Designing a wearable interaction system to improve teenagers’ sitting posture

Supervisor Marco Ajovalasit

Author ZHOU Xin

Student ID number 10736585

POLITECNICO
MILANO 1863

Academic Year 2021/2022

ABSTRACT

The health problems of young people are continuously getting serious. Due to their schoolwork and long-time computer use, teenagers have longer time in sedentary behavior. It is obvious that bad sitting postures are harmful for their health, for example, they may lead to nearsightedness, scoliosis, etc.

There are various ways to help teenagers to keep good postures, methods like wearable technology based on IMUs, or computer vision technology based on cameras have been widely explored. Smart textile sensing technology is one of the fields that has developed rapidly in recent years. Smart textiles have the functions of electronic components and the characteristics of textile. They have great potential in the monitoring of body postures.

This thesis focuses on teenagers' sitting posture, following the approach of research through design, by identifying the problems and challenges, testing multiple textile samples, performing locations analysis, and finally propose a smart shirt integrated with six stretchable textile strain sensors. The resistance of each textile sensor will change linearly through the length change. The sensors are located at C5-T2, L1-L3 of the back, two on top of the infraspinatus and two on external oblique muscles. Together with the classification model in MATLAB, the smart shirt can distinguish bad postures with an accuracy rate of 99.1% in the algorithm stage. This thesis also proposes a feedback design and performed a wizard-of-oz field study to see how the smart shirt may help the teenagers to maintain good postures and how do the participants value the system's usability.

The testing results demonstrate the system can help the participants facilitate improving their posture in sedentary work. Besides, this thesis provides a clear way of designing a wearable interactive system based on smart textile.

ABSTRACT

I problemi di salute dei giovani attualmente sono in crescita a causa del loro lavoro scolastico e l'uso prolungato del computer. Gli adolescenti hanno più tempo nel comportamento sedentario. Le cattive posture sono dannose per la loro salute, ad esempio, possono portare a miopia, scoliosi, ecc.

Ci sono vari modi per aiutare gli adolescenti a mantenere buone posture, sono stati ampiamente esplorati metodi come la tecnologia indossabile basata su IMU o la tecnologia di computer vision basata su telecamere. La tecnologia rilevamento intelligente dei tessuti è uno dei settori che si è sviluppato rapidamente negli ultimi anni. I tessuti intelligenti hanno le funzioni di componenti elettronici e le caratteristiche del tessuto. Hanno un grande potenziale nel monitoraggio delle posture del corpo.

Questa tesi si concentra sulla postura seduta degli adolescenti, e applica la ricerca di design attraverso la progettazione, individuando i problemi e le sfide, prova di campioni tessili multipli, effettuare analisi dei luoghi, e infine proporre una camicia intelligente integrata con sei sensori estensibili in tessuto. La resistenza di ogni sensore tessile cambierà linearmente attraverso il cambiamento di lunghezza. I sensori si trovano a C5-T2, L1-L3 della parte posterior, due sopra l'inframinato, e due sui muscoli obliqui esterni. Insieme al modello di classificazione in MATLAB, La camicia intelligente può distinguere le cattive posture con un tasso di precisione del 99.1% nella fase dell'algoritmo. Questa tesi ha anche proposto un progettazione del feedback, ed ha eseguito un wizard-of-oz studio sul campo per vedere come la camicia intelligente può aiutare gli adolescenti a mantenere buone posture e in che modo i partecipanti apprezzano l'usabilità. I risultati delle prove dimostrano il sistema può aiutare i partecipanti facilitare il miglioramento della loro postura nel lavoro sedentario.

Inoltre, questa tesi fornisce un modo chiaro di progettare un sistema interattivo indossabile basato su tessuto intelligente.

