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**Development of Finger Exercise Device for the Early Stage of
Osteoarthritis Patients
[Homecare Ex Gloves]**

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Abstract

In recent years, ageing population is one of the issues being discussed in Hong Kong. Osteoarthritis (OA) is a major disease burdening the elderly, the main regions of onset are knee, shoulder and finger joints. In order to perform activities of daily living (ADL) independently, finger OA is focused on this project which aims to improve or preserve finger dexterity. Among the treatments of OA, exercise is achievable with less harm on patients. From the research of OA, four exercise postures are recommended for OA patients, however, most of the current hand exercise devices are not particularly designed for OA patients. Therefore, the objectives of this project are to design and manufacture a finger exercise device for the early stage of OA elderly, and to design and edit the mobile application and website for data management. Such system utilizes technology of bend sensor, Arduino program, Android application, cloud storage and website. The exercise device is called “Homecare Ex gloves”, collecting exercise record and sending data to mobile application. The mobile application is designed for patients, as user-interface and mainly for saving data. The website is designed for medical specialists, such as occupational therapists or physical therapists. As a result, they can monitor patients’ exercise habit and send monthly report to patients. As a homecare exercise product, it facilitates development of appropriate exercise habit of patients and allows effective use of healthcare resources.

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List of Abbreviations

ADL	Activity of daily life
CMC	Carpometacarpal joint
CTS	Carpal Tunnel Syndrome
DAQ	Data acquisition
DIP	Distal interphalangeal joint
LTTP	Low Temperature Thermoplastic
IP	Interphalangeal joint
OA	Osteoarthritis
OT	Occupational therapist
PIP	Proximal interphalangeal joint
PT	Physical therapist
RA	Rheumatoid Arthritis

Chapter 1. Introduction

1.1 Project design

Ageing population is an issue in Hong Kong. The population of people suffering from ageing-associated diseases is inclining which raises demand on the healthcare service or resource. However, the healthcare resource is limited by human resources, healthcare equipment and financial support. Homecare is a new idea of providing healthcare service, such system enhances healthcare resource efficiently. Patients receive the professional support or treatment even staying at home.

Osteoarthritis (OA) is caused by wear or tear problem of subchondral bone or articular cartilage, consequently, functions of affected joint are completely or partially lost. OA can be diagnosed as two types, radiographic OA and symptomatic OA. People suffering from OA, may experience pain, swelling, inclined joint stiffness, etc. The common affected joints are knee, shoulder and hand.

Independence is one of the key components of live. Hand OA patients with low finger dexterity may not be able to perform activity of daily life (ADL). Hand allows performance of the ADL, such as dressing, eating and drinking. Patients may have low self-esteem when they are bordered from independency by OA. As a result, the focus of this project is finger OA. To preserve independence of finger OA patients, exercise is the main treatment to preserve or improve range of motion on joints. Current treatments of OA are training, surgery and medication. As the first step of OA treatment, exercise is more achievable with lower harm to the patients. Therefore, homecare exercise gloves with associated system is designed to assist exercise treatment for early stage of hand OA patients.

Homecare exercise gloves with associated system is designed to assist exercise treatment for early stage of finger OA patients. The exercise gloves are called “Homecare Ex gloves” which consist of elastic bands, bend sensors, LEDs, Bluetooth clip and Arduino board. They monitor patient’s exercise pattern, share the data to the mobile application for patient’s use and the website through the cloud for medical specialist’s use. By training finger flexor muscle strength, the joints can be protected and the range of motion can be improved or preserved.

1.2 Aim and objectives

The goal of this project is to design a finger exercise equipment for early stage of OA patients.

To achieve this aim, there are five objectives:

1. Research on information of finger osteoarthritis.
2. Design a finger exercise equipment for the early stage of finger OA patients.
3. Build a finger exercise equipment for the early stage of finger OA patients.
4. Test on the functionality of the equipment.

Chapter 2. Literature Review

2.1 Osteoarthritis

Osteoarthritis (OA) is caused by wear or tear problem of subchondral bone or articular cartilage, consequently, functions of affected joint are completely or partially lost. There are two types of OA, radiographic OA and symptomatic OA. The first one is diagnosed with the changes in joint structure or condition through observation on X-ray (Kellgren & Lawrence, 1957). Symptomatic OA patients will experience pain, swelling, deformity and dysfunction on affected joint (Zhang et al., 2002). The common joints affected by finger OA are distal interphalangeal (DIP) joints, proximal interphalangeal (PIP) joints and carpometacarpal (CMC) joint of the thumb (Stamm et al., 2002). Symptoms of OA include pain, swelling, dysfunction, deformity of joint and increment of joint stiffness (Kean, Kean, & Buchanan, 2004). The average joint stiffness of healthy CMC, MCP and interphalangeal (IP) joint are 0.15, 0.10 and 0.05 Nm/rad respectively (Cutlip Robert, Li, Wu John, & An, 2009) which are indicating the energy required to move, flex or extend fingers. From the same research, joints affected by OA have higher stiffness, about 150% to 200% of stiffness compared to healthy joints. In another word, finger flexors have to generate 5N force to flex fingers for healthy joints, however, 7N to 8N force is required for OA joints. As a result, range of motion on affected joints is limited. The fingers are not able to perform full flexion as well as natural activities of daily living by themselves.

To preserve independence of finger OA patients, exercise is the main treatment to preserve or improve range of motion on joints. It is suggested that managing OA with sequential treatment. Firstly, provide information to patients. Secondly, self-care treatment of patients, like analgesics and lifestyle modification. The last stage is non-surgical interventions or joint replacement

surgery. The second step focuses on this project. Homecare exercise gloves with associated system is then designed (Dieppe & Lohmander, 2005).

2.2 Risk factors

Generally, OA is caused by immoderate mechanical stresses from excessive movements affecting systemic susceptibility to OA which could be raised by genetic factors, age, and gender (Felson & Nevitt, 2004). In case of knee OA, figure 1 illustrates the schematic diagram of risk factors.

Figure 1 illustrates that while individual's susceptible joint causes the pathoformic factors for knee OA, mechanical factors contribute and enable the development of OA. Furthermore, joint loading which is usually generated by mechanical stress from the weight may affect the progression of OA.

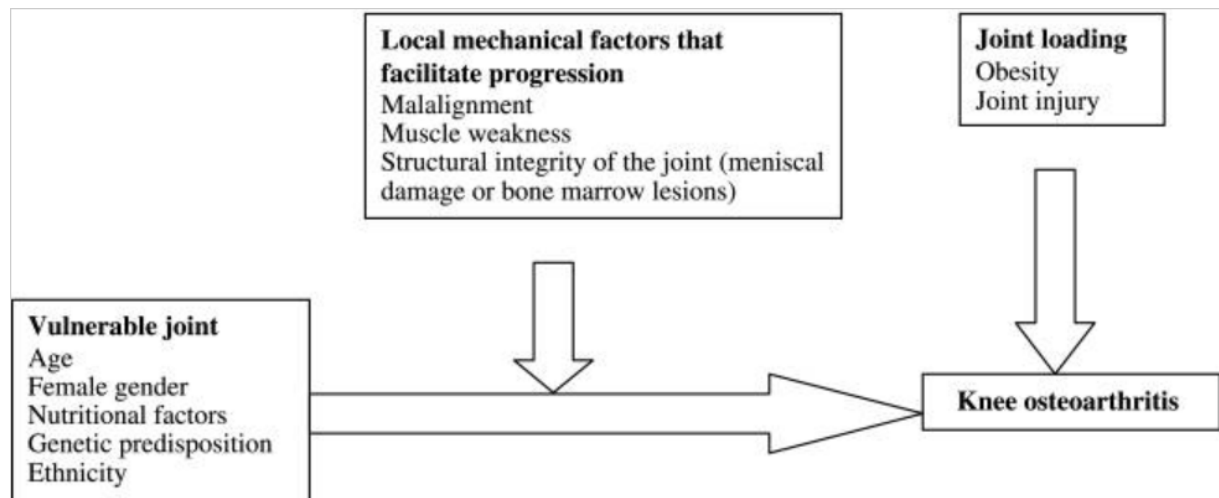


Figure 1. Schematic diagram of the risk factors for knee OA.

2.3 Epidemiology

The common patients who claim the symptoms of OA are mostly in old aged group, especially females show higher prevalence than males. The current stated incidence of OA may vary in the method of the conducted evaluation, either symptomatic or radiographic. According to National Household Education Survey (NHES), the incidence of OA on finger was 29.5% above 25 years old in the states in 2012 (Allen & Golightly, 2015). Furthermore, National Health and Nutrition Examination Survey (NHANES) also indicated that about 35% among those aged above 60

years old for both genders resulted knee OA after diagnosed through x-ray, radiography in the same year (Allen & Golightly, 2015). In case of China, the prevalence of OA showed 45% greater prevalence of OA than the states by having 22% in males and 43% in females among those aged above 60 years old (Tang et al., 2016). In addition, occurrence of OA on knee was 30% in females and 11% in males among rural population in Japan (Iidaka et al., 2016).

Knee is the most well-known area for OA to be developed. Hand symptomatic OA, however, has more prevalence rate than others, particularly for distal and proximal interphalangeal joints, and carpometacarpal joint of the thumb (Hunter & Eckstein, 2009). Furthermore, 5% of females and 3% of males have experienced functional disorder of hand due to the symptomatic hand OA (Zhang et al., 2002)

2.4 Current treatment

Figure 2 sums up the strategies for OA care and management including both pharmacological and non-pharmacological recommendations based on the National Institute for Health and Care Excellence (NICE) guidance. They are considered as primary and secondary level of treatments since joint replacements or braces and splints are seldom recommended.

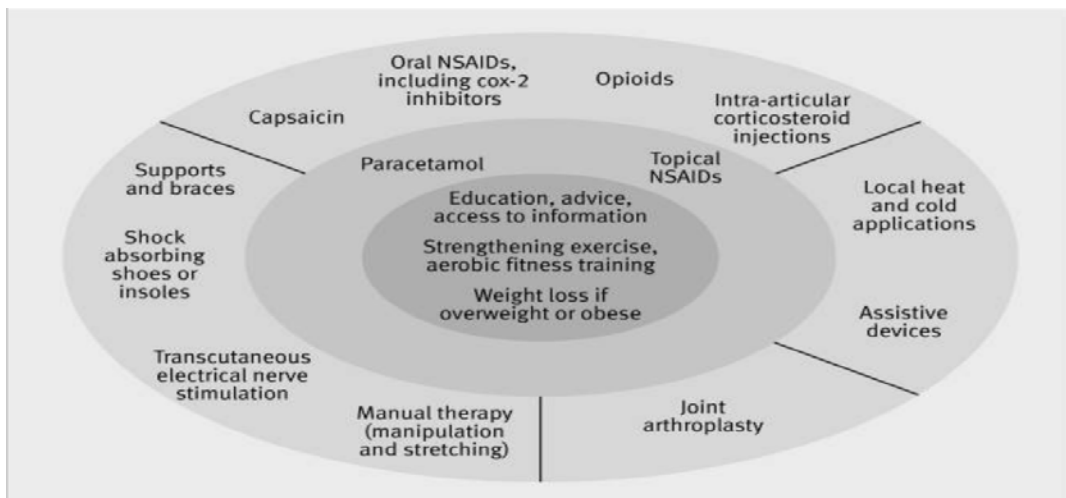


Figure 2. Treatments suggested to OA patients according to NICE guidance (P. G. Conaghan, Dickson, & Grant, 2008)

2.5 Barriers to Primary Care

Due to the continuous rising trend of the incidence of OA and economic burden following health management service, it is significant to implement primary care efficiently to restrict the use of costly treatments. However, current OA management in primary care level has several challenging issues on primary care as shown on table 1. The list of challenges was ranked by 1006 different general practitioners and only a few participants responded as they were providing optimal OA management to the patients (S. R. K. a. P. G. Conaghan, 2012). In addition, currently, there is a few statistical or analytical evidence showing the barriers and direct damage cases for OA patients with primary care. As such indirect data like survey demonstrates that mostly chronic symptomatic OA patients, early or mild, implement self-cure system instead looking for specialists' helps (S. R. K. a. P. G. Conaghan, 2012). Table 2 follows table 1 by suggesting possible strategies for provision of more effective primary treatments to OA patients.

