximetry value % | | |
| Male 1 | 98 | 98 | 96 |
| Male 2 | 96 | 99 | 97 |
| Male 3 | 99 | 100 | 96 |
| Female 1 | 98 | 100 | 99 |
| Female 2 | 97 | 99 | 95 |
| Female 3 | 99 | 96 | 100 |

**Table 4.9: Body temperature measured by the wearable device.**

| Body temperature measured by the wearable device | | | |
|---|---|---|---|
| Tester | Body temperature °C | | |
| Male 1 | 35.1 | 35.4 | 35.8 |
| Male 2 | 36.0 | 36.2 | 35.7 |
| Male 3 | 34.9 | 35.2 | 35.6 |
| Female 1 | 36.4 | 36.0 | 36.2 |
| Female 2 | 35.6 | 35.4 | 35.8 |
| Female 3 | 35.8 | 36.1 | 36.5 |

**Table 4.10: Body temperature measured by Microlife thermometer.**

| Body temperature measured by Microlife thermometer | | | |
|---|---|---|---|
| Tester | Body temperature °C | | |
| Male 1 | 35.5 | 35.8 | 36.1 |
| Male 2 | 36.3 | 36.4 | 36.0 |
| Male 3 | 35.3 | 35.6 | 35.8 |
| Female 1 | 36.6 | 35.8 | 36.6 |
| Female 2 | 36.0 | 35.5 | 36.1 |
| Female 3 | 35.7 | 36.4 | 36.8 |

**Table 4.11: Mean errors of heart rate, blood oxygen and body temperature.**

| Mean errors of heart rate, blood oxygen and body temperature | | | |
|---|---|---|---|
| Tester | Mean error of heart rate error (beat/min) | Mean error of blood oxygen (%) | Mean error of body temperature (°C) |
| Male 1 | 6.0 | 2.0 | 0.37 |
| Male 2 | 4.3 | 1.7 | 0.27 |
| Male 3 | 5.7 | 1.0 | 0.33 |
| Female 1 | 7.0 | 1.0 | 0.27 |
| Female 2 | 5.3 | 1.7 | 0.27 |
| Female 3 | 5.0 | 1.3 | 0.23 |
| Average | 5.6 | 1.45 | 0.29 |

From Table 4.11, it can be concluded that the single-point heart rate measurement error between the wearable device and the YK81D detector is within ±7 beats per minute; the single point blood oxygen measurement error between the wearable device and the YK81D detector is within ±3%; and the single point temperature measurement error between the wearable device and the Microlife thermometer is within±0.4℃. In addition, the average mean errors of the heart rate, blood oxygen and body temperature test results are ±5.6 beat/minute, ±1.45%, and ±0.29 ℃, respectively.

### 4.7.1 Analysis of mean errors

For measurements of heart rate, different measurement positions of the wearable device (wrist) and the YK801 detector (finger) affected the experimental results. At the same time, the amplitude of the measured heart rate signal has many external influences, such as skin perfusion pressure, skin temperature, measurement position, skin density, skin pigmentation and the blood pressure. Similarly, for body temperature, different measurement positions also impacted the results of the experiment, increasing the error.

The average heart rate error of the wearable device (wrist) of this study is 8.53%. Compared with the official data from the respective heart rate bracelet manufacturers on the market, for example, the resting heart rate error of the high-end watch Garmin 3 is less than 5%, and Xiaomi Bracelet is generally less than 10%. The average error of measuring heart rate of Huawei Bracelet 3 in static state is 10%. The heart rate error of M3plus is about 28%. As for the error measurement of blood oxygen, the error of blood oxygen of bracelets on the market is less than 5%, and the average error of blood oxygen of the wearable device developed in this study is usually 3%. Thus, the error rates are comparable with the relevant products on the market.

There are many reasons for introducing errors in measurement. For example, when the bracelet is loose, the bracelet and wrist do not fit well, and the pulse signal of wrist may not be recognized. The environment is also important. Stains and excessive perspiration can affect the accuracy of heart rate measurement, and arm scars, tattoos and luxuriant hair can also cause the bracelet not making good contact with the skin. Heart rate during regular exercise (such as jogging, walking, cycling, etc.) is easier to measure; irregular exercise (such as playing ball, free activity, etc.) and wrist strength exercise (such as weightlifting) may not allow measurement of heart rate.

Whether it is the specifically designed wearable device or the wearable devices on the market, there is still a gap between the precision required by the professional medical equipment. Nevertheless, the wearable devices still have certain reference value for the measurements of heart rate, blood oxygen and body temperature.

# CHAPTER 5: RESULTS AND ANALYSIS

This study used a mixed-method approach to perform data analysis. Quantitative data analysis was first conducted to determine the effectiveness of the developed system in encouraging participants exercising as well as impacting their exercise habits. Qualitative analysis was then conducted based on information from the interviews with the participants to determine how well the participants were encouraged to exercise. The quantitative data analysis of this study was conducted using SPSS analysis software. The qualitative data analysis of this study was carried out with the help of the analysis software NVIVO.

## 5.1 Results of Quantitative Data Analysis

Firstly, this study makes a descriptive analysis of the quantitative analysis data to compare the participants' average exercise frequency and average daily exercise time during the baseline stage (2 weeks) and the intervention stage (2 weeks) to demonstrate the effectiveness of the whole system in encouraging exercise. Second, this study examined the differences between post intervention stage A and intervention stage, to demonstrate the importance of the wearable device (hardware component) in encouraging exercise. Third, this study examined the difference between the baseline stage and post-intervention stage B to explore whether the participants maintained their level of physical activity after the intervention week without using the system at all. During the analysis of the quantitative data, SPSS software was used to analyze the quantitative data and the results were tested to verify the three research hypotheses.

### 5.1.1 Normality test

SPSS provides results for test of normality, the Kolmogorow-Smironov (KS) test, for small samples. If the significance value is larger than 0.05, the distribution is normal. In addition, the histogram is a good way to visualise the distribution of the data for normality. Further confirmation can be obtained by checking the Q-Q plot. If the graph is basically around a straight line of y=x, it can be considered to obey a normal distribution. The result of the Kolmogorow-Smironov (KS) test, is shown in Table 5.1; while the histogram and Q-Q plot are shown in Figures 5.1 and 5.2, respectively. The results show that the average time per exercise is normal distributed.