Contents

Table of Contents

1 Introduction and Background

1.1 Research Background

1.2 Research Goals and Challenges

1.3 Research Methodology

2 Sitting Postures and its Detection Methods

2.1 Standards of Sitting Postures

2.2 Sitting Posture Detection Methods

2.3 Comparative Analysis of Existing Products

3 Strain Textile Sensors and Wearable interaction system

3.1 Strain Textile Sensors

3.1.1 The Definition of Strain Textile Sensors

3.1.2 The Working Principles of Strain Textile sensors

3.2 Applications of Strain Textile Sensors

3.3 The Definition of a Wearable Interaction System

3.3.1 The Concept of Input

3.3.2 The Concept of Output

3.3.3 The Input and Output Modes used in this Study

3.4 Design Method for Wearable Interaction System

4 Wearable Interaction System Design

4.1 Define the Target Users and Scenarios

4.2 The Settings of Target Sitting Postures

4.3 Framework for Wearable Interaction System

5 The Prototype Development

5.1 Textile Sensor Selection

5.2 Sensors Pattern Test on the Shirt

5.3 The Connection Test of the Sensors and the Shirt

5.4 Final Prototyping

5.5 The Classification through Software

5.6 Feedback Design and Implementation

6 Testing and Validation

6.1 Evaluation Planning of the Wearable Interaction System

6.2 User Testing of the APP Interface

6.2.1 Heuristic Evaluation

6.2.2 Usability Test

6.3 Effectiveness Test of the System

6.3.1 The Content and Procedure of the Test

6.3.2 The Result and Analysis of the Effectiveness Test

7 Conclusion and Future Development

7.1 Conclusion from the Design Research

7.2 The Interaction System's Prototype

7.3 Research Deficiencies and Optimization Points

References

Table of Contents

Chapter 1 Introduction and Background

In this chapter, an over-view of this reseach is described, including the perobIem behind-explain why the research was started, the methods applied-explain how the research was carried out, and the challenges and goals.

1.1 Background

Teenagers are in a critical period of skeletal development, and the habits formed at this stage will greatly affect later life. The World Health Organization defines the age of adolescents as 10 to 19 years old, with the character of a large change and growth for body. Research shows that adolescents sit for most time of their study life, it also shows the average daily sedentary time for children and adolescents on school days is 565.77 mins, while on rest days, the average daily sedentary time has also reached to 544.61 mins(Yang,2020). The poor sitting posture may impact their vision, bone development and sleep quality, they may even develop myopia, cervical and spinal diseases. From a physiological point of view, the human spine supports the body and takes most of the body pressure. When sitting in a correct posture, the spine maintains its natural physiological curvature, allowing the intervertebral and surrounding muscle tissue to have the most suitable pressure.

Therefore, it is essential to maintain a relatively correct sitting posture and the self-correction method has gradually become a trend. It usually works follow two steps, first, the user's sitting posture is detected by vision or sensor technology to determine whether it is correct or not, then a reminder is provided to the user to tell them to adjust and correct their sitting posture. Regarding the posture sensing technology, wearable systems have been widely explored and smart textiles show great potential with the developments of advanced materials.

This thesis developed a novel smart shirt based on strain textile sensor networks, the system is capable of detecting wrong sitting postures that teenagers tend to behave. This thesis also investigated the performance and user experience of the system, and the testing results shows the system has great potential to help the participants to improve their posture in sedentary work. More importantly, this research is following the approach of research through design, a clear method of designing interaction wearable system can be concluded from the process.

1.2 Research Goals and Challenges

The starting point of the study was the posture problems of teenagers. Through the design of sitting posture detection system, using human-computer interaction design, to help teenagers avoid bad sitting posture and develop good sitting habits. The value and contribution can be concluded as follows.

1. Sitting posture detection methods innovation

The practical results of this study bring a new solution to the existing sitting posture detection system. Compared with previous studies on sitting posture detection, this system has its advantages of comfort and privacy, which are difficult to replace. In addition, in the way of sitting posture reminder, this research has also made a supplement and innovation, which can achieve a better sitting posture reminder effect.

Compared with the detection and analysis method of video images, wearable sensor detection method has better privacy protection, portability, and collect user data all day without palace limitation. Compared with inertial sensors like three-axis acceleration sensors and other traditional hardware sensors, fabric sensors are breathable, comfortable and washable, which are closer to clothing and the way of wearing.

2. Exploring the practical value of fabric sensors

The research results provide theoretical and practical reference for the design of wearable interactive system based on fabric sensor network. In the previous system of fabric sensor network, it was biased to study the validity of detection and lacked the exploration of feedback, so it was not systematic and interactive. This study starts from the perspective of design, from the definition of user needs to the end of product testing, providing reference for the design of interactive system based on fabric sensor network.

3. Feedback modes design for sitting posture recorrection

It also provides a more specific and effective design reference for the reminder design of sitting posture correction. In the design of feedback mode, wearable hardware and mobile phone APP are combined to provide a more flexible way to remind the users. In the specific content of the presentation through a more detailed interface design to provide users with a clear posture error reminder and adjustment instructions.