Table 1. Challenging issues of the current OA management (S. R. K. a. P. G. Conaghan, 2012)

	Number (%) of respondents		
	Rank 1	Rank 2	Rank 3
Achieving adequate pain control	77 (33)	46 (20)	37 (16)
Lack of time in consultations	58 (25)	14 (6)	16 (7)
Getting patients to make lifestyle changes/take exercise	44 (19)	56 (24)	49 (21)
Co-morbidities related to OA	14 (6)	28 (12)	25 (11)
Assessing severity of the problem	11 (5)	16 (7)	11 (5)
Side effects	11 (5)	35 (15)	17%
Getting the diagnosis right	9 (4)	9 (4)	9 (4)
Patients not taking medication as directed	5 (2)	26 (11)	28 (12)
Communicating risk management advice to patients	0 (0)	46 (20)	9 (4)
Providing patients with adequate information/educational material	0 (0)	2 (1)	7 (3)

Table 1. Possible solutions for Table 1 (S. R. K. a. P. G. Conaghan, 2012)

	Number (%) of respondents
More time to see patients	121 (52)
Collaboration with specialist team	102 (44)
Tools to aid patient communications around risk	97 (42)
Accredited training course	81 (35)
More staff/resources	53 (23)
Not required, already managing effectively	35 (15)
Other	9 (4)

2.5 Impact

2.6.1 *Functional boundaries*

OA can limit the physical functions due to the pain and joint stiffness (Felson & Nevitt, 2004) which is common to the patients as 42.4% of those with OA have informed to National Health Interview Survey (NHIS) in 2007 to 2009 (Helmick, 2012). The major activities in which the patients are suffering are extension and flexion of the joints, and even walking and standing (Helmick, 2012).

2.6.2 *Hospitalization*

Increase in OA may increase the rate of healthcare uses as it is approximately proved in the past few years. In case of USA, there were up to 12.3 million outpatient clinic cases and 85 thousand emergency room visits due to OA. Agency for Healthcare Research and Quality (AHRQ) reported there were 921 thousand cases of hospitalization costing the mean of \$45,443 per stay due to OA related symptoms or treatments which was more than twice of the cases in 1997, 418 thousand hospitalizations. (AHRQ, 2011) Furthermore, OA took indicated fourth highest frequency of hospital diagnosis and treatment in 2009 which was 16th place 9 years ago (Wier LM, 2010). Most cases of hospitalization are extended due to the joint replacement surgery on knee and hip (Kean et al., 2004). The rate of joint replacement for those with knee and hip OA indicates rapid rise in the states by increasing 58% in 6 years, 2000-2006 (Kurtz S, 2007). In this way, there were 8.7 surgery cases per a thousand medicare beneficiaries in 2006 (CDC, 2009). Nowadays, however, the joint replacement procedures are performed for middle aged groups, 45-64 years old and the number of cases is still increasing (Murphy et al., 2011).

2.6.3 *Death rate*

In U.S., a slight increase in death rate has been demonstrated for those with knee OA (MC, 2008). The result from the research that the morality of radiographic OA patients had 50% higher possibilities of death than normal people without OA in females and 20% higher in males (MC, 2008).

2.6.4 Psychological anguish

Serious illness often brings further mental illness with its painful symptoms, disabilities, economic burden, and tough curative procedures. According to the study regarding burden of diseases in U.S., it was projected that 6.3%, roughly 940 hundred, of the subjects selected OA as a cause of the suffering of life due to its disability (Michaud et al., 2006). In addition, OA placed as the third most painful reason that leads to life suffering after depression and alcoholism (Michaud et al., 2006).

2.7 Exercise and OA

Performing exercise with the right posture and amount is one of the essential treatment and prevention of OA. Throughout the exercise, mechanical stress can be reduced, the range of motion can be improved, stiffness can be prevented by remaining the elasticity of the cartilage and pain can be relieved by strengthening the muscles around the joint (Ettinger WHJ, 1997) (Bennell KL, 2005). Aerobic exercise programs are highly recommended to OA patients (Roddy et al., 2005). As such, walking, rowing machine, water aerobics, cycling, etc. are low impact but helpful without potential damages to OA patients for strengthening the joint muscles at the same time which is beneficial to OA patients (Hunter & Eckstein, 2009).

It is significant to personalize the exercise program for each OA patient because different patients have different resistance of loading depends on their OA stage. Journal of the American Geriatrics Society stated that to provide the appropriate therapeutic exercise program to the patients, suitable advice and tutoring session should be promoted ("Exercise prescription for older adults with osteoarthritis pain: consensus practice recommendations. A supplement to the AGS Clinical Practice Guidelines on the management of chronic pain in older adults," 2001). Besides, recording and monitoring scheme should be designed to accurately estimate the improvement and avoid the long-term consequences such as adherence (Hunter & Eckstein, 2009). Similarly, OA patients should consider their acceptance of the amount and duration of exercise under specialist's consideration in order to encourage the long-term contribution with positive effects. As mentioned above, OA patients are highly encouraged to perform low impact exercises like aerobic exercise. Furthermore, there is a specific magnitude of forces

recommended to OA patients in their exercises of hand depends on the patient types, as table 3 illustrated (Rogers & Wilder, 2009).

Table 2. Recommended force on OA exercise treatment (Rogers & Wilder, 2009)

Patient Type	Expected Force (N) in Exercise
Beginner	8.896
Junior trained	13.345
Senior trained	22.241

Chapter 3. System Design Criteria

There are several goals that should be achieved throughout the system design. For the hardware part, the exercise gloves should facilitate users to perform finger exercise and improve the quality of homecare exercise. For example, clear instructions are provided to users during exercise, ensuring users perform correct exercise posture and suitable exercise loading is provided. The exercise posture that the system needs to detect included “Like shape”, “O shape”, “Finger Bend” and “Hold a Fist” which suggested by researcher (Kjeken, Grotle, Hagen, & Østerås, 2015). (Figure 3) During the development, the comfortability of the device, accuracy of posture detecting sensors and loading of toning band should be well considering.

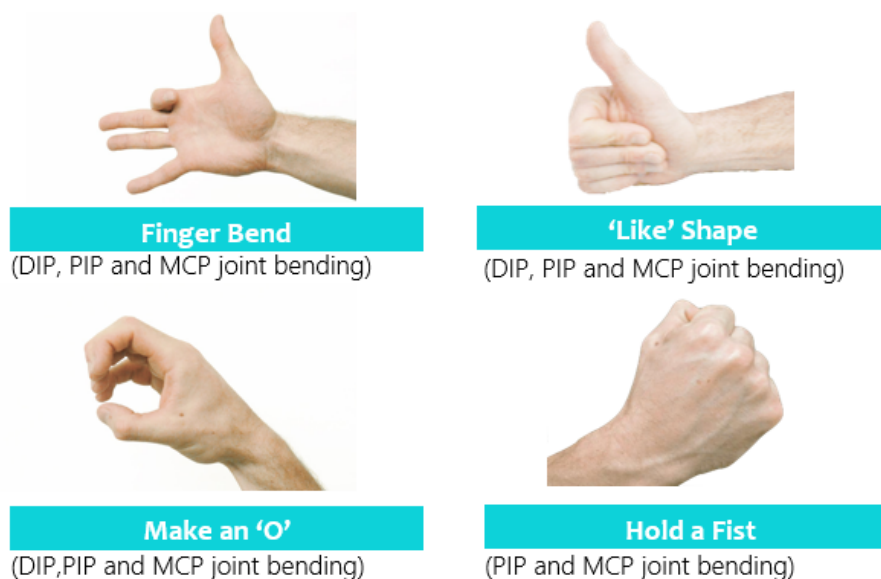


Figure 3. The recommended exercise postures

For the software part, the mobile application aims to provide a platform for users to record and review the exercise progress. The website aims to provide a convenient way for medical specialists to monitor the self-exercise progress of their patients and provide comments or supports to them. The design criteria of the software part is to develop a simple and user-friendly interface to the elderly users.

Chapter 4. Methodology

Homecare Ex Glove can mainly divide into two components, which are the exercise glove and data recording system. In the exercise glove, elastic material was used to give loading to the fingers during exercise, conductive material or sensor used to detect the exercise posture. In the data recording system, mobile application and website were developed to receive, display and store exercise data. The development progress of the device can be divided into 3 stages, which are first prototype, second prototype, and third prototype.

4.1 The first prototype

The first prototype was made up by low-temperature thermoplastic (LTTP), toning band for fitness training, metal buckles and conductive ink. LTTP sheets could be softened at around 70°C and reshaped into any shape in an easy control way, it is often used for fabricating splint. Thus, LTTP was used in the first prototype for making a wrist supporter, it could provide a basic idea about the working principle of device and fast proofing of concept. The metal buckles were used to allow users to replace broken elastic band or change to other elastic band with different loadings. Conductive ink was used as the conductive material placed on the fingers and palm, but the resistance of ink was too high to create a complete circuit for detecting exercise posture.



Figure 4. The first prototype.

4.2 The second prototype

4.2.1 Product design

In the second prototype, LTTP replaced with cycling glove. Cycling glove is softer than thermoplastic, it is more comfortable and provides greater flexibility to hand and finger during exercise. Cycling glove also provides wrist support function to prevent twisting of wrist during exercise. Smaller metal rings were used to replace the metal buckles, in order to reduce the weight of device and ensure the alignment of elastic band on the fingers. The conductive ink was replaced by aluminum foil on the index finger tip and palm, aluminum is a good conductor with lower resistance. During exercise, finger flexed causing aluminum foil scripts on the index finger and palm touch with each other to create a complete circuit. A LabVIEW program was designed to acquire the voltage of the circuit, thus the exercise posture could be detected. However, the second prototype was only designed to detect “Finger Bend” and “Like Shape” posture. The upper aluminum strip was used to detect “Finger bend” posture and the lower one is for detect “Like Shape” posture.