**Table 5.1: Tests of Normality (average time per exercise).**

Tests of Normality

|  | Kolmogorov-Smirnov[a] |  |  |
|---|---|---|---|
|  | Statistic | df | Sig. |
| Observed value | .054 | 188 | .200* |

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

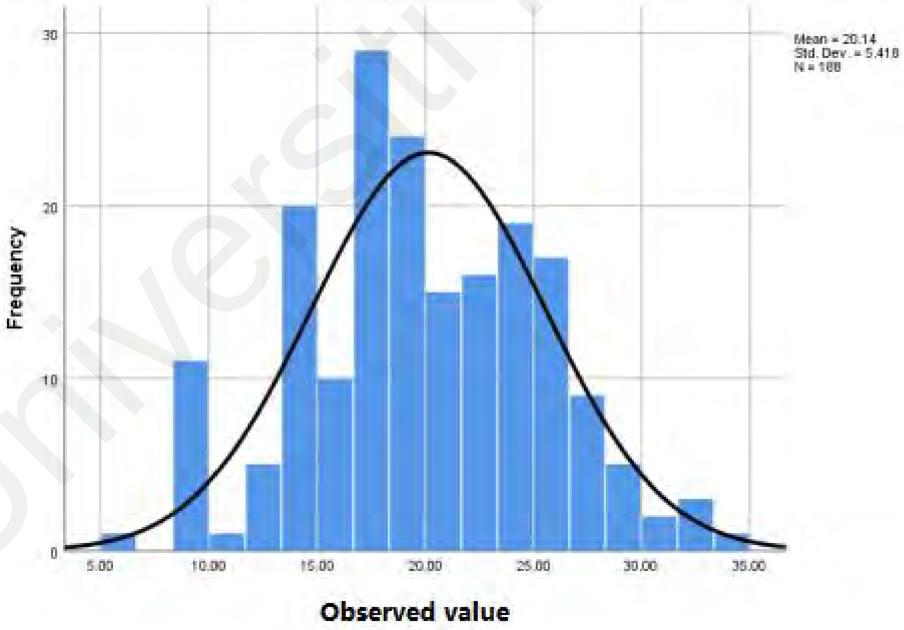


Figure 5.1: Normal histogram plot of Observed value.

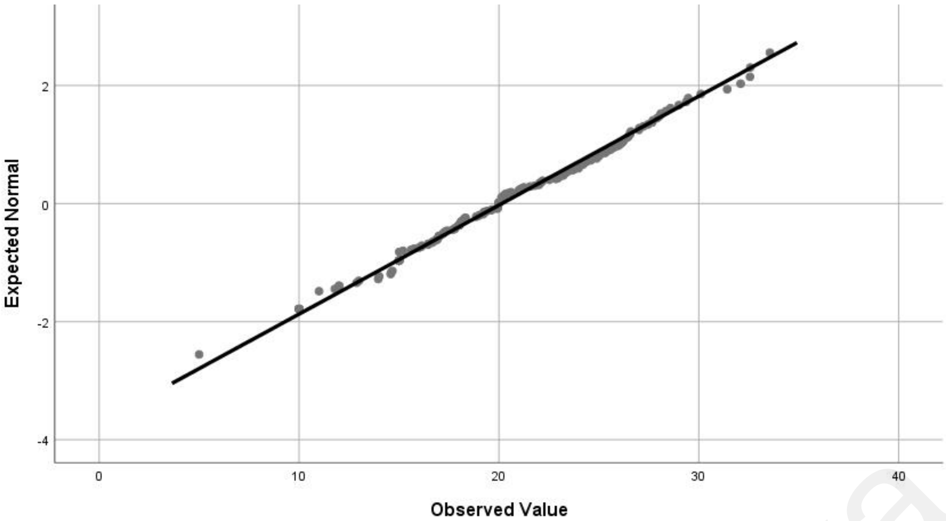


Figure 5.2: Normal Q-Q plot of Observed value.

### 5.1.2 Increase in the Average Length of Exercise by Participants

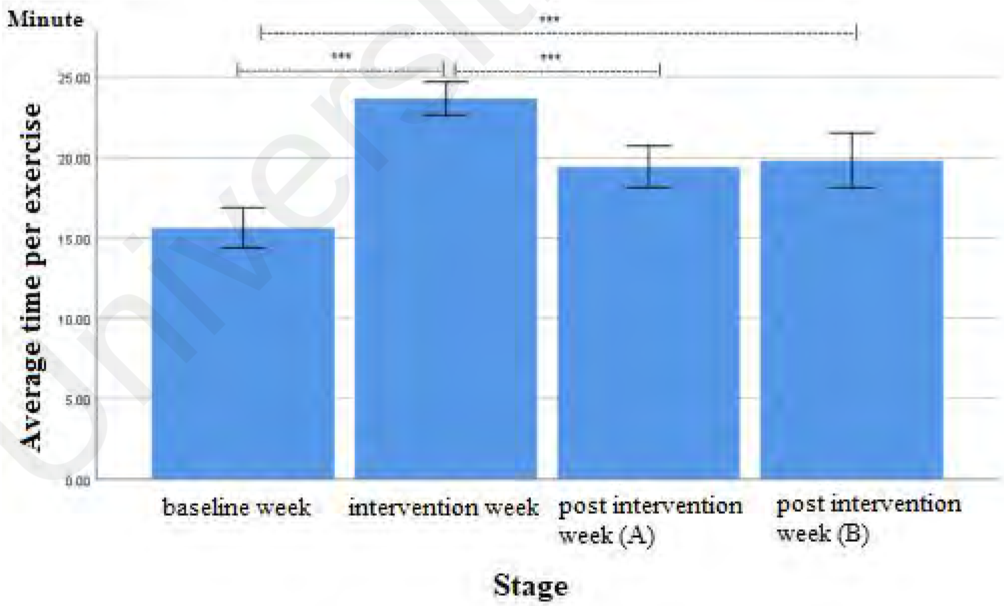


Figure 5.3: Average time per exercise (two weeks)

Figure 5.3 shows the descriptive statistical analysis of average time per exercise of each group. The mean value shows in this descending order: intervention stage, post intervention stage B, post intervention stage A, baseline stage. Compared with the baseline stage (Duration of each exercise of 15.63 min), the average time per exercise increased by 8.03 min during the intervention stage ((Duration of each exercise of 23.66 min). The average time per exercise in the post intervention stage A was 19.43 min and that in the post intervention stage B was 19.81 min.