1.3 Research Methodology

This research was started from the basic user needs, to develop a functional system, so multiple research methods had been applied during the process.

1. Desk Research

Since this study involves knowledge in multiple disciplines, it is necessary to collect and understand relevant knowledges. The content of each part has important reference value for the feasibility of the overall study and the rationality of the research method. At the same time, there are precedents in the industry and academia to apply similar theoretical knowledge to other design objectives, their methods and contents can be referenced. In the part of literature research, this study summarizes posture problems, design of wearable devices, and behavioral feedback, which play established the framework in the early stage of the study and guiding the design in the later stage.

2. Questionnaire survey

Quantitative research provides a reliable factual basis for this research. In the early stage of the study, the launch and later analysis of questionnaires are helpful for the study to have an effective understanding of the current situation of teenagers' sitting behaviour. At the same time, the research content in the questionaire includes the key points of wearable device design based on the acceptability of teenagers, which asked teenagers to evaluate and score the usability of wearable products they used. In this thesis, questionnaire method played as fast and effective survay method. At the same time, the questionnaire survey will also be applied to the comparative experiment method, used to explain the effect of the design data.

3. User interview method

On the basis of quantitative research, the research will need to obtain more detailed user information, so qualitative methods need to be added. In this study, it will adopt the interview method to conduct qualitative research. In the early stage of the study, it will select a part of typical target users and conduct in-depth interviews. Based on the collected questionnaires, it will have a detailed understanding of the target population's views on physical health related issues and their attitudes of wearable devices. In the later stage of the research, when the designed products and systems are tested by users, it is also necessary to understand their deep thoughts and feelings, so as to summarize the future optimization direction.

4. Comparative experiment

Research results of this thesis includes a set of designed for adolescent behaviors and habits of wearable equipment system, in order to validate the design and the corresponding generated to guide the design principles, this research will be carried out on the object being measured scene contrast experiment, through variable factors in the process of control test system evaluation. After the test, the evaluation was summarized and analyzed by means of questionnaires and scales.

Chapter 2　Sitting Postures and its Detection Methods

In this chapter, existing posture detection technologies and relative products are listed and analized through the dimensions set according to the goals of this research. It provides a clear view of the advantages and deficiencies as a reference for the design, which also further proves the value of this research.

2.1 Standards of Sitting Postures

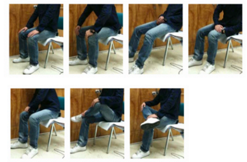
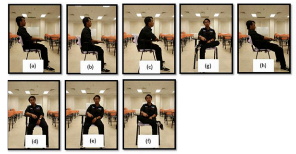
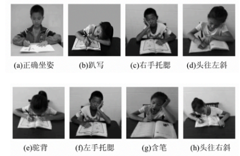
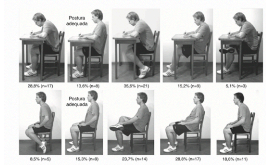
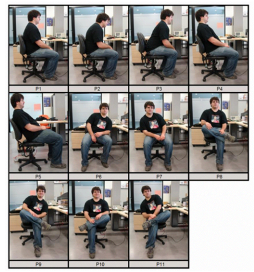
When detecting sitting postures, there are two key points needed to be clarified. The first is the sitting posture standard, which is the fundamental of the detection research, the second is the method of the detection, that is how to effectively collect the sitting posture data and how to process the collected signals to achieve accurate classification results.

In the discussion of the standard classification of sitting posture, 544 physical therapists were asked regarding the best sitting and standing postures, to select the most correct sitting posture from the professional perspective of the physical therapist. And 97.5% of the physical therapists reached an agreement that the spine perpendicular to the chair surface without bending the back is the best one (Korakakis et al, 2019).

Kamiya's experiment divided the recognized sitting position into sitting upright, leaning forward, leaning backward, leaning left, leaning right, right leg crossed, left leg crossed, and hunched (Kamiya, 2008). In Skach's research, a smart device combined with textile equipment was proposed, and it has recognized 19 different settings postures, they included not only the common setting positions, also with the hands on the laps as one type of them (Skach, 2019). Martins classified the sitting postures that may appear in office scenes into sitting upright, slounched, leaning forward, leaning backward, leaning backward without backrest, leaning left, leaning right, right leg crossed, and left leg crossed (Martins,2013).