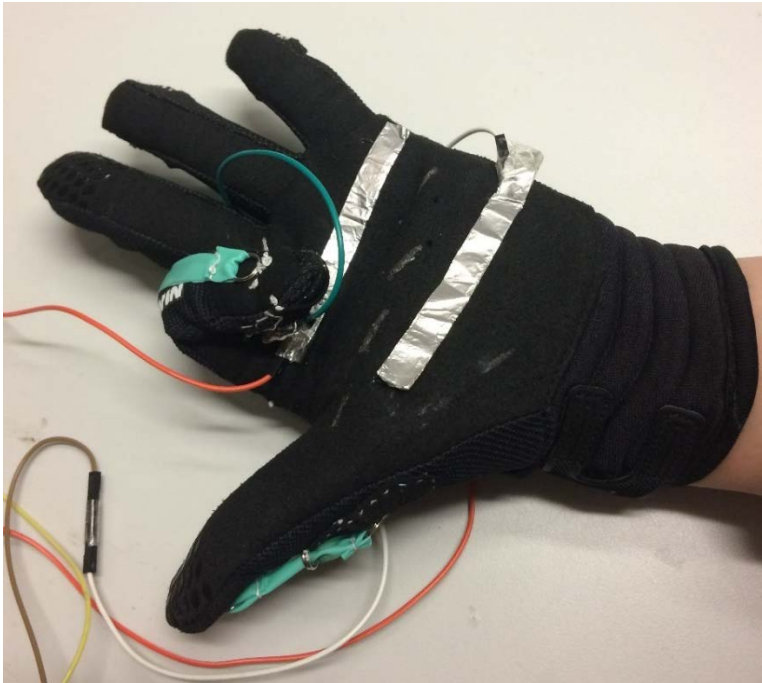


Figure 5. The second prototype.

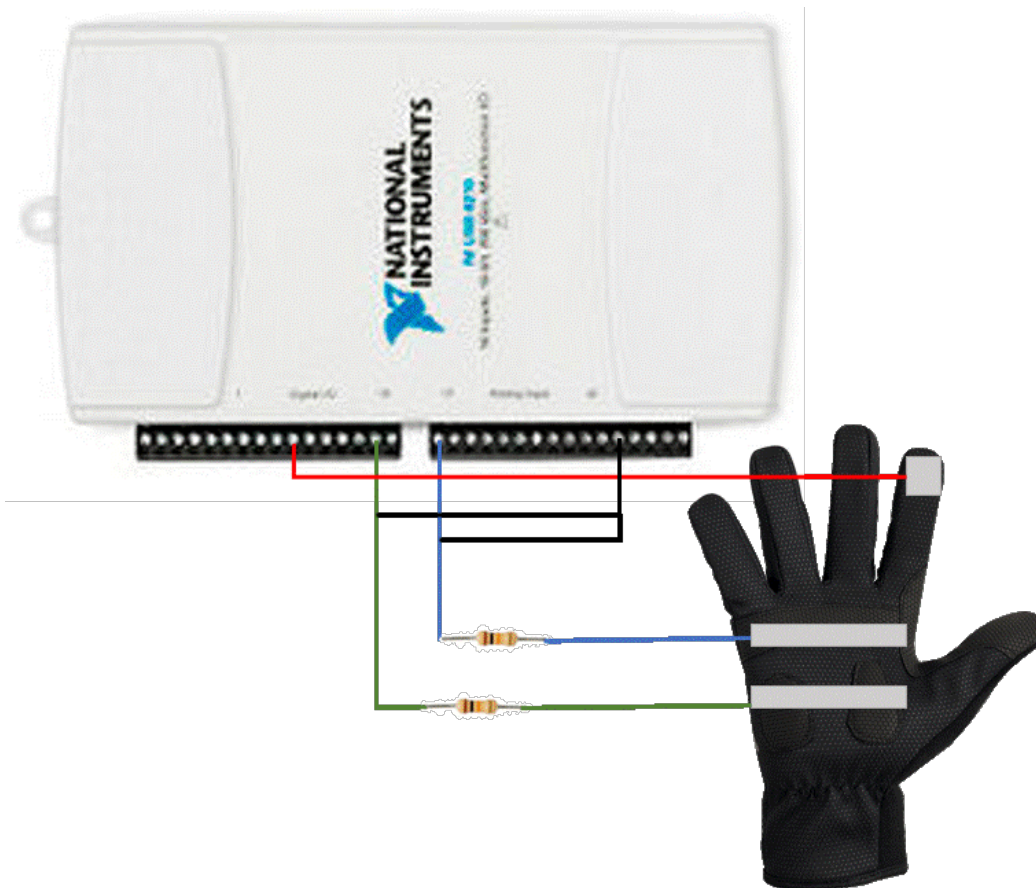


Figure 6. The connection between DAQ and exercise glove

LabVIEW is a program editor and computer-user interface with block diagram. The LabVIEW program was designed to give exercise instruction to users and acquired voltage of the circuit. (Figure 7) A signal simulator was created to simulate the standard frequency of exercise, which showed in a waveform chart. A Boolean (LED) would act as an indicator to give instruction about the exercise frequency to users. Users just need to follow the Boolean for flexing and extending their fingers. Voltage acquired by DAQ, two channels were created for measuring the voltage, which connected to the aluminum foil on palm. 5V was provided to aluminum foil on index finger. In ideal case, 5V would be detected for complete circuit (during finger flex) and 0V would be detected for incomplete circuit (during finger extend). After signal acquired by DAQ, the signal would be filtered by a moving average filter to remove noise caused by shaking hand. The voltage value would be real time displayed on the graph, in order to show the frequency of exercise. The threshold of signal detection was set to 4V. When the voltage of the circuit was higher than 4V, the Boolean will be switch on, to indicate the users performed the related posture. The number of exercise that users have done would also show in a counter and the frequency of exercise would show in a waveform chart. The LabVIEW program could also save the exercise data to an excel file.

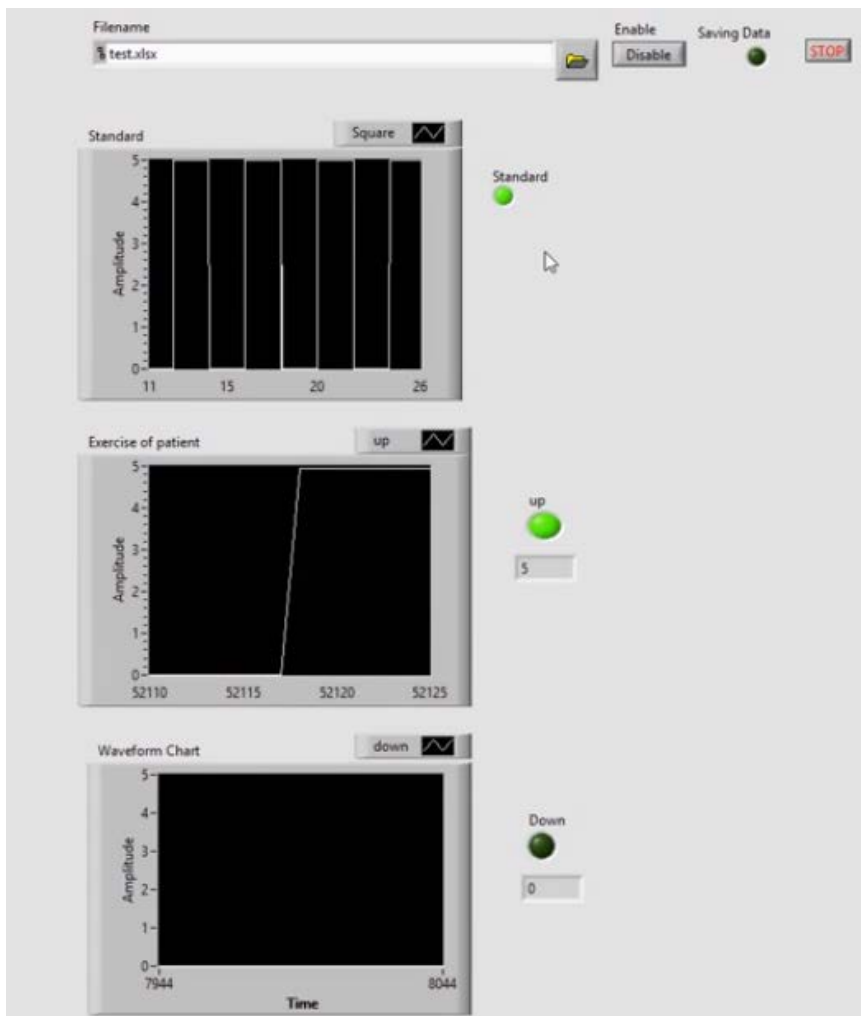


Figure 7. The front panel of the LabVIEW program.

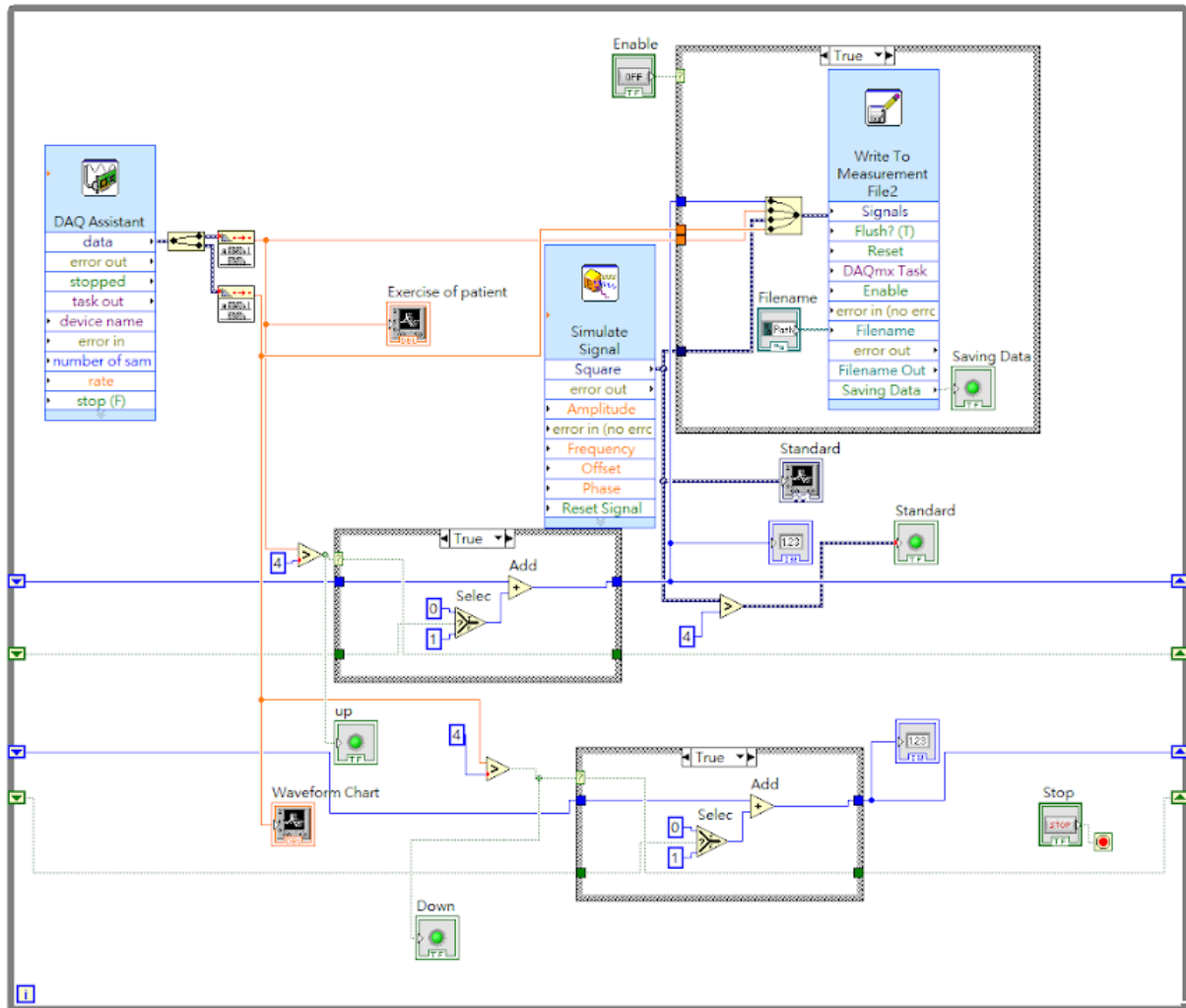


Figure 8. The block diagram of LabVIEW program.