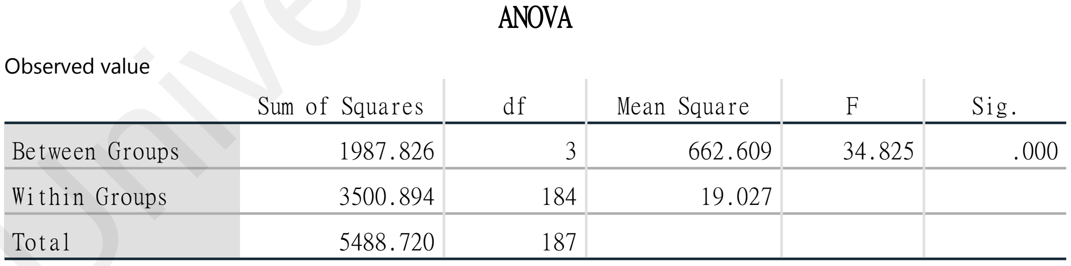
There are three hypotheses about the average time per exercise：

H1: The participants'duration of exercise in the intervention period was significantly higher than the duration of exercise in the baseline period.

H2: The participants' duration of exercise in the intervention period was significantly higher than the duration of exercise in the post-intervention period A.

H3: The participants' duration of exercise in post-intervention phase B was significantly higher than the duration of exercise in the baseline period.

**Table 5.2: Anova test for Average time per exercise (two weeks)**



ANOVA

Observed value

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 1987.826 | 3 | 662.609 | 34.825 | .000 |
| Within Groups | 3500.894 | 184 | 19.027 | | |
| Total | 5488.720 | 187 | | | |

The ANOVA test result (F(3, 184)=34.825, $P < 0.05$) in Table 5.2 shows that there are significant differences between at least two among the four groups. Through the LSD post test shown in Table 5.3, data between two groups were compared. If $p< 0.05$, it means that there was a significant difference between the two groups.

**Table 5.3: LSD post test table**

### Multiple Comparisons

Dependent Variable: Observed value

LSD

| | | | | | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| (I) Group | (J) Group | Mean Difference (I-J) | Std. Error | Sig. | Lower Bound | Upper Bound |
| baseline | Intervention | -8.03282* | .79168 | .000 | -9.5948 | -6.4709 |
| | post intervention (A) | -3.80134* | .97449 | .000 | -5.7240 | -1.8787 |
| | post intervention(B) | -4.18048* | 1.01448 | .000 | -6.1820 | -2.1790 |
| intervention | baseline | 8.03282* | .79168 | .000 | 6.4709 | 9.5948 |
| | post intervention (A) | 4.23148* | .91118 | .000 | 2.4338 | 6.0292 |
| | post intervention(B) | 3.85234* | .95382 | .000 | 1.9705 | 5.7342 |
| post intervention (A) | baseline | 3.80134* | .97449 | .000 | 1.8787 | 5.7240 |
| | intervention | -4.23148* | .91118 | .000 | -6.0292 | -2.4338 |
| | post intervention(B) | -.37914 | 1.11025 | .733 | -2.5696 | 1.8113 |
| post intervention(B) | baseline | 4.18048* | 1.01448 | .000 | 2.1790 | 6.1820 |
| | intervention | -3.85234* | .95382 | .000 | -5.7342 | -1.9705 |
| | post intervention (A) | .37914 | 1.11025 | .733 | -1.8113 | 2.5696 |

*. The mean difference is significant at the 0.05 level.

Firstly, in the comparison between the baseline stage and the intervention stage, the independent variable was the whole system (wearable device and app); the dependent variable was the duration of exercise. Through the LSD post test, it is found that there was a significant difference between the baseline stage and the intervention stage, where $p<0.05$and hypothesis H1 holds.

In the comparison between the post intervention stage A and the intervention stage, the independent variable was the app; the dependent variable was the duration of exercise. Figure 5.5 shows the average time per exercise of 19.43 minutes during the post intervention stage A, where the participants only used the app and did not use the wearable device, compared to 23.66 minutes during the intervention stage. The participants' average daily exercise duration decreased by 4.23 minutes during the period when they did not use the wearable device. Through the LSD post test, it was found that there was a significant difference between the intervention stage and intervention stage A, where $p<0.05$. Therefore, it can be concluded that the wearable device has a positive impact on the participants' duration of exercise and H2 holds.

The comparison between the baseline stage and the post intervention stage B was a pre- and post-test; the dependent variable was the exercise duration. Through the LSD post test, it was found that there was significant difference between the baseline stage and the post intervention stage B, where $p<0.05$, showing that the participants' average time per exercise was significantly increased during the post intervention stage B than baseline stage. Thus, hypothesis H3 holds.

### 5.1.3 Participants' Exercise Frequency is Improved

The average frequencies of exercise during the baseline stage, intervention stage, and post-intervention stage were calculated separately for each participant for comparative analysis. The amount of increase in exercise frequency per stage (baseline, intervention, and post-intervention) is an indication of how much the participants had improved in exercising. However, the data on the exercise frequency do not satisfy the normal distribution. Thus, only descriptive analyses are provided below and the detailed data are shown in Table 5.4.

**Table 5.4:Average exercise frequency multiple comparisons per stage (Two Weeks)**

Multiple Comparisons

Dependent Variable: frequency

LSD

| (I) Group | (J) Group | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| baseline | Intervention | -2.400* | .269 | .000 | -2.95 | -1.85 |
| | post intervention (A) | -1.500* | .329 | .000 | -2.18 | -.82 |
| | post intervention(B) | -.700* | .329 | .043 | -1.38 | -.02 |
| intervention | baseline | 2.400* | .269 | .000 | 1.85 | 2.95 |
| | post intervention (A) | .900* | .329 | .011 | .22 | 1.58 |
| | post intervention(B) | 1.700* | .329 | .000 | 1.02 | 2.38 |
| post intervention(A) | baseline | 1.500* | .329 | .000 | .82 | 2.18 |
| | intervention | -.900* | .329 | .011 | -1.58 | -.22 |
| | post intervention(B) | .800* | .380 | .045 | .02 | 1.58 |
| post intervention(B) | baseline | .700* | .329 | .043 | .02 | 1.38 |
| | intervention | -1.700* | .329 | .000 | -2.38 | -1.02 |
| | post intervention (A) | -.800* | .380 | .045 | -1.58 | -.02 |

*. The mean difference is significant at the 0.05 level.

Figure 5.4 and Figure 5.5 show the change in participants' exercise frequency over the three research stages.