This thesis refers to the sitting posture classification types mentioned above, and more importantly, combined with the observation of the real scenes, to determine the postures aimed to detect in this research. Because our research is more related to the teenagers' group.

Table 1. Several common classifications of sitting posture in existing studies

Detection method	Pressure sensor array seat pad	Pressure sensors for seat cushions and backrests	Image detection: feature fusion image algorithm
Application scenarios	Household scenario	Study, meeting	Adolescent writing scene
Classification			
Description	Sit up straight, lean back, lean forward, lean left, lean right, fold right leg, fold left leg	Sit straight, lean back, lean forward, lean left, lean right, Right leg folded, left leg folded, hunched	Sit right, face down, right hand cheek, head to the left, hunched, left hand cheek, pen, head to the right
Application scenarios	School learning and attending classes	Household scenario	Office Scenario
Classification			
Description	Sit right, face down, right hand cheek, head to the left, hunched, left hand cheek, pen, head to the right	Sit up straight, hunch back, lean forward, lean back, lean left, lean right, cross right leg, cross right foot, cross left leg, cross left foot, hand on leg, hand on knee	Sit up straight, hunch back, lean forward, lean back, lean left, lean right, cross right leg, cross right foot, cross left leg, cross left foot, hand on leg, hand on knee

2.2 Sitting Posture Detection Methods

In the existing systems for sitting posture detection, the methods can be divided into two video image-based detection and sensor-based detection.

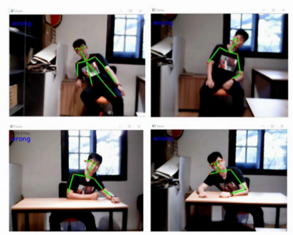
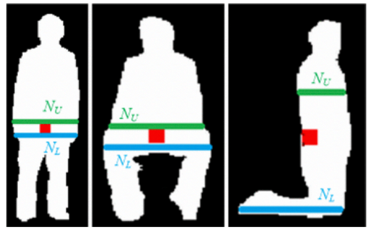
1.Video image-based detection

The detection is classifying postures by capturing user images and applying algorithms to extract key features of the human body in the images. Different algorithms correspond to different key feature extraction and classification methods, which can be summarized into two major types of feature extraction methods. The first type is to extract the human bone nodes in the image, to form the skeleton of the human body so it can classify postures. Another way is to segment and extract the contours of the human body and the background, combined with the calculation of the gravity center of the target object in the image to determine the spatial position and obtain the pose classification.

2. Sensor-based detection

Sitting posture detection methods based on sensor detection methods can be divided into seat attachment sensors and wearable sensors according to their positional relationship with the human body. Seat attachment sensors usually involves pressure sensors embedded in the seat cushion or backrest, and judging the user's sitting posture based on the pressure distribution generated by the contact surface between the user and the seat. For example, the eCushion designed by Xu et al. used an array of pressure sensors made of conductive fabric in the seat cushion to determine different types of sitting postures based on different pressure distributions. The wearable systems usually involved multiple sensors attached to specific body segments. In previous studies, inertial measurement units (IMU) were mostly used, for example, Du et al proposed a smart garment embedded two IMUs to support office workers to maintain good postures in sedentary work. While some researchers also adopted other sensing technologies, for example, SmartArse integrated pressure sensors on the pants to detect the pressure distribution to detecting the wearer's sitting posture.

Table 2. Video image posture detection methods

Classification method	Bone point extraction	Contour extraction
Schematic diagram		
Description	Key bone points were extracted to generate bone lines and the relative angles between them were calculated to judge the posture	Body and background were extracted from the contour, and the center of gravity was extracted to determine the relative position to determine posture

2.3 Comparative Analysis of Existing Products

In order to get a better understanding of the existing posture correctors, relevant products were collected and analyzed in this section, including the basic product information, its target users, detect methods, technical characteristics, and limitations, etc.

The analysis dimensions are set as the comfort of wearable devices, the usability of interactive experience, the accuracy of posture detection, and the effectiveness of posture correction.

Product 1: ComfyBrace

Fig 1. ComfyBrace posture corrector

This is an early published and most common corrector for slouch posture. The user's back can be supported by external forces to prevent back slouch. This product can be seen as a coat with a fixed back, and there is no extra interaction. Due to its low cost, it has big market sharing and users group. From the feedback of the users, we can see the overall feeling is not well due to the external force on the back, and there are certain limitations in the types of wrong sitting postures because it only functions on the upper back.