4.2.2 Tension testing of toning band

Tension of toning bands also measured in the second prototype. The Bose ElectroForce 3220 Series III Test Instrument was used as tensile testing equipment. The machine provides high resolution on low force testing (Instruments, 2015). Therefore, it would be suitable for test on the tensile force in little material deformation. Axial tensile loading test was conducted on the toning band to find out the stress-strain curve of the material. The Young's modulus and relationship between length and tension could be known from the curve, thus the tension provided to each finger could be calculated. There were a few assumptions in the experiment. It was assumed that the width of toning bands is uniform and the stress-strain relationship of each elastic band is the same. Also, there is no shear stress created to elastic band during exercise.

4.3 The third prototype

In the third prototype, the aluminum foil was replaced by bend sensors, which put on the back side of fingers. The bend sensors used in the exercise glove are 2.2" conductive ink bend sensor produced by Spectra Symbol. Resistance bend sensor has special carbon ink printed on one side of the sensor. Resistance of the sensor increased when the ink side bend outward, vice versa when ink side of sensor bend inward (Orengo, Lagati, & Saggio, 2014). The resistance of bend sensor inclines with the degree of bending, thus the bending angle of finger can be calculated. This type of bend sensor is flexible and light, which is commonly used on measuring the bending angle and angular velocity of human joint motions (Borghetti, Sardini, & Serpelloni, 2014). During exercise, the bending angle of each finger could be measured by the sensors. Users could not cheat recording system easily by just moving two conductive materials together. Also, the bend sensors could be used to identify if the users performed the correct exercise posture. The DAQ was replaced by Arduino UNO microprocessor for receiving exercise data. For the software part, LabVIEW was replaced by Arduino program and Android-based mobile application. There are also add on function on the third prototype, which is the TinyWeb Database for storing previous exercise data and website for displaying data to medical specialists.



Figure 9. The Third Prototype.

In the Arduino UNO microprocessor, the five bend sensors were connected to the analog pins A0 to A5 and two LEDs connected to digital pin 7 and 8 for giving instruction to users about the exercise pattern and acting as an indicator about the correct exercise posture. A Bluetooth HC-06 connected to pin Rx and Tx for transmitting exercise data to mobile application (Figure 8). At this stage, only times of exercise could be transmitted to the mobile application. The bend sensor in each finger has been calibrated to measure finger bending angles in the Arduino code. (Figure 9) The resistance of bend sensor changes during bending, thus straight resistance (resistance at 0°) and bend resistance (resistance at 90°) was used to calibrate the bend sensor. It is noted that the resistance of bend sensors in each location were quite different, as the bending area of sensors were different, therefore the sensors calibrated individually after attached on the gloves. For the detection of exercise posture, the bending angle of each finger for the exercise posture has been measured for five trials. The criteria were set up, and data were set in an if-else function for identifying the correct posture and for controlling the LED and counter as well (Figure 10). As the bending angle would be deviated from different subjects, as a result calibration is needed for every user before using the product.

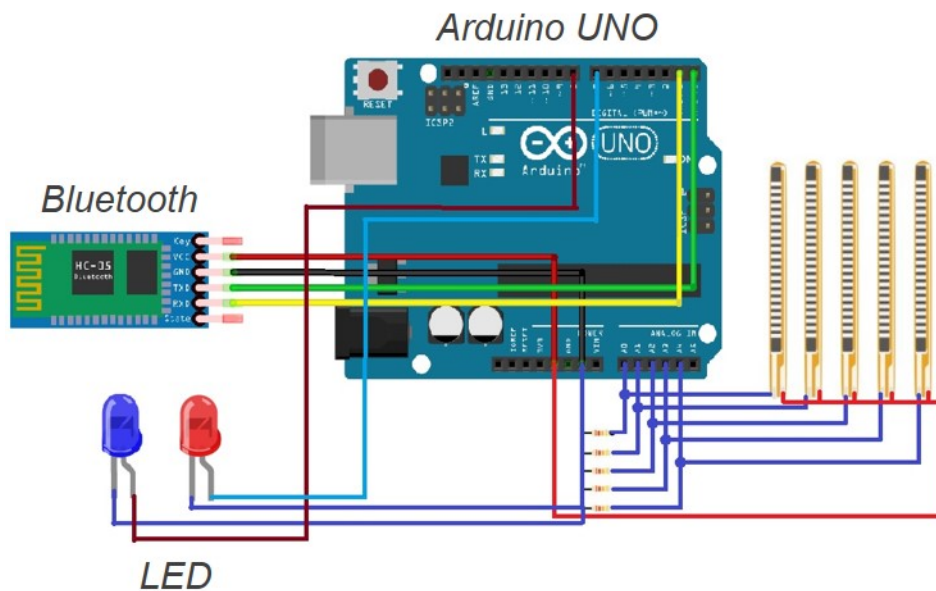


Figure 10. Arduino microcontroller circuit and pin configuration.

```

// Measure the voltage at 5V and the actual resistance of your
// 10k resistor, and enter them below:
const float VCC = 5; // Measured voltage of Arduino 5V line
const float R_DIV = 10000; // Measured resistance of 10k resistor

// straight_resistance is resistance at 0 deg
//Bend_resistance is resistance at 90 deg
const float STRAIGHT_RESISTANCE = 38700.0; // thumb
const float BEND_RESISTANCE = 92200.0;
const float STRAIGHT_RESISTANCE1 = 30400.0; // index
const float BEND_RESISTANCE1 = 64700.0;
const float STRAIGHT_RESISTANCE2 = 26200.0; // middle
const float BEND_RESISTANCE2 = 51200.0;
const float STRAIGHT_RESISTANCE3 = 24700.0; // ring
const float BEND_RESISTANCE3 = 55900.0;
const float STRAIGHT_RESISTANCE4 = 35800.0; // pinky
const float BEND_RESISTANCE4 = 45000.0;

```

Figure 11. Arduino code for calibrate of bend sensor.

```

if (angle > 60 && angle1 > 80 && angle2 > 90 && angle3 > 70 && angle4 > 75) // Hold a fist counting
{
  counterA++;
  digitalWrite(8, HIGH);
  delay(1000);
  Serial.println( String(counterA)+ "/15");
  Serial.println( "|");
  Serial.println( String(counterB)+ "/15");
  Serial.println( "|");
  Serial.println( String(counterC)+ "/15");
  Serial.println( "|");
  Serial.println( String(counterD)+ "/15");
}
else
{
  digitalWrite(8, LOW);
}

```

Figure 12. Arduino code for counting hold a fist posture as an example.

The mobile application was developed by MIT App Inventor and the website was designed by WiX platform, MIT App Inventor allows developer to develop mobile application by using block diagram. Serval programming code related to data transition is implemented into the mobile application. For the communication between Arduino and mobile application, a Bluetooth function was created in the application. In the Exercise page, when users click the “Start” button

to start the exercise, a character would be sent to Arduino to start a specific action. For example, when users click on the “Start” button of “Hold a Fist” posture, a character “a” is sent to Arduino via Bluetooth for running the code that responsible to record “Hold a Fist” exercise posture. For the data transmitting from Arduino, all data are transmitted in a string. After the string received in the mobile application, with designed decoding method, which is splitting text between “|” symbols, the data can be displayed in a readable format.

4.4 Expenses

Table 3. Cost of first prototype

Material	Cost (HKD)
Low temperature thermoplastic	50
Conductive ink	220
Metal Buckle	46
Toning Band	5
Total	321

Table 4. Cost of second prototype.

Material	Cost (HKD)
Gloves	128
Aluminum foil	32
Small rings	7
Toning band	5
Total	172

Table 5. Cost of third prototype.

Material	Cost (HKD)
Gloves	128
Bend sensors	500
Small rings	7
Toning band	5
Arduino UNO	100
Bluetooth	12
Electrical Wires	20
Total	772

Chapter 5. Results

5.1 Resistance on elastic band

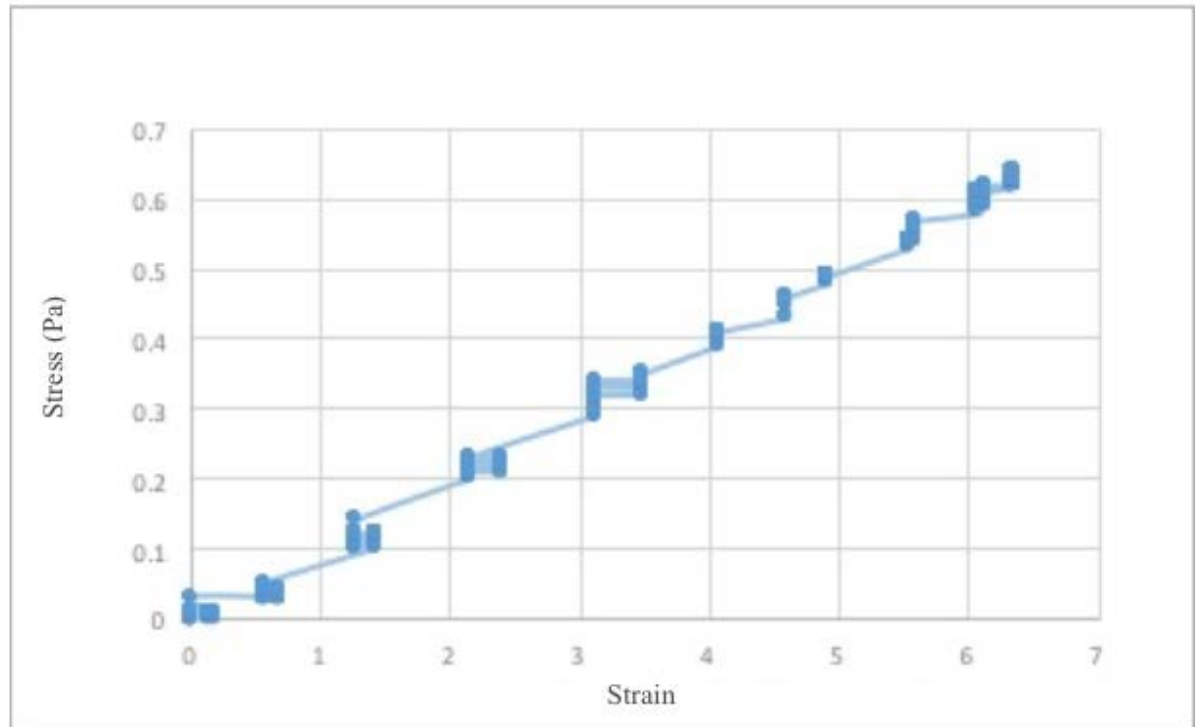


Figure 13. Graph showing the change in stress against strain of the elastic band with width of 2cm

Table 6. List of force required to extend elastic band when subject holds a fist

	Original length of elastic band = A (cm)	Length of elastic band when holding a fist = B (cm)	Change in finger length = B-A (cm)	Strain $= \frac{B-A}{A}$	Force (N) to extend the elastic band (10^{-5} N)
Thumb	4.4	6.9	2.5	0.568	11.250
Index	7.8	10.2	2.4	0.308	6.092
Middle	9	12.3	3.3	0.367	7.260
Ring	7.7	11.1	3.4	0.442	8.743
Pinky	6.1	8.7	2.6	0.426	8.439

From Figure 13, it was found that the slope of graph is 9.887, which is equal to the Young's modulus of the elastic band. The tension on elastic band is calculated as follow:

Cross-sectional area of the elastic band:

$$\frac{2}{100} \times \frac{0.1}{100} = 0.00002 \text{ m}^2$$

Force when holding a fist:

$$\text{Pressure (Pa)} = \frac{\text{Force (N)}}{\text{Area (m}^2\text{)}}$$

$$\text{Force (N)} = k \times \text{Strain (Equation 1)}$$

$$\text{Young's Modulus} = \frac{\text{Stress (Pa)}}{\text{Strain}}$$

$$\text{Young's Modulus} \times \text{Strain} = \frac{k \times \text{Strain}}{\text{Area (m}^2\text{)}}$$

Take thumb as an example:

$$9.887 \times 0.568 = \frac{k \times 0.568}{0.00002}$$

$$k = 0.198 \text{ m}$$

By calculated from Equation 1, the force for flexing of each finger can be calculated.