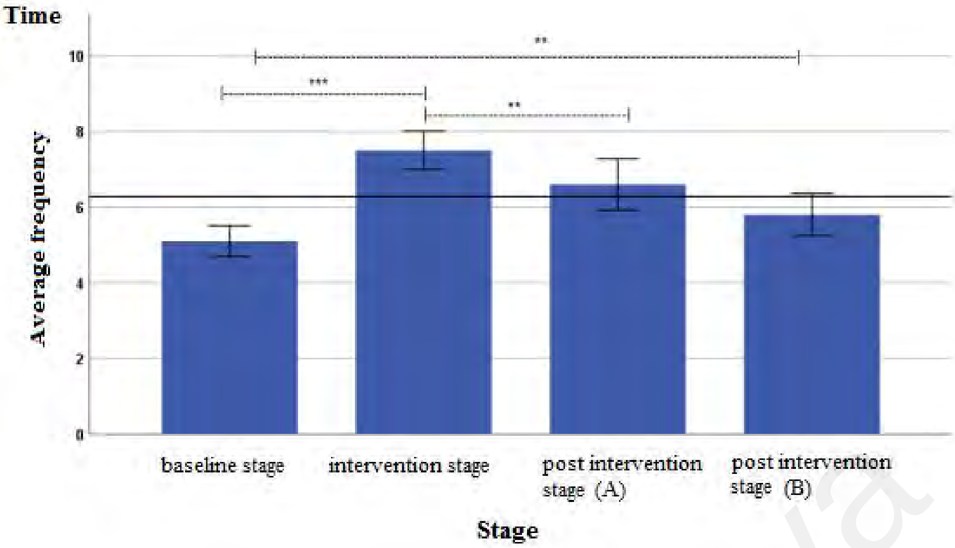


**Figure 5.4: Average exercise frequency per stage (Two Weeks).**

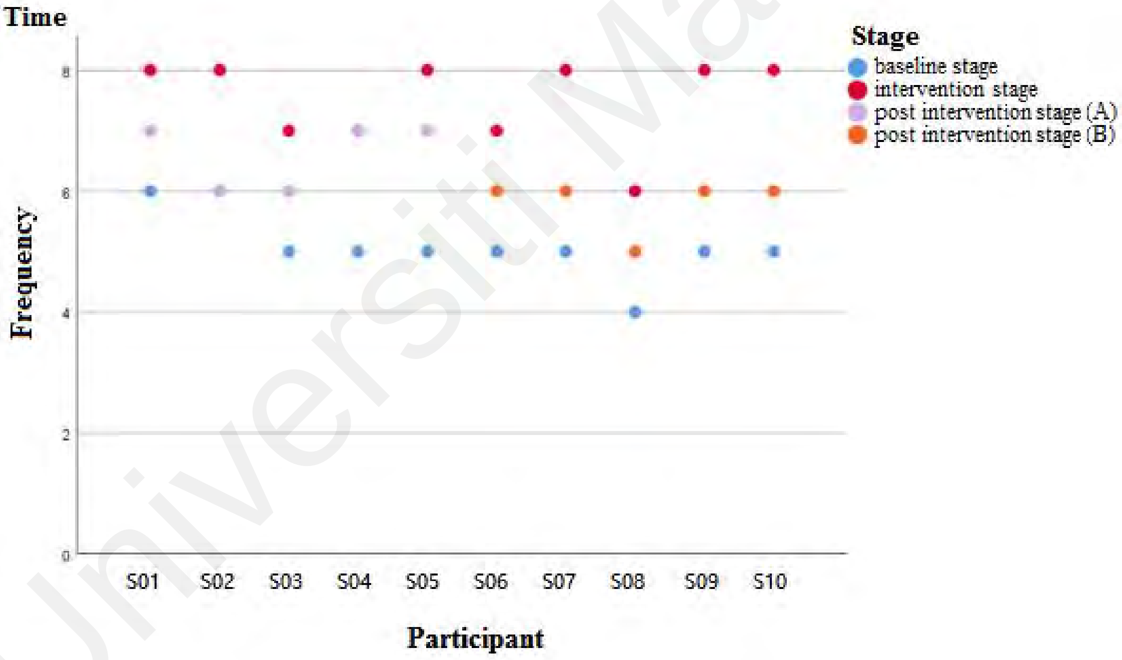


**Figure 5.5: Average exercise frequency distribution chart (Two Weeks).**

**Note1: the points of post intervention and intervention stages of S02 overlap.**

**Note2: the points of baseline and intervention stages of S04 overlap.**

According to the descriptive statistical analysis of exercise frequency in Table 5.4, Figure 5.4 and Figure 5.5, the mean values are in this descending order: intervention stage, post intervention stage A (experiment group), post intervention stage B (control group), baseline stage. The average frequency of intervention stage is 7.5 times, the max of intervention stage is 8 times. The average frequency of post intervention stage A is 6.6 times, the max frequency of post intervention stage A is 7 times. The average frequency of post intervention stage B is 5.8 times, the max frequency of post intervention stage B is 6 times. The baseline stage average frequency is 5.1 times.

Firstly, compared with the baseline stage (5.1 times), the average frequency of intervention stage (7.5 times) increased by 2.4 times. In the comparison between baseline stage and intervention stage, the independent variables was the whole system (wearable device and app); the dependent variable was the exercise frequency. According to the average data of exercise frequency, it can be seen that through the intervention of the whole system, participants have improved in exercise frequency.

Secondly, compared with the post intervention stage A (6.6 times), the average frequency of intervention stage (7.5 times) decrease by 0.9 times. The independent variable was the wearable device (The participants’ exercise frequency during the post intervention stage A, where the participants used only the app and no wearable device); the dependent variable was the exercise frequency. According to the mean data of exercise frequency, due to the lack of wearable hardware intervention between the intervention stage and post intervention stage a, the exercise frequency of participants decreased by 0.9 times.

Thirdly, compared with the baseline stage (5.1 times), the average frequency of post intervention stage B (5.8 times) increased by 0.7 times, which was a 13.7% increase over the baseline stage.The dependent variable was the exercise frequency.There was no intervention between the baseline stage and post intervention stage B. However, the participants' exercise frequency increased by 0.7 times. It can be seen from the average data of exercise frequency that the participants in phase B did well in maintaining exercise frequency after the intervention.

### 5.1.4 Discussion on the Quantitative Data Analysis

The first of the three hypotheses of this study is that by using the full system of interventions, participants show significant improvements in average exercise frequency, the average duration of exercise per day. This effect was particularly reflected during the intervention stage when the whole system had a significant effect on the participants' motivation to exercise.

The comparisons in Figures 5.6 to 5.8 confirm the second hypothesis, which is that the average exercise frequency, the average duration of exercise per day all indicate that the wearable device (hardware component) has an important role to play in the overall system.