Product 2: PosturePerfect

Fig 2. PosturePerfect posture corrector

PosturePerfect adds vibration feedback on the basis of the normal corrector. It provides vibration as a prompt to remind the user. The detection module was not introduced in detail, but most likely by the IMU(Inertial Measurement Unit). Therefore, it can be considered that the product can recognize more sitting postures and thus prevent them. However, due to the physical support by external force, it still lacks of comfort. Also, the price of the product is much higher than ordinary correctors.

Product 2: PosturePerfect

UprightGo is a small digital posture corrector, which can be worn through necklace or sticking to the back. The underlying technology in wearables is the inertial measurement units (IMU), which typically consists of accelerometers and gyroscopes, and may include magnetometers. When the wearer's posture goes wrong, it reminds them by the vibration. There haven been some evaluation researches about the Upright Go, like University of Mississippi and Colombia University to investigate the use of Upright Go as a posture training tool. And their results showed the product works well.

Fig 3. UprightGo posture corrector

Product 4: LumoBack

Fig 4. LumoBack posture corrector

LumoBack is an intelligent detection belt worn on the lower back, consists of a haptic motor, microcontroller, accelerometer, Bluetooth chip and flash memory. Its algorithm normalizes and calibrates accelerometer data to be converted into angular data. Attached via a belt, the device measures the angle of the pelvis when sitting or standing with a resolution of 1°. Preliminary study findings have revealed postural score differences between asymptomatic individuals and those with low back pain (LBP) using this device. The LumoBack device has also shown acceptable test-retest reliability for the posture score and time spent sitting.

Product 4: LumoBack

Fig 5. ALEX+ posture corrector

ALEX+ is a smart wearable device that encourages good posture habits by measuring the angle of the neck. If a user’s neck bends too far into a “poor posture angle”, ALEX will gently vibrate to alert the user to correct their posture. ALEX+ is designed to lightly rest on the back of the neck with two legs hanging around the ears for support. ALEX+ has very flexible legs that can be stretched and shortened to fit any head and neck shape.

Product 6: SitAPP

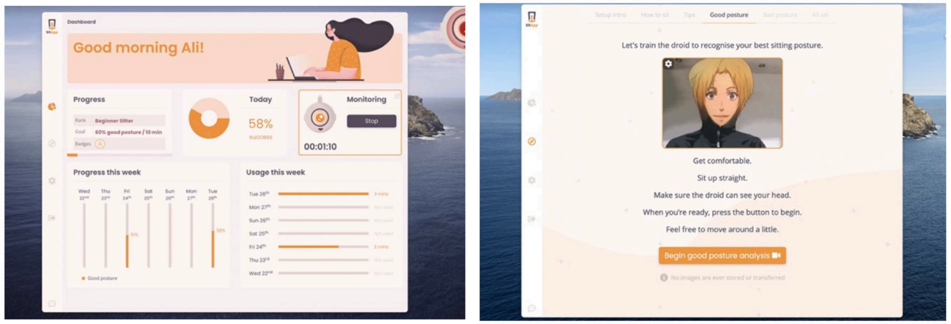


Fig 6. SitAPP desktop application

With the development of application and the needs of sitting to work for long period, an app named SitAPP was developed, it is a desktop app that monitors your posture and reminds you to sit up straight. It uses the computer's camera to capture user's sitting figures and through algorithm to see if the user is in a straight posture, it also has the recording and analysis panel to help the users understand better about their perform.

The advantage of this application is that it is not limited by hardware products. It can be installed and used on the computer without additional physical media. However, because the application relies on the UI interface for sitting posture feedback and related operations, it must rely on the computer to use, so it is more conducive to the Office population. It would be difficult to be applied in the teenagers' group and their studying context dur to its needs of computer.

Product 7: Dali Reading Lamp

Dali Lamp is an intelligent desk lamp specially designed for teenagers. It combines the screen and camera to the lamp, and it is also allowed to online communication and finding learning materials. At the same time, it uses its own camera to record and detect the user's sitting posture, recognize the bad sitting posture and remind the users by voice message, so as to achieve the purpose of correction.

Fig 7. Dali Lamp

Product 8: CZUR

Fig 8. CZUR posture corrector

CZUR is a new Intelligent Desktop sitting posture corrector. It recognizes the sitting posture through the camera and remind through voice and indicator light. According to the introduction of the official website, three types of bad sitting posture-bowed head, forward head and sinking lower back-can be detected, but the specific application technology was not introduced in detail. In terms of user experience, the product is favored by users for its convenience and intelligence. Users can simply set the detection mode of the product through the app on the mobile phone and monitor their sitting posture at the same time.