Table 7. The Force for flexing of each finger

	Strain	Force(N)
Thumb	0.568	0.1125
Index	0.308	0.0609
Middle	0.366	0.0726
Ring	0.442	0.0874
Pinky	0.426	0.0843

5.2 Flexing angle of different exercise postures

Table 8. The bending angle measurement and counter criteria of finger bend posture

	Trial 1(°)	Trial 2(°)	Trial 3(°)	Trial 4(°)	Trial 5(°)	Counting Criteria (°)
Thumb	-10	-4	-13	-8	-10	<1
Index	89	98	95	87	88	>82
Middle	90	111	108	90	102	>85
Ring	65	78	76	64	72	>59
Pinky	58	62	64	59	67	>53

Table 9. The bending angle measurement and counter criteria of O shape posture

	Trial 1(°)	Trial 2(°)	Trial 3(°)	Trial 4(°)	Trial 5(°)	Counting Criteria (°)
Thumb	32	23	22	32	44	17-49
Index	57	58	67	60	84	52-89
Middle	57	61	68	49	85	44-90
Ring	40	45	48	34	50	29-55
Pinky	32	38	41	32	40	27-46

Table 10. The bending angle measurement and counter criteria of hold a fist posture

	Trial 1(°)	Trial 2(°)	Trial 3(°)	Trial 4(°)	Trial 5(°)	Counting Criteria (°)
Thumb	32	23	22	32	44	17-49
Index	57	58	67	60	84	52-89
Middle	57	61	68	49	85	44-90
Ring	40	45	48	34	50	29-55
Pinky	32	38	41	32	40	27-46

Table 11. The bending angle measurement and counter criteria of like shape posture

	Trial 1(°)	Trial 2(°)	Trial 3(°)	Trial 4(°)	Trial 5(°)	Counting Criteria (°)
Thumb	-7	-12	-9	-10	-9	<-2
Index	58	56	49	62	64	44-69
Middle	30	24	25	41	31	19-46
Ring	25	30	29	31	32	20-37
Pinky	22	31	28	27	30	17-36

5.3 System design

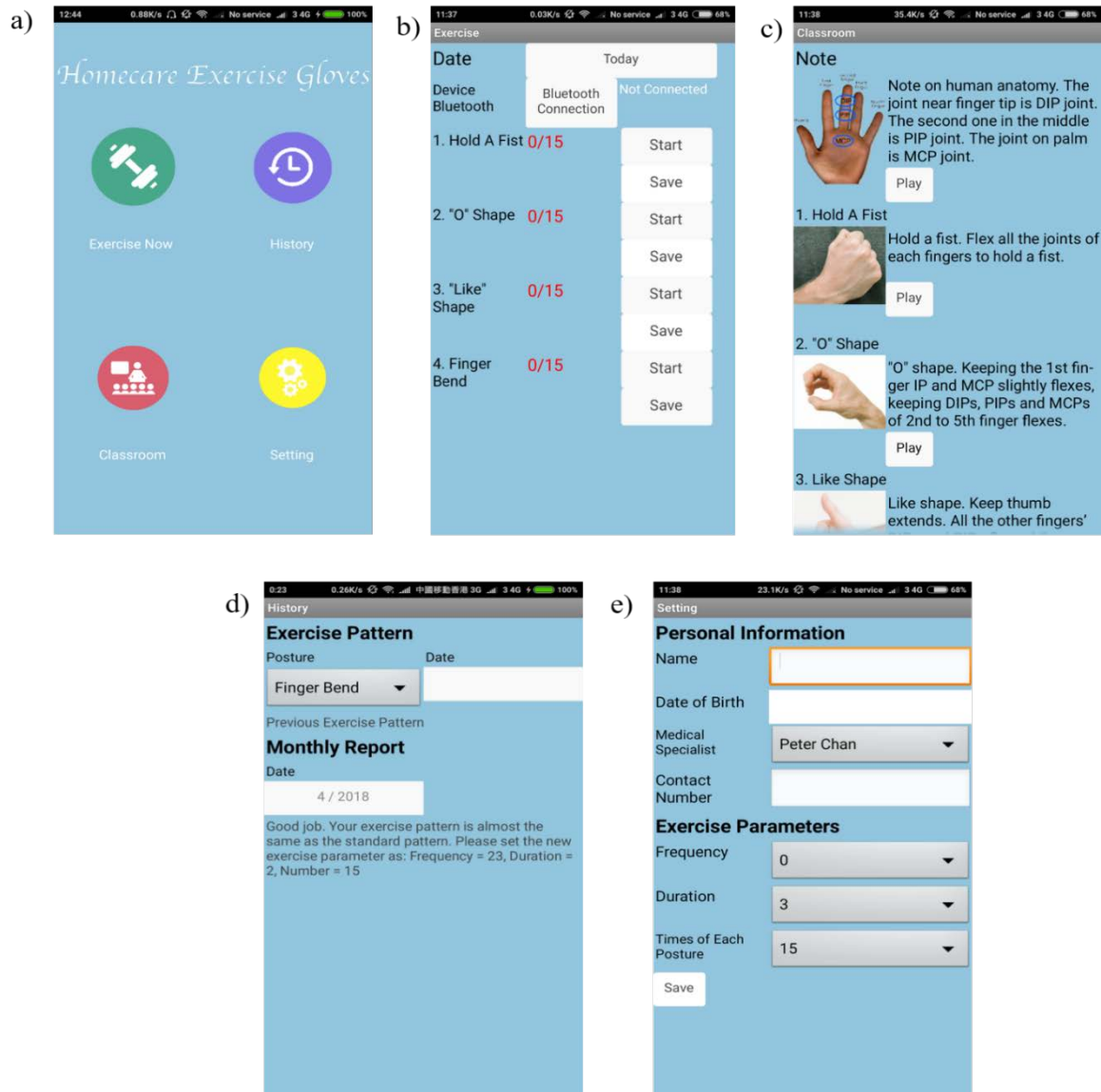


Figure 14. The screen capture of mobile application a) Home page b) Exercise now c) Classroom d) History e) Setting

a)

[Home](#)
[About](#)
[View Data](#)
[Monthly Report](#)
[Contact](#)

Hello kyliec1029
[Log out](#)

Chan
Hong Kong
Age: 60
Occupation: Housewife
Stage: 1
Present setting:
-Frequency = 10 / min
-Duration = 3s
-Number = 15

Wong
Hong Kong
Age: 63
Occupation: Housewife
Stage: 2
Present setting:
-Frequency = 11 / min
-Duration = 3s
-Number = 15

Wong
Hong Kong
Age: 63
Occupation: Housewife
Stage: 2
Present setting:
-Frequency = 11 / min
-Duration = 3s
-Number = 15

Kwok
Hong Kong
Age: 71
Occupation: -
Stage: 1
Present setting:
-Frequency = 7 / min
-Duration = 3s
-Number = 15

Chan
Hong Kong
Age: 60
Occupation: Housewife
Stage: 1
Present setting:
-Frequency = 10 / min
-Duration = 3s
-Number = 15

b)

[Home](#)
[About](#)
[View Data](#)
[Monthly Report](#)
[Contact](#)

Hello kyliec1029
[Log out](#)

Chan
Hong Kong
Age: 60
Occupation: Housewife
Stage: 1
Present setting:
-Frequency = 10 / min
-Duration = 3s
-Number = 15

Average	
Posture 1	15/15
Posture 2	15/15
Posture 3	1/15
Posture 4	0/15

Exercise Pattern

— Posture 1
— Posture 2
— Posture 3
— Posture 4

[Download](#)

Figure 15. The screen capture of website a) Example of information of patients b) Example of data displayed

Chapter 6. Discussion

6.1 Exercise counting criteria

For the criteria for each finger of finger bend posture, the greatest or the smallest value degree in the 5 trials was used and plus or minus by 5 respectively so as to minimize the error of performing the correct posture but not counting and hand shaking problem. The criteria for each finger of other postures was set as a range from the smallest value minus 5 degrees to the greatest value plus 5 degrees to prevent the same error and also to separate the criteria in different postures. This could prevent wrong counting between the four postures.

6.2 Tension measurement

Comparing the tension testing result with the recommended force on OA exercise treatment, the force provided by the elastic band is insufficient for giving loading to have exercise purpose. As tension testing did not perfectly meet the actual practice of using the product, this might affect the comparison. For the testing, it was performed by vertically pull of the elastic band. It was in a straight status. However, in the exercise, users perform exercise by flexing fingers. This causes bending of elastic band. Therefore, the tension in real situation might be different from that in the testing.

6.3 Functions of mobile application

In the exercise page, when users click on the “Start” button to start each exercise posture, the red LED on the glove will start blinking to give exercise instruction. When users perform the correct exercise posture, the blue LED will light up and the counter number will increase by 1. When users finish the exercise, data can be uploaded to the TinyWeb Database storage by clicking on the “Save” button.

In the classroom page, users can read from the descriptions to learn the correct exercise postures. To facilitate elderly’s learning, audio is used to the descriptions.

In the history page, users can review the previous exercise data by choosing the date of exercise. Users can also receive the monthly reports and comments from medical specialists to improve

their exercise progress. In the setting page, users can input their personal information, such as name, date of birth and contact number for identification by medical staff.

In the setting, the exercise parameters, such as frequency, duration and times of exercise can also be adjusted in order to provide a suitable exercise program for different users. The TinyWeb Database is used to simulate the cloud storage. The exercise data can be uploaded to the database. By inputting the date of exercise to the database, the previous exercise data can be displayed.

6.4 Functions of website

The function of the website is for medical specialists to review the exercise progress of their patients and give better treatment by analyzing the data and sending monthly comment or report to their patients. As data privacy would be an important issue, therefore a log in system has been created, medical specialists need to log in their own account to view the data.