Finally, by analyzing the baseline stage and post-intervention stage for Group B, the results in terms of average exercise frequency, average daily exercise duration show that the participants still exercise more than they did during the baseline stage.  Thus, the whole system had a role in maintaining the participants' exercise level. In summary, the quantitative findings suggest that the system had a positive effect in encouraging participants to exercise more.

## 5.2 Results of Qualitative Data Analysis

The participants were interviewed to understand the impact of the entire system on the encouragement of exercise and what the implications of the entire system are in terms of maintaining exercise for the users. At the same time, this qualitative data can provide evidence of the participants' acceptance and conformance to the system, compensating for the small sample size in the quantitative study. The researcher imported all interview transcripts into NVIVO software, categorized all transcribed texts into relevant themes, and conducted a thematic analysis. Following the qualitative analysis, the quotes were categorized into two themes: how the whole set of systems impacted on encouraging exercise; and what is the impact of the individual system components to health exercise level. For ease of comprehension, the results of the qualitative data were made into the following charts by the researcher.

### 5.2.1 Impact of the System on Encouraging Exercise

Quantitative analysis shows that the whole system of interventions was effective in increasing the participants' physical activity levels. According to interview responses, the suite of interventions led to a significant increase in the frequency and duration of exercise beyond the participants' previous level of exercise. Most participants perceived the intervention week to be positive and reported significantly better exercise status and a significant increase in their weekly exercise frequency and duration. These findings are elaborated below in two aspects.

#### 5.2.1.1 Frequency and duration of the exercise

The interview data indicated that the system was effective in encouraging exercise by significantly increasing the frequency and duration of exercise, which promoted physical activity among the participants. The system increased the participants' awareness of fitness and motivated them to change their original exercise status. The majority of participants during the benchmark stage indicated that they were less satisfied with how often they exercised each week and how much time they spent exercising each time, and generally felt a lack of motivation to go to exercise, i.e., participants barely went to exercise or spent very little time exercising. For example, one participant (S7) reported exercising very little each week: "Barely exercising, currently working as a PR manager in my company. I exercise twice a week, each exercise will last about 15 minutes, I am busy with my daily tasks and I get off work late, so I exercise very little." Another participant (S2) stated, "Hardly ever exercise because I am too busy studying on weekdays, I might go shopping on Saturdays and Sundays, that should be the only exercise I do." A participant (S10) stated, "I exercise about once or twice a week. I will do about 10 minutes each time. Most of the time I have to work, and after work, I want to rest." Figure 5.6 summarizes the qualitative themes during the benchmark stage.

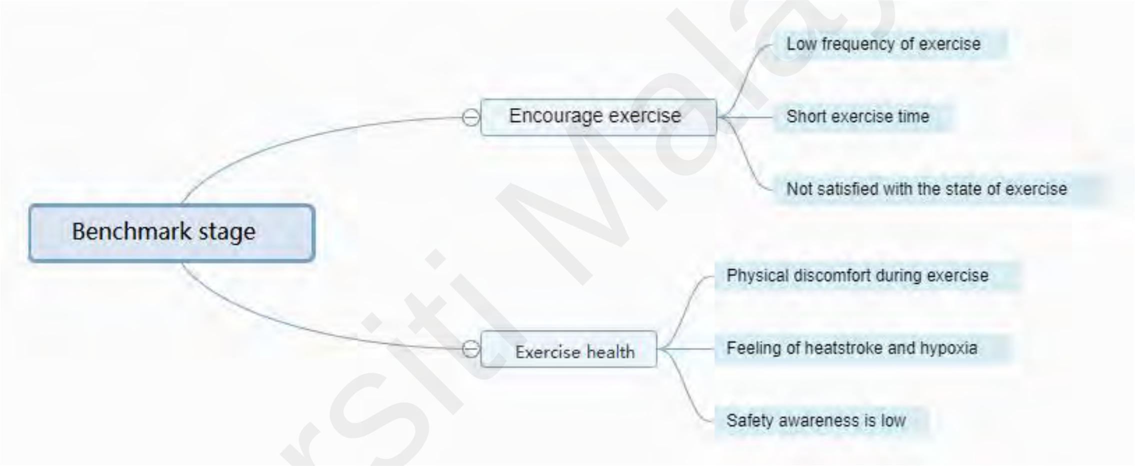


**Figure 5.6: Summary of themes during the benchmark stage.**

However, all 10 participants performed well during the intervention stage and showed significant improvement both in terms of frequency of exercise and the amount of time spent on each exercise session. For example, one participant (S1) reported a significant improvement in the duration and frequency of exercise during the intervention stage. "The frequency of exercise and the time per exercise has improved significantly after using the system. Before, it was basically just three times a week and it was only 10 minutes each time. Now I can exercise five times a week for 20 minutes each time, and the app shows me my daily exercise data and I feel exceptionally good."

Another participant (S7) stated, “Exercised significantly more in the last two weeks than a while ago. Now able to exercise 4 times a week, significant improvement after using the system, gradually breaking through.” Another participant (S8) stated, “The frequency and duration of exercise per session has improved significantly after using this system. I was basically exercising twice a week, but now I can exercise about 4 times a week for 25 minutes each time. I now do running every day and I think I have fallen in love with exercise. From the above qualitative data analysis, it can be found that the system is effective in increasing the frequency and duration of exercise and promoting the participants’ physical activity. Qualitative data support the results of quantitative data. Figure 5.7 summarizes the qualitative themes during the intervention stage.