On the whole, CZUR has commercialized sitting posture detection on the basis of image recognition technology, making it highly portable, which is a great progress in user experience.

Table 3. Existing posture correctors

	PosturePerfect	UprightGo	LumoBack	Alex+	SitAPP	Dali Lamp	CZUR
Image							
Users	all	all	all	all	adults	children	all
Placement	back	Neck back	lower back	Ears	Computer	on the desk	on the desk
Detect Tech	IMU	IMU	IMU	IMU	Visual Algorithm	Visual Algorithm	Visual Algorithm
Reminder	vibration	vibration /APP	vibration /APP	vibration /APP	graphic	graphic/audio	light/audio /APP

According to the different use scenarios and use methods, the above-mentioned products on posture detection and correction can be summarized into four different types, which are Intelligent wearing device, physical external brace, desktop product and computer software. Through the collection of user comments and relevant product analysis reports, the multi-dimensional scores are given based on the comfort, usability, recognition accuracy and correction effect.

To sum up, although there are wearable clothes and devices being studied and published in recent years that can realize real-time monitoring of human posture, however, there is still much space for improvement in the user experience.

It can be seen from the observation table that the detection and correction effect of intelligent wearable devices is better than that of non-wearable products, because its feedback sense is stronger. Meanwhile, non-wearable products have better comfort.

Therefore, in the design process of this study, a balance between the comfort and the effectiveness is going to be pursued.

Table 4. Existing posture correctors categories

	Intelligent Wearable	External brace	Desktop product	Software APP
products				
comfort	●●●	●●	●●●●	●●●●
usability	●●●●	●●●	●●●●	●●●●
recognition accuracy	●●●●		●●●	●
effect	●●●	●●●	●●●	●●

Chapter 3 Strain Textile Sensors and Wearable interaction system

In this chapter, the new material as strain sensor is introduced, expaining how it works and its potential to be used. Meanwhile, wearable interaction system is defined by its key component.
Then a design method is formed to instruct the system design and evaluation.

3.1 Strain Textile Sensors

3.1.1 The Definition of Strain Textile Sensors

Strain textile sensor is one of the fabric sensors, which is a fabric electronic device, which refers to the fiber or fiber combination with the function of generating, transmitting, modulating and measuring electronics. One type is the material with electronic function that directly generates fibers, yarns or fabrics. The other is to use electronic devices such as chips in the fiber to realize fabric's multifunctions. In this thesis, the former conductive fabric is mainly used.

Conductive fabric refers to the combination of conductive material and ordinary textile so that it has electrical properties. They can be divided into metal-based materials, carbon-base materials and polymer materials according to their different substrate constructing materials. The conductive fabrics are prepared after the proper combination of these three conductive materials and fabric fibers or fabrics.

The manufacturing methods of conductive fabrics can be divided into the following three types according to the different stages of combining conductive materials to fabric.

1. In the fiber stage, conductive fibers made by metals or polymerized materials are made into yarn. Or ordinary fibers covered with conductive coating are used to make conductive yarns with other materials. And then they are manufactured into conductive fabrics by knitting or weaving .

2. In the weaving stage, conductive yarn and ordinary yarn are woven into fabrics so to make it conductive fabrics;

3. In the fabric stage, the woven fabric can be endowed with conductive properties by surface coating such as screen printing and electroplating.

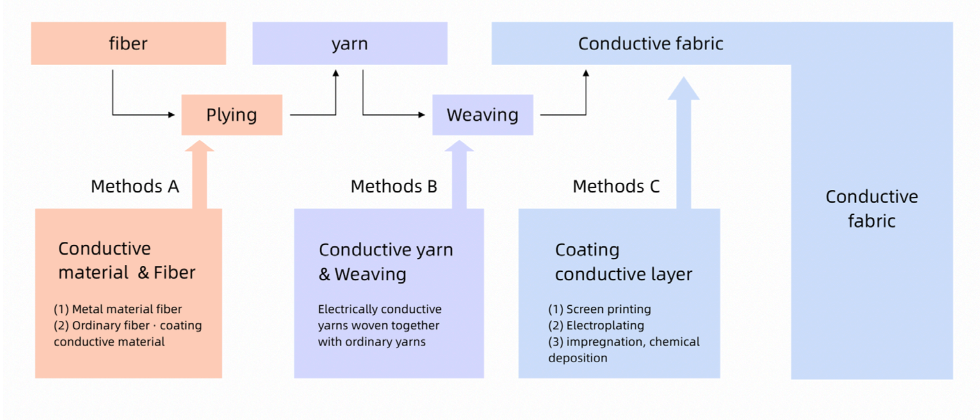


Fig 9. The manufacturing process of conductive fabric.