6.5 Critical appraisal

There were positive comments from rehabilitation experts. Dr. Hu, who is one of the developer of “Hand of Hope”, believed that the product is a helpful homecare device for long-term rehabilitation service and the data collected by the system is useful for big data analysis and research purpose. The occupational therapist of Haven of Hope Causeway Bay Medical Centre, Miss Tam, also believed that it is a good product and can be further extended to target on rheumatoid arthritis (RA) and carpal tunnel syndrome (CTS) patients.

6.6 Limitations and solutions

As there is limited time to finish the project, there are some limitations which have not been improved or solved.

For the latest prototype, it can only record four exercise postures including finger bend, “like” shape, “O” shape and fist. However, there are also other postures, such as finger lift and thumb bend, which can be used to train up users’ finger joints.

Also, the motivation provided for users' long-term training is not enough. The mobile application can only store daily number of exercise of each posture. Users can only succeed in completing all exercise requirement. There is a blue LED lighting up when users are performing a correct posture. There are no animations provided as an encouragement. It is better to add games like shooting a basket or walking upstairs. If users are doing the correct posture, the animations can show the animation of shooting in successfully and get a score or get one stair up. Different levels can be designed to attract them. Rather than looking at the lightness of the LED, they can have more fun in playing games. A sense of accomplishment can be provided for long term use of the product. Adding friends with interactive functions can also be added to enhance the communication between users and keep their willingness of using the product.

Apart from motivation, the mobile application only support for android smartphones as it is written by MIT App Inventor. It is used as an intuitive and visual programming environment is better for easier catch up of function designs. For the language used in writing mobile application, Swift is used for iOS while Java is used for android. Therefore, Swift language should be tried in the future development to have an approach to iPhone users in order to enlarge the target users.

For the data storage in cloud, it is not yet tested in any common storage services. There are two major storage systems found for further improvement of our product, which are Azure and Amazon Simple Storage Services. By comparing the needs of the product, Amazon will be chosen. It is the first multinational cloud provider in China while Azure have no services provided in China. As China can be the potential countries to develop the product, Azure is not suitable in this case. For Amazon, there are multi-choices of language, tools and operating system. More professionals are relying on that service. It is also a hybrid software to prevent problems happened in third parties. To ensure the suitability for the product, there is one-year free trial with limited memory quota. Therefore, Amazon Simple Storage Service are going to be used in cloud storage.

Other than software part, there are hardware problems needed to be improved. There is a box containing all the circuit board and electric wires, which is too bulky to be a homecare product.

The finger movement may be affected. Currently, there are small circuit board which can perform the same functions as the larger one. Electric wires can also be printed in the board to prevent exposure and space occupation. All components can be hidden on the back of hand and do not affect users' exercise performance. For the bend sensors, they are now exposed, which may be damaged easily. It is better to be covered to prevent environmentally destruction.

6.7 Globalization

In 2016, there were 63 health centres in Hong Kong, which were nearly 50% of all the health facilities (DoH, 2017a). Yet, in 2017, there were only 1340 physiotherapists and 947 occupational therapists economically active in the local occupational therapy profession facilities (DoH, 2017b). Due to the great demand of rehabilitation services and lack of medical specialists for rehabilitation field, homecare rehabilitation devices would have increase trend for long-term training and monitoring. The developed product might have higher acceptance for fulfilling the needs of homecare exercise device.

For the number of health care institutions in USA, there were only 58 institutions that have achieved The Gold Seal of Approval from The Joint Commission. As the population of USA was 325.7 million (WB, 2018), which was much greater than Hong Kong, the rehabilitation services were very few although the number of health care institutions was similar to that of Hong Kong. Therefore, the product made for homecare purpose would have potential to enter the market in USA.

For the culture of using smartphone, the differences across regions might affect the product sales and user experience or outcome. As mobile application is the main feature of the product, widespread and high frequency use of smartphone is needed in that region to maintain the normal functions like data recording and friends adding. During the third quarter of 2017, smartphone shipments in Africa were 21.7 million units, which decreased by 5.5% compared with that in 2016 (IDC, 2017). It was predicted that the shipments in 2018 or later would be relatively low which would be similar to that in 2017 due to the phenomenon of slower uptake of smartphones in Africa. As a result, it is not a potential region for selling the product.

Due to the limited use of smartphones in Africa, the product design might also be affected in order to meet the demand. Other replacement such as display screen with Bluetooth connection could be used to replace the mobile application. While maintaining the functions, product price could also be considered to attract more customers.

Chapter 7. Further Development

After further modification of the product, testing on subjects will be carried out. 50 subjects with early stage of hand OA will be asked to join the test. Ethical approval will be needed. The effectiveness of using the product and user experience will be evaluated by asking their feeling, comfort and checking of finger motion and pain improvement with medical specialist. The product will be modified according to the testing result and have better direction for a marketable product.

In order to have the product in the market, the population of potential customers and product analysis are considered.

For the situation in Hong Kong, 38.1k people were suffering from hand OA in 2012 and the number people was predicted to be 67.1k after 30 years, which would increase 76% by comparing with situation in 2012 (Lee, Paik, Lim, Kim, & Gong, 2012). For the population of RA and CTS in Hong Kong, there were 0.35% (25,000) and 4% (290,000) population in 2011 and 2018 respectively (Zhu, Tam, & Li, 2011).

For the product analysis, BCG Matrix was used to clarify the merits and limitations. By considering the market in hand rehabilitation and exercise field, it was believed that the product would be placed in Question Mark area, which has high market growth with high technology. Market share, however, would be low as it is new and has focused group. Comparing the product with the existing devices such as grip strengtheners and squeeze eggs, it still has advantages of adjustable loading and suitable exercise for different users. Therefore, the proposed strategies for reaching the Star zone like “Hand of Hope” would not only getting high investment, but also having effective promotion. The product would be sold to health institutions and rehabilitation

centres. Patients could buy via these channels. Promotion of product by joining related exhibitions and advertising through websites and public displays would be considered.

To set up the price of the product, the cost of the third prototype is used for estimation for that of the final product. For the cost of the device including materials, manufacture, maintenance and service, it would be around 2 500HKD with 2 years warranty. For the cost of the website system connected to mobile application, data storage, maintenance and service would be included and estimated to be 288 000HKD with 5 years warranty. By considering the profits, the estimated prices for the device and website system would be 3 000HKD and 300 000HKD respectively.

Chapter 8. Conclusion

In conclusion, all of the objectives were achieved. At first, information of finger osteoarthritis was researched. Literatures were reviewed to understand the definition, risk factors, epidemiology, current treatment, barrier to primary care and impact of OA. After research, a finger exercise equipment for the early stage of finger OA patients was designed. With addition to technology used for the mobile application and website, homecare treatment of OA could be enhanced. For the building of the product, different materials were used to test for the most suitable one. Programs were built and modified to satisfy the needs of different functions. Lastly, the functionality of the product was proved by a number of trials. The exercise glove was used for performing exercise. The mobile application was used for users to review exercise postures, exercise record and monthly reports. Website with log-in system was used for medical specialists to monitor patients exercise and give suggestions. Calibration was required for the first use of the product. There were some limitations for the latest version of the product. Possible solutions and further development were proposed for future studies.

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Appendix

Appendix 1. The Arduino code.

```
#include <SoftwareSerial.h>
#include <Wire.h>
SoftwareSerial BTserial(0,1);
const int FLEX_PIN = A0; // Pin connected to voltage divider output
const int FLEX_PIN1 = A1;
const int FLEX_PIN2 = A2;
const int FLEX_PIN3 = A3;
const int FLEX_PIN4 = A4;

// Measure the voltage at 5V and the actual resistance of your
// 10k resistor, and enter them below:
const float VCC = 5; // Measured voltage of Arduino 5V line
const float R_DIV = 10000; // Measured resistance of 10k resistor

// Upload the code, then try to adjust these values to more
// accurately calculate bend degree.
const float STRAIGHT_RESISTANCE = 38700.0; // thumb
const float BEND_RESISTANCE = 92200.0;
const float STRAIGHT_RESISTANCE1 = 30400.0; // index
const float BEND_RESISTANCE1 = 64700.0;
const float STRAIGHT_RESISTANCE2 = 26200.0; // middle
const float BEND_RESISTANCE2 = 51200.0;
const float STRAIGHT_RESISTANCE3 = 24700.0; // ring
const float BEND_RESISTANCE3 = 55500.0;
const float STRAIGHT_RESISTANCE4 = 35800.0; // pinky
const float BEND_RESISTANCE4 = 45000.0;

//exercise counter
int counterA; //Hold a Fist
int counterB; //"O" shape
int counterC; //"Like shpe
int counterD; //Finger Bend

//standard led
int standard_led=0;
unsigned long previous_standard=0;
long OnTime1=1000; //switch on one s
long OffTime1=1000; //switch off 1s

//pexercise led
int led=0;
int exercise;

char character;

//bend sensor
int flexADC;
float flexV;
```

```

float flexR;
float angle;

int flexADC1;
float flexV1;
float flexR1;
float angle1;

int flexADC2;
float flexV2;
float flexR2;
float angle2;

int flexADC3;
float flexV3;
float flexR3;
float angle3;

int flexADC4;
float flexV4;
float flexR4;
float angle4;
unsigned long current_standard;
void setup()
{
  Serial.begin(9600);
  pinMode(FLEX_PIN, INPUT); // thumb
  pinMode(FLEX_PIN1, INPUT); // index
  pinMode(FLEX_PIN2, INPUT); // middle
  pinMode(FLEX_PIN3, INPUT); // ring
  pinMode(FLEX_PIN4, INPUT); // pinky
  pinMode(8, OUTPUT); // exercise led
  pinMode(7, OUTPUT); // standard led
  while(!Serial.available())
  {}
  character=Serial.read();
}

void loop()
{ while(!Serial.available())
{
  switch (character){
  case 'a':
  current_standard= millis();
  // Read the ADC, and calculate voltage and resistance from it
  flexADC = analogRead(FLEX_PIN);
  flexV = flexADC * VCC / 1023.0;
  flexR = R_DIV * (VCC / flexV - 1.0);
  // Use the calculated resistance to estimate the sensor's
  // bend angle:
  angle = map(flexR, STRAIGHT_RESISTANCE, BEND_RESISTANCE,