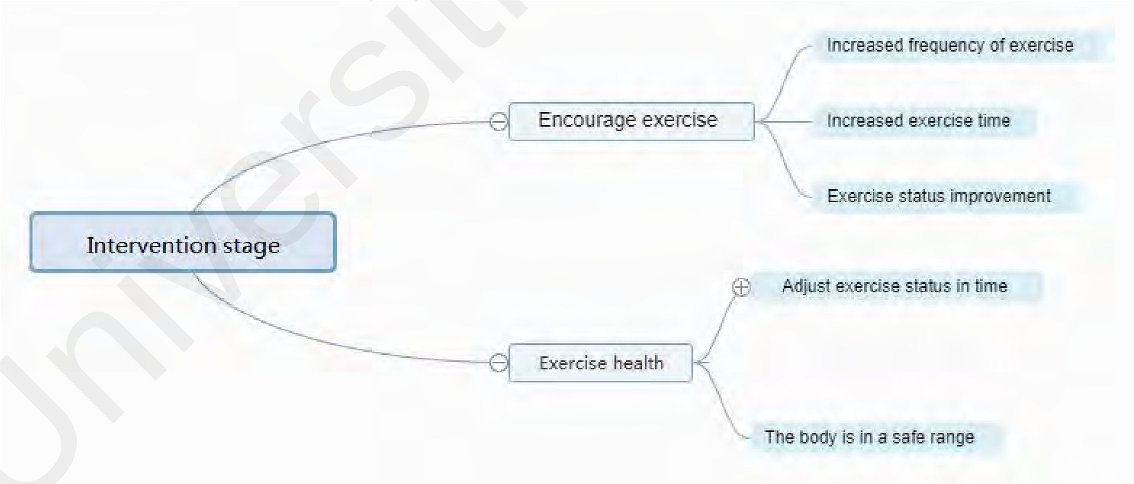


**Figure 5.7: Summary of themes during the intervention stage.**

The whole system of interventions can be seen to have improved the frequency and duration of the participants’ exercise over the intervention period. All five participants in the post-intervention stage for Group B also exercised well. Although the duration and frequency of the participants’ exercise decreased slightly from the intervention stage, the status of their exercise was significantly better than the baseline stage. For example, one participant (S7) stated, “Even though the two weeks are not using the system, it is still a change from the beginning, because with the two-week intervention with the system on, I still maintain good exercise habits, although the quality of exercise is not as good as when I was wearing the device, but it is higher than the initial two weeks (of the benchmark stage). My life used to be all about working every day, but now I can still run after working overtime.” Another participant (S10) stated, “Now will exercise 3 times a week, each exercise will last about 20 minutes. I still exercise every week, although the duration and frequency of exercise are not as high as the first two weeks (intervention stage). After the intervention, I find myself finding time to exercise and trying different exercises every week. I used to know I was supposed to exercise, but I couldn’t. Now I want to do more exercise.” Another participant (S5) stated, “Exercising 3 times a week for about 20 minutes each time. Now more interested in exercising than during the baseline stage and have a sense of habit-formation. Exercise status and duration of exercise has improved. Exercise is more regular now and I feel more confident about working out. Feel like I would want to exercise when I have free time.”

Interviews in the post-intervention stage revealed that the participants had basically developed an exercise habit and would want to exercise. Although not as much as the frequency and duration of exercise in the intervention stage, there has been a significant improvement in the frequency and duration of exercise relative to the baseline stage. Typically, the participants were able to exercise about three times per week in the post-intervention stage (Group B). From the above qualitative data analysis, it can be found that the participants have basically formed the habit of exercise in the post-intervention stage, and there is a good improvement in exercise state and exercise habit. The results of qualitative analysis positively support the results of quantitative data. Figure 5.8 summarizes the themes during the post intervention stage (Group B)

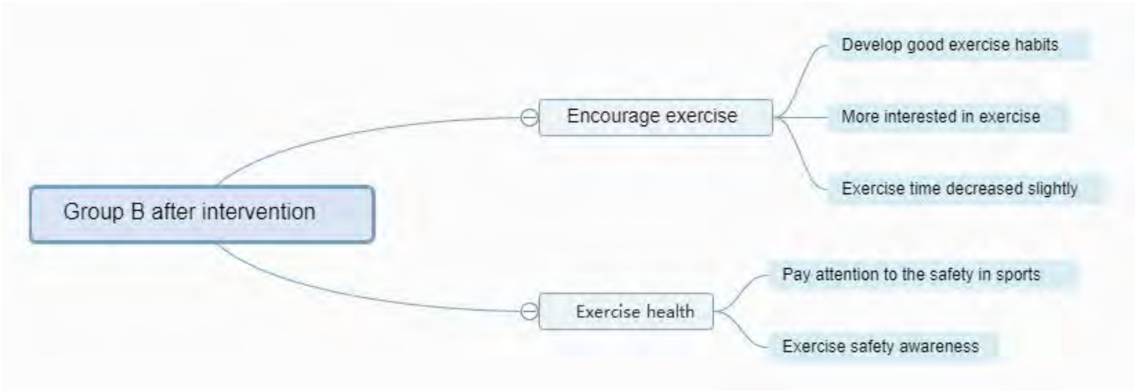


**Figure 5.8: Summary of themes during the post intervention stage (Group B).**

#### 5.2.1.2 Exercise conditions

Based on the data from the interviews, the entire system has shown to be effective in encouraging the participants to improve their exercise status. All participants during the benchmark stage indicated that they had not been using the wearable device system before and also expressed dissatisfaction with their current exercise status. For example, S1 said, “I haven’t been wearing a relevant exercise device before and I’m pretty much not exercising much per week at the moment. Not too happy with the current state of exercise. I feel that I should increase my self-discipline and try to do more exercise every week, which is also better for my body.” Another participant (S2) expressed dissatisfaction with his current exercise status: “I barely exercise and I’m not in good shape, and I always want to rest and I have no motivation. I am not satisfied with my current exercise results and feel that I should improve my exercise status properly and increase the amount of time I spend on each exercise.” Another participant (S5) also expressed less satisfaction with her recent exercise status and said that she recently wanted to try using an app that allows her to sign in and record her exercise: “I am not satisfied with my current exercise status and I would like to increase frequency of my sports and exercise. And recently considered using a sports wearable device to record my exercise, preferably for signing in and out, which would encourage me to keep exercising."

Based on the data from the interviews and questionnaires, it can be seen that the participants were not satisfied with their current exercise status and would like to exercise more and change their exercise status. The whole system could be seen to be effective in encouraging the participants to change their exercise status during the intervention stage. Many of the participants mentioned that the goal setting, message prompt, recording of exercise data, monitoring, exercise evaluation, and sign in functions of the wearable device were useful and effective in encouraging them to improve their exercise status and stay active. For examples, participant S8 said: "The whole system has had a positive impact in encouraging exercise, the sign in function, goal setting and evaluation are all very effective". Another participant, S7, said: "The exercise message prompt, goal setting and monitoring of health during exercise are very effective and encourage me to do more exercise". Another participant, S2, said, "Seeing the evaluation of the system after each exercise gives me confidence and motivation to exercise." The participants also indicated that the system kept them informed of their workouts. The participants also indicated that the system kept them informed of their workouts. For example, participant S10 said, "After using the system, I feel better. I used to exercise once a week for 10 minutes, but now I can exercise for 30 minutes every day and have started to try different exercises. I can feel my physical condition improving as I continue to exercise. The function of encouraging exercise in this system help me to keep exercising and feel that I have more energy than before."