3.1.2 The Principles of Strain Textile Sensors

Sensor can be defined as receivers detect the signals or stimulus, and then transfer it into electrical data that can be measured with specific equipment like processing module.

According to the type of external stimulus signal obtained, fabric sensors can be divided into the following types.

1. Mechanical sensor is because the textile is soft and deformable characteristics, and it is combined with electrical characteristics. When external stress is placed on it, the deformation can be transferred into electrical signals.

2. Temperature sensor is made by integrating thermistor, thermocouple and other materials into the fabric structure, it has the ability of sensing external temperature.

3. Humidity sensor has resistance changes when the external humidity changes, the conductive resistance changes thus produce electrical signals.

4. Chemical sensor uses the conductive polymers in the fabric, so to produce resistance change characteristics. For example, when polypyrrole mixed with palladium and copper, It will shows changes in resistance to

hydrogen and carbon monoxide.

In this thesis, the focus is to detect human motion changing, so the analysis is mainly from the perspective of mechanical sensing. In mechanical fabric sensors, they can be divided into resistive, capacitive and piezoelectric based on different principles of electrical signal changes.

Resistance fabric sensor

Resistance is the physical quantity of the guide body for the obstruction of current flow. Resistance principle in fabric sensing applications is the conductive fabric as a conductor of electricity, decorate in the human body surface, when the wearer movement, fabric due to the influence of physical force, shape change, contact resistance between the internal resistance of the yarn change yarn so change, which result in the resistance of fabric overall affected, changes in the generated signals. According to Holm's contact physics calculation formula, the contact resistance between two objects can be expressed by the following formula.

$$R = \frac{\rho}{1.13}\sqrt{\frac{\varepsilon H}{nF}}$$

In the formula, R represents resistance, ρ and H represent resistivity and hardness respectively, and N represents the number of contact points. In Holm's theory, contact surfaces can be represented by multiple contact points, the larger the contact area, the more contact points, and F represents the contact force applied. Contact resistance is the key point of this kind of fabric sensing. How to design the contact point and contact surface is the research focus of this sensor. Resistive fabric sensors have a wide range of applications. In several studies, it has been verified that the position of resistance changes can be detected to determine the position of applied forces, so that further analysis can obtain more usable data.

Capacitance refers to the physical quantity of charge that moves freely between the electrodes at both ends, and the quantity of charge determines the current transmission. The principle of fabric sensing is to make conductive fabric alone or act as base and capacitor together to make electrode plate, and the dielectric layer in the middle is usually non-conductive and easy to deformation material, capacitance is commonly expressed by formula below.

$$c = \varepsilon \frac{S}{d}$$

In the formula, ε represents the relative permittivity of the dielectric, S represents the area of the plate, and D represents the distance between the plates. Change of capacitance can be caused by several of these factors changes, in the applications of fabric, usually caused by external stress, changes the distance between the electrode plates that cause the change of the electric charge eventually formed the production of electrical signals, such as the rubber coated with dielectric pressure of two conductive yarn, yarn s increasing contact area and relative distance d decreases, and capacitance increases. Capacitive fabric sensors are commonly used for tactile and pressure sensing.

Piezoelectric fabric sensor

Piezoelectric principle refers to the use of piezoelectric material special lattice structure of the piezoelectric effect - that is, by external pressure when the electric dipole moment of the material is shortened, the material in order to maintain the original state and produce equal amount of charge, so as to change the resistance, piezoelectric sensor has high sensitivity and reaction rate.

3.2 Applications of Strain Textile Sensors

In the industrial application of fabric sensing technology, strain textile snesors are often made into wearable products or modules because of its soft and high sensitivity. It is widely applied in the fields of medical health, sports detection, intelligent protection, entertainment industry and so on.

In the medical and health field, strain textile sensors are made into intelligent rehabilitation clothes, which are used to detect patients