```

```

    0, 90.0);

flexADC1 = analogRead(FLEX_PIN1);
flexV1 = flexADC1 * VCC / 1023.0;
flexR1 = R_DIV * (VCC / flexV1 - 1.0);
angle1 = map(flexR1, STRAIGHT_RESISTANCE1, BEND_RESISTANCE1,
    0, 90.0);
flexADC2 = analogRead(FLEX_PIN2);
flexV2 = flexADC2 * VCC / 1023.0;
flexR2 = R_DIV * (VCC / flexV2 - 1.0);
angle2 = map(flexR2, STRAIGHT_RESISTANCE2, BEND_RESISTANCE2,
    0, 90.0);
flexADC3 = analogRead(FLEX_PIN3);
flexV3 = flexADC3 * VCC / 1023.0;
flexR3 = R_DIV * (VCC / flexV3 - 1.0);
angle3 = map(flexR3, STRAIGHT_RESISTANCE3, BEND_RESISTANCE3,
    0, 90.0);
flexADC4 = analogRead(FLEX_PIN4);
flexV4 = flexADC4 * VCC / 1023.0;
flexR4 = R_DIV * (VCC / flexV4 - 1.0);
angle4 = map(flexR4, STRAIGHT_RESISTANCE4, BEND_RESISTANCE4,
    0, 90.0);

if((standard_led == HIGH) && (current_standard - previous_standard >= OnTime1))
{
    standard_led = LOW; // Turn it off
    previous_standard = current_standard; // Remember the time
    digitalWrite(7, standard_led); // Update the actual LED
    led++;
}
else if ((standard_led == LOW) && (current_standard - previous_standard >= OffTime1))
{
    standard_led = HIGH; // turn it on
    previous_standard = current_standard; // Remember the time
    digitalWrite(7, standard_led); // Update the actual LED
}

if (angle > 60 && angle1 > 76 && angle2 > 87 && angle3 > 57) // Hold a fist counting
{
    counterA++;
    digitalWrite(8, HIGH);
    delay(1000);
    Serial.println( String(counterA)+ "/15");
    Serial.println( "|");
    Serial.println( String(counterB)+ "/15");
    Serial.println( "|");
    Serial.println( String(counterC)+ "/15");
    Serial.println( "|");
    Serial.println( String(counterD)+ "/15");
}
else

```

```

{
digitalWrite(8, LOW);
}
delay(500);
break;

case 'b':
{
current_standard= millis();
flexADC = analogRead(FLEX_PIN);
flexV = flexADC * VCC / 1023.0;
flexR = R_DIV * (VCC / flexV - 1.0);
angle = map(flexR, STRAIGHT_RESISTANCE, BEND_RESISTANCE,
            0, 90.0);
flexADC1 = analogRead(FLEX_PIN1);
flexV1 = flexADC1 * VCC / 1023.0;
flexR1 = R_DIV * (VCC / flexV1 - 1.0);
angle1 = map(flexR1, STRAIGHT_RESISTANCE1, BEND_RESISTANCE1,
            0, 90.0);
flexADC2 = analogRead(FLEX_PIN2);
flexV2 = flexADC2 * VCC / 1023.0;
flexR2 = R_DIV * (VCC / flexV2 - 1.0);
angle2 = map(flexR2, STRAIGHT_RESISTANCE2, BEND_RESISTANCE2,
            0, 90.0);
flexADC3 = analogRead(FLEX_PIN3);
flexV3 = flexADC3 * VCC / 1023.0;
flexR3 = R_DIV * (VCC / flexV3 - 1.0);
angle3 = map(flexR3, STRAIGHT_RESISTANCE3, BEND_RESISTANCE3,
            0, 90.0);
flexADC4 = analogRead(FLEX_PIN4);
flexV4 = flexADC4 * VCC / 1023.0;
flexR4 = R_DIV * (VCC / flexV4 - 1.0);
angle4 = map(flexR4, STRAIGHT_RESISTANCE4, BEND_RESISTANCE4,
            0, 90.0);

if((standard_led == HIGH) && (current_standard - previous_standard >= OnTime1))
{
    standard_led = LOW;
    previous_standard = current_standard;
    digitalWrite(7, standard_led);
    led++;
}
else if ((standard_led == LOW) && (current_standard - previous_standard >= OffTime1))
{
    standard_led = HIGH;
    previous_standard = current_standard;
    digitalWrite(7, standard_led);
}

if (angle>17 && angle<49 && angle1>52 && angle1<89 && angle2>44 && angle2<90 &&
angle3>29 && angle3<55 && angle4>27 && angle4<46) // O shape counting

```

```

{
counterB++;
digitalWrite(8, HIGH);
delay(1000);
Serial.println( String(counterA)+ "/15");
Serial.println( "|");
Serial.println( String(counterB)+ "/15");
Serial.println( "|");
Serial.println( String(counterC)+ "/15");
Serial.println( "|");
Serial.println( String(counterD)+ "/15");
}
else
{
digitalWrite(8, LOW);
}
delay(500);
}break;

case 'c':
{
current_standard= millis();
flexADC = analogRead(FLEX_PIN);
flexV = flexADC * VCC / 1023.0;
flexR = R_DIV * (VCC / flexV - 1.0);
angle = map(flexR, STRAIGHT_RESISTANCE, BEND_RESISTANCE,
0, 90.0);
flexADC1 = analogRead(FLEX_PIN1);
flexV1 = flexADC1 * VCC / 1023.0;
flexR1 = R_DIV * (VCC / flexV1 - 1.0);
angle1 = map(flexR1, STRAIGHT_RESISTANCE1, BEND_RESISTANCE1,
0, 90.0);
flexADC2 = analogRead(FLEX_PIN2);
flexV2 = flexADC2 * VCC / 1023.0;
flexR2 = R_DIV * (VCC / flexV2 - 1.0);
angle2 = map(flexR2, STRAIGHT_RESISTANCE2, BEND_RESISTANCE2,
0, 90.0);
flexADC3 = analogRead(FLEX_PIN3);
flexV3 = flexADC3 * VCC / 1023.0;
flexR3 = R_DIV * (VCC / flexV3 - 1.0);
angle3 = map(flexR3, STRAIGHT_RESISTANCE3, BEND_RESISTANCE3,
0, 90.0);
flexADC4 = analogRead(FLEX_PIN4);
flexV4 = flexADC4 * VCC / 1023.0;
flexR4 = R_DIV * (VCC / flexV4 - 1.0);
angle4 = map(flexR4, STRAIGHT_RESISTANCE4, BEND_RESISTANCE4,
0, 90.0);

if((standard_led == HIGH) && (current_standard - previous_standard >= OnTime1))
{
standard_led = LOW;

```

```

    previous_standard = current_standard;
    digitalWrite(7, standard_led);
    led++;
}
else if ((standard_led == LOW) && (current_standard - previous_standard >= OffTime1))
{
    standard_led = HIGH;
    previous_standard = current_standard;
    digitalWrite(7, standard_led);
}

if (angle < -2 && 44 < angle1 && angle1 < 69 && 19 < angle2 && angle2 < 46 && angle3 > 20 &&
angle3 < 37 && angle4 > 17 && angle4 < 36) // Like Shape counting
{
    counterC++;
    digitalWrite(8, HIGH);
    delay(1000);
    Serial.println( String(counterA)+ "/15");
    Serial.println( "|");
    Serial.println( String(counterB)+ "/15");
    Serial.println( "|");
    Serial.println( String(counterC)+ "/15");
    Serial.println( "|");
    Serial.println( String(counterD)+ "/15");
}
else
{
    digitalWrite(8, LOW);
}
delay(500);
break;
}

case 'd':
{
    current_standard= millis();
    flexADC = analogRead(FLEX_PIN);
    flexV = flexADC * VCC / 1023.0;
    flexR = R_DIV * (VCC / flexV - 1.0);
    angle = map(flexR, STRAIGHT_RESISTANCE, BEND_RESISTANCE,
               0, 90.0);
    flexADC1 = analogRead(FLEX_PIN1);
    flexV1 = flexADC1 * VCC / 1023.0;
    flexR1 = R_DIV * (VCC / flexV1 - 1.0);
    angle1 = map(flexR1, STRAIGHT_RESISTANCE1, BEND_RESISTANCE1,
               0, 90.0);
    flexADC2 = analogRead(FLEX_PIN2);
    flexV2 = flexADC2 * VCC / 1023.0;
    flexR2 = R_DIV * (VCC / flexV2 - 1.0);
    angle2 = map(flexR2, STRAIGHT_RESISTANCE2, BEND_RESISTANCE2,
               0, 90.0);
}

```

```

flexADC3 = analogRead(FLEX_PIN3);
flexV3 = flexADC3 * VCC / 1023.0;
flexR3 = R_DIV * (VCC / flexV3 - 1.0);
angle3 = map(flexR3, STRAIGHT_RESISTANCE3, BEND_RESISTANCE3,
             0, 90.0);
flexADC4 = analogRead(FLEX_PIN4);
flexV4 = flexADC4 * VCC / 1023.0;
flexR4 = R_DIV * (VCC / flexV4 - 1.0);
angle4 = map(flexR4, STRAIGHT_RESISTANCE4, BEND_RESISTANCE4,
             0, 90.0);
if((standard_led == HIGH) && (current_standard - previous_standard >= OnTime1))
{
    standard_led = LOW;
    previous_standard = current_standard;
    digitalWrite(7, standard_led);
    led++;
}
else if ((standard_led == LOW) && (current_standard - previous_standard >= OffTime1))
{
    standard_led = HIGH;
    previous_standard = current_standard;
    digitalWrite(7, standard_led);
}

if (angle<1 && angle1>82 && angle2>85 && angle3>59 && angle4>53)// finger bend counting
{
    counterD++;
    digitalWrite(8, HIGH);
    delay(1000);
    Serial.println( String(counterA)+ "/15");
    Serial.println( "|");
    Serial.println( String(counterB)+ "/15");
    Serial.println( "|");
    Serial.println( String(counterC)+ "/15");
    Serial.println( "|");
    Serial.println( String(counterD)+ "/15");
}
else
{
    digitalWrite(8, LOW);
}

delay(100);
}
break;

case 'e':
{digitalWrite(8, LOW);
digitalWrite(7, LOW);
led=0;}
break;

```

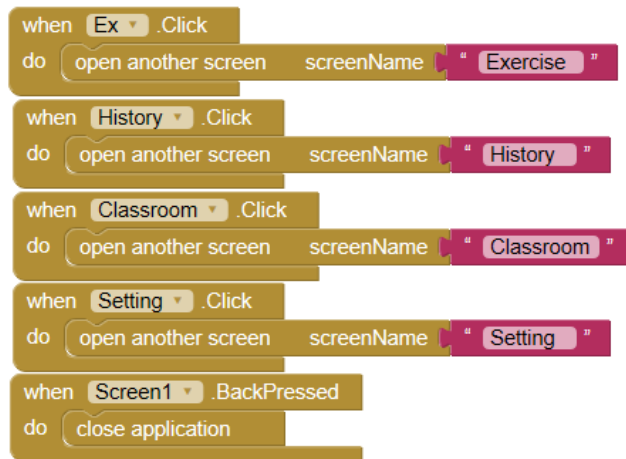
```

}
}
character=Serial.read();//read data from bluetooth
}

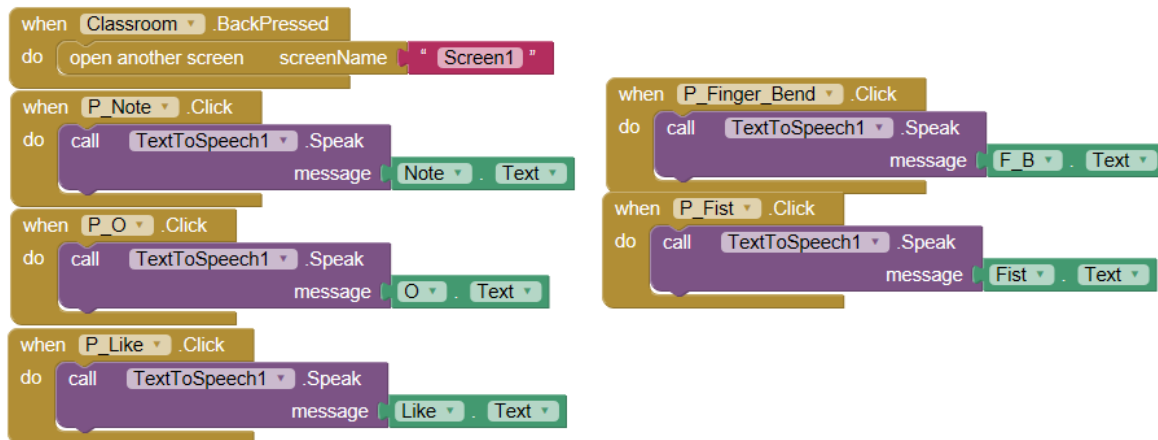
```

Appendix 2. Mobile application Block diagram from MIT App Inventor.