Another participant (S9) stated that the monitoring function, rating and signing functions were effective: "I feel that my exercise time and frequency have significantly improved, I am now exercising for longer periods of time each time and I can exercise multiple times a week. The monitoring function of the system allows me to keep up to date with my body's exercises, which is more visual and (I) feel more comfortable. And the rating and sign in function after exercise are very convenient to see how I am doing on a daily basis, and I feel like I have improved my exercise." Another participant (S5) stated, "I can adjust my next workout in time based on the exercise rating, and the sign in feature allows me to keep exercising, and I feel like my body has become as young as it was in the past two weeks with the combined use (of the wearable device and app). I feel more motivated to sign in and out every day. It's very helpful for my exercise and weight loss. Whenever I feel tired and don't want to exercise trying to be lazy, just the thought of the exercising sign-in feature suddenly gives me motivation."

A participant (S7) stated, "The signing feature has allowed me to keep exercising, and the combined use of it feels like my body has become more energetic in the past two weeks. And the workout is significantly better, I really enjoy using the device's signing feature to record my workouts." Another participant (S4) also said, "the monitoring of my physical health during exercise time and exercise is very effective, it allows me to keep track of my physical activity, it is more visual, I feel more comfortable, and with the post-exercise evaluation and sign in function, it is very easy to see my daily exercise, very convenient. I think this system has changed me from someone who basically never worked out, to someone who would actively work out hard, and I would even say that this system has changed my lifestyle. Because before I barely had time to exercise, but after using this system, I would sign in and out every day and I was especially productive after each time (of workout)."

It was clear from the participants' statements that the entire system was effective in encouraging the participants to exercise more and change their exercise status during the intervention week. Interviews with the five Group A participants during the post-intervention stage revealed that although the decline in exercise frequency was small, the impact of the wearable device in the participants' exercise status and the experience was greater. For example, S1 said, "I think the software-only use had some effect on encouraging exercise, I could still sign in and out every day, and even still have a score for the exercise after each time, but I couldn't see my real-time heart rate and blood oxygen and a bunch of other body metrics during the exercise. This makes me feel like I'm slacking off at times during the workout. I think the hardware is very important in the whole system because it monitors a range of body metrics and allows me to see my body status in real-time as I'm exercising, and in a way, the hardware has a considerable impact on the status of the exercise."

Participant S9 stated, "During the period when I wasn't using the hardware device, the exercise was fine overall and I was able to work out three times a week. I was still able to sign in and out every day, but with fewer body metrics to monitor, I couldn't know if I was now in a safe state to affect my exercise status. I feel safe during exercise when I am using the hardware, but without it I feel worried about my health when I exercise, which causes me to not be able to concentrate when I am exercising." Another participant (S6) stated, "I felt like I lacked some motivation to exercise without the hardware, but overall it was still better than before when I was not using anything. I can still sign in and out, but the only difference is that I can't monitor my body and know how I'm doing while I'm exercising."

Analysis of the interviews revealed that the lack of wearables (hardware) in the post-intervention stage had a significant impact on the participants' exercise status. Hence, the importance of the wearable device in the overall system is seen - when it is missing the participants are less motivated to exercise.

### 5.2.2 Adjustment of exercise conditions and exercise health awareness

According to the data from the interview, the complete system helped participants to adjust their exercise status appropriately. The majority of participants indicated that they had not used any wearable devices before. Some participants, on the other hand, reported having experienced heat stroke but did not adjust their exercise status in time, instead of waiting until after the exercise to realize that mild heat stroke and oxygen deprivation had already occurred during the exercise. For example, one participant (S5) said, “Because the weather is hot and running is more physically demanding, sometimes I feel like I have heat stroke after exercise.” Another participant (S2) reported symptoms of hypoxia and high body temperature during exercise, “Sometimes I feel hypoxia, especially when I do exercise outdoors because the temperature is very high and I feel some uncomfortable symptoms.”

The analysis of the baseline stage revealed that most participants reported a precursor of hypoxia or heat stroke symptoms while exercising, but the participants did not adjust to exercise appropriately in a timely manner, which led to worsening of their situation, nausea, heatstroke, and other noticeable symptoms after exercise. However, during the following intervention stage, the participants were able to effectively adjust their exercise status based on the body parameters monitored by the system by using the entire system to keep their exercise. For example, one participant (S1) said, “When my heart rate was higher, I would run a little slower, and when my body temperature was higher, I would jog a little bit, rehydrate a little bit, and then jog some more when my body temperature dropped. I would watch the data and adjust my exercise intensity based on the data, and the system would also make an alert prompting me to rest in time when I was overloaded.” Another participant, S9, said that she would adjust her exercise status appropriately according to the values monitored by the system: “I’m doing running exercise and anaerobic exercise every day, and every time I exercise I can see my heart rate, blood oxygen and body temperature values in time to adjust the intensity of the exercise I do."

During the intervention week the whole system could be seen to be very effective in keeping the participants health during exercise. The participants were able to use the whole system to keep them informed about their health and adjust their exercise status in a timely manner. All five participants in Group B in the post-intervention stage were also in good exercise condition, with participants generally developing good exercise habits, being more conscious of health during exercise, and stopping to take a break when exercise became uncomfortable. Overall it appeared that the participants' exercise status was significantly better than during the baseline stage. For example, one participant (S4) stated, "The two weeks of intervention has helped me develop good exercise habits, and I am more aware of exercise safety." Another participant, S5, said, "I feel more interested in exercise and have a sense of habit formation. Exercise is more regular and at the same time, I feel more confident about fitness. I am also more concerned about healthy during exercise."

From the interviews and questionnaires conducted in the post-intervention stage, it was evident that the participants had largely developed an exercise habit and the participants showed significantly better exercise status and awareness of exercise in the post-intervention stage than in the baseline stage.

## 5.3 Summary

Results from both quantitative and qualitative analyses suggest that the system encouraged the participants to exercise more in three ways. First, the whole system encouraged the participants to exercise for longer duration per session. Second, the whole system encouraged the participants to increase the frequency of exercise. Third, the whole system led to a better exercise status, with participants moving from being disinterested in exercise and fitness to becoming physically active and developing an exercise habit.