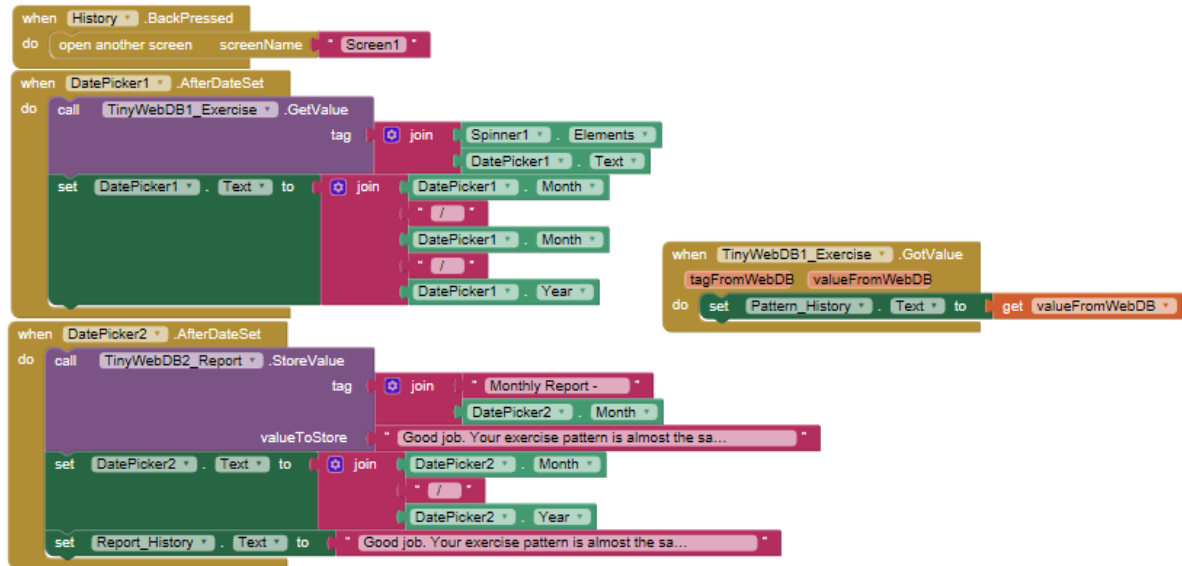
Appendix 2-1. Homepage



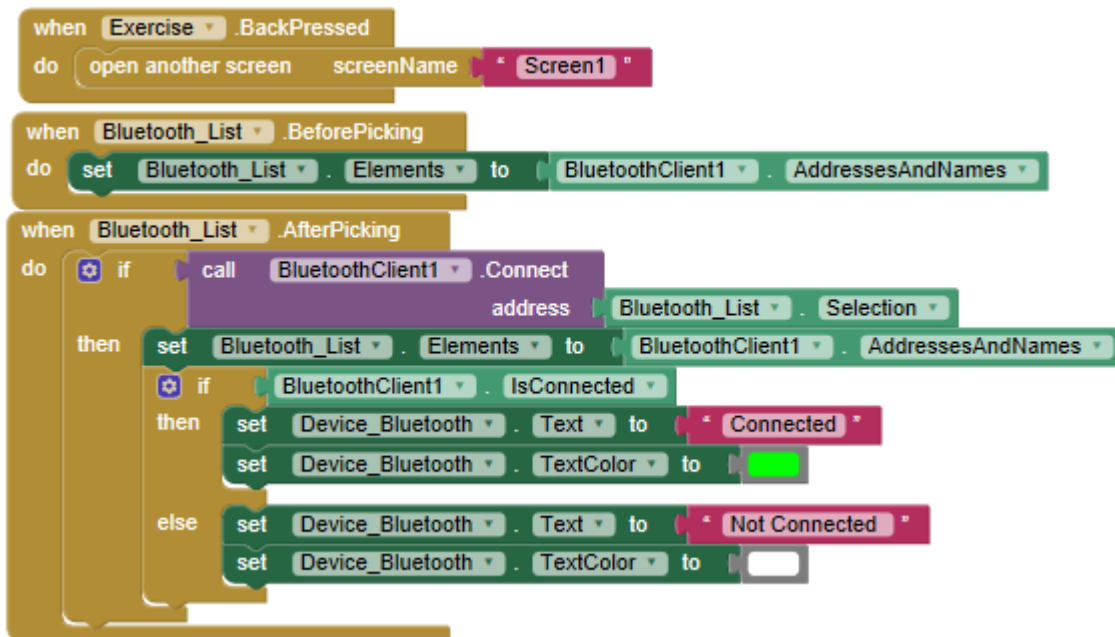
Appendix 2-2. Classroom

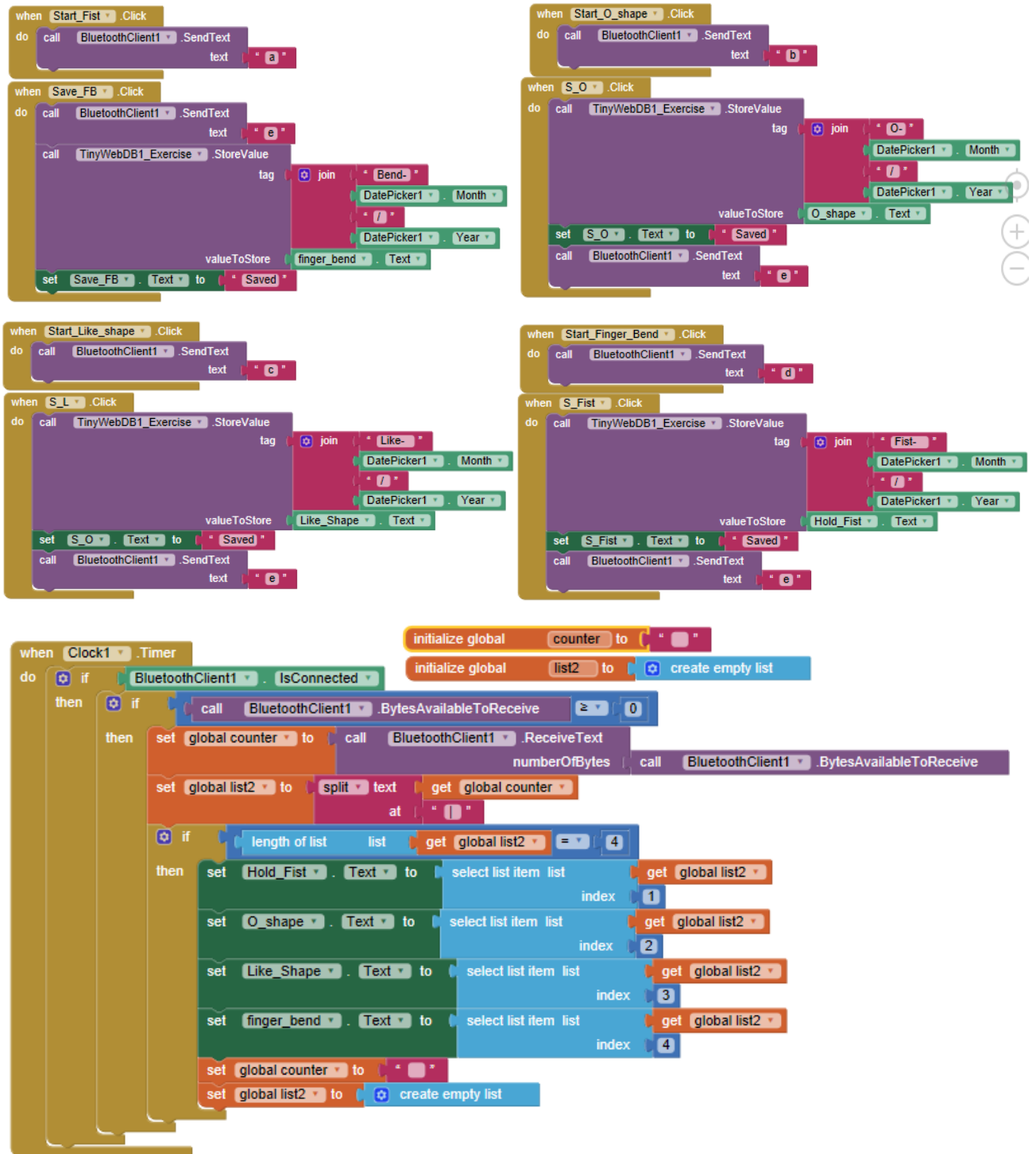


Appendix 2-3. History



Appendix 2-4. Exercise.





Appendix 2-5. Setting

```

when Setting .BackPressed
do open another screen screenName Screen1

when Setting .Initialize
do
  set Set_Medical . Elements to make a list
  Peter Chan
  Sally Wong
  Apple Lee
  Bob Yuen

  set Set_duration . Elements to
  0
  1
  2
  3
  4
  5
  6
  7
  8
  9
  10

  set Set_Number . Elements to
  0
  1
  2
  3
  4
  5
  6

```

0
Varnings

```

when Save .Click
do
  call TinyWebDB1 .StoreValue
  tag Name
  valueToStore Patient_Name . Text

  call TinyWebDB1 .StoreValue
  tag Birth
  valueToStore Birth . Text

  call TinyWebDB1 .StoreValue
  tag Medical
  valueToStore Set_Medical . Selection

  call TinyWebDB1 .StoreValue
  tag Tel
  valueToStore Tel . Text

  call TinyWebDB1 .StoreValue
  tag Freq
  valueToStore Set_Frequency . Selection

  call TinyWebDB1 .StoreValue
  tag Duration
  valueToStore Set_duration . Selection

  call TinyWebDB1 .StoreValue
  tag Number
  valueToStore Set_Number . Selection

  set Save . Text to Saved

```

```

  7
  8
  9
  10
  11
  12
  13
  14
  15

  set Set_Frequency . Selection to 20
  set Set_duration . Selection to 3
  set Set_Number . Selection to 15
  set Set_Frequency . Elements to
  make a list
  0
  1
  2
  3
  4
  5
  6
  7
  8
  9
  10
  11
  12
  13

```

0
arnings

```

when Set_Frequency .AfterPicking
do set Set_Frequency . Text to Set_Frequency . Selection

when Set_Medical .AfterPicking
do set Set_Medical . Text to Set_Medical . Selection

when Set_Number .AfterPicking
do set Set_Number . Text to Set_Number . Selection

when Set_duration .AfterPicking
do set Set_duration . Text to Set_duration . Selection

when Patient_Name .GotFocus
do set Patient_Name . Text to

when Birth .AfterDateSet
do
  set Birth . Text to
  join Birth . Day
  Birth . Month
  Birth . Year

```

Appendix 3. Meeting minutes