The hardware and software developed in this study were designed to encourage exercise. Although there are already many sports bracelets on the market, such as the Desk-job system, Fitbits, iWatch, Xiaomi bracelet, etc., the features of the system developed in this research were designed for encouraging exercise based on the needs of sedentary young people, while incorporating ideas from the previous research. The system developed in this research has a set of seven features for encouraging exercise: record exercise frequency, logs exercise data, sets exercise goals, grades exercise intensity according to exercise (rewards), provides prompts for functions such as signing in, and exercise health monitoring, which is unique when compared with existing research and systems.

In addition, the past research studied the impact of the whole exercise encouraging system, this research on the other hand has studied the respective effects of the wearable device (hardware) and mobile application (software). This study has revealed the importance of the wearable device (hardware) in the suite of systems. When the participants used the app-only intervention, the effect of encouraging exercise was not as good as that of the whole system intervention. Thus, it can be concluded that the wearable device is important for encouraging exercise.

# CHAPTER 6: CONCLUSION

## 6.1 Overview and Contribution

This study has developed and investigated a system that integrates a wearable exercise monitoring device with an associated mobile application. In the case of the wearable device, it collects three parameters from the user, namely heart rate, blood oxygen and body temperature. It will then send the parameters via Bluetooth communication to a mobile app that adds various effective ways to encourage exercise mobility. The features for encouraging exercise features are persuasive message prompt (include prompt of incomplete goal), goal setting, real-time monitoring of exercise, exercise evaluation and sign in. The system uses the above features to encourage participants to exercise.

An empirical experiment was designed to test the effectiveness of the whole system in encouraging exercise by comparing data on exercise duration, exercise frequency, and other data from the participants in the baseline, intervention, and post-intervention stages. The study also investigated the importance of the wearable device (hardware subsystem) to overall exercise level, and to understand participants' retention of exercise level in the post-intervention stage.

The quantitative results indicate that, first, the whole-system was effective in improving the participants' physical activity, as their average frequency of exercise, average daily exercise duration was significantly higher during the intervention stage than during the baseline and post-intervention stages. Secondly, through the post-intervention stage, Group A has shown that the wearable device has an important role inoverall physical activity, as they performed significantly lower on average exercisefrequency, average daily exercise duration, and average duration per exercise in thepost-intervention stage than in the intervention stage. Thirdly, the analysis of Group B in the post-intervention stage has shown that the participants' average exercise frequency, average daily exercise duration and average duration per exercise were all higher than during the baseline stage.

The qualitative findings indicate that, first, the intervention system enabled the participants to significantly increase their exercise frequency and duration beyond their original exercise level. The whole system provided tracking of their health and physical activity. Second, the lack of hardware monitoring of the system had a considerable impact on the participants' exercise status and experience, suggesting that the wearable device has an important role to play in encouraging exercise. Third, the participants basically developed an exercise habit after the intervention, and there was already a significant improvement in the frequency and duration of exercise relative to the baseline stage.

Firstly, the contribution of this research in software engineering design is mainly that this design is developed in strict accordance with user needs. This research defines the objectives of the system design, and develops a system with functional suitability, effectiveness, modularity, and reliability. In the system design, software app and hardware wearable device are controlled by appropriate processes respectively. In terms of hardware wearable device, STM32F103 embedded motherboard is used as the core to control the work of body parameter acquisition sensors, and wireless Bluetooth technology is used to establish an interface with the Android-based app for communication. The data collected by the sensors are wirelessly transmitted to the software app through Bluetooth to obtain the advantage of software and hardware integration.

A system architecture is established in the app design, which organizes the code by separating business logic, data and interface display into respective components. While improving and customizing the interface and user interaction, there is no need to rewrite the business logic. The algorithms and time-consuming tasks are placed in the logic layer. At the same time, the system has a unified visual style in the presentation layer. The layout achieves consistent visual effect. The whole system adopts this design with low coupling. Each layer can be well separated to reduce the interaction between module codes. Due to low coupling, the code is extendable for modification while reducing the occurrences of bugs.

## 6.2 Achievement of Objectives

Youth are now more likely to sit in front of a screen than go out for exercise. Therefore, this study focused on a group of young adults between 15 and 30 years old, who were encouraged to do more exercise. The analysis of the data from the baseline and intervention stages exhibits the significant intervention effects of the integrated system. Some participants were not interested in exercise during the baseline stage, but the participants' exercise duration and frequency increased after the intervention, even in the absence of the mobile apps and/or the wearable device. The analyses confirm that this study has accomplished its objectives, which are:

1.To develop an integrated system comprising an exercise monitoring wearable device and an exercise encouraging mobile application.

2. To evaluate the effectiveness of the developed integrated system in encouraging exercise among young people.

3. To study the importance of the exercise monitoring wearable device in encouraging exercise.

4. To study the effectiveness of the system in encouraging young people to maintain their active lifestyle in the absent of the system after the system had been used for a period of time.

## 6.3 Limitations and Future Work

This is an exploratory study to investigate whether a system that integrates a wearable device with a corresponding exercise encouraging mobile app could be effective in encouraging young people to exercise more. The study also aims to understand the importance of the wearable device in encouraging exercise, and the participants' retention in exercise level after intervention.

These findings may need to be interpreted with caution due to the following limitations. First, this study was conducted in a six-week experiment in which volunteers participated for a relatively short period of time. A six-week experimental period may not be sufficient to demonstrate long-term behavioural change in the participants. Secondly, due to the impact of the Covid-19 pandemic, this study used a small sample in each experimental cycle which may affect the significance of the findings. Thirdly, the study focused on the Malaysian region, which may prevent the findings from being generalized to people in other countries/regions (i.e., a more diverse population). Fourthly, as the selected participants of this study were young people aged between 18 and 30 years old, the effectiveness of the campaign in groups under 18 and over 30 years of age is unknown. Fifth, there are still some shortcomings in the functionalities of the integrated system for further enhancement.

To this end, future improvements could be made in these aspects:

1. For the sample and duration of study:
    a. Study a more diverse population (e.g., age groups and regions).
    b. Conduct a longitudinal study to investigate whether the integrated system results in long-term behavioural change in exercise habit among the participants.
2. For the wearable device:

    a. Improve the accuracy of heart rate, blood oxygen, and body temperature monitoring.
    b. Optimize the design to make the device smaller, select suitable packaging materials and design casing to make it more resistant to wear and tear, more comfortable and convenient to wear, and easier to maintain.
    c. Measure other physiological parameters such as blood pressure and blood glucose without significantly increasing the total cost of the device.
3. For the mobile application
    a. Study the impact of each exercise encouraging feature to changing the participants' exercise behavior.
    b. Explore new features for encouraging exercise among the participants.
    c. Study how usability of the apps affects the participants' exercise behavior.

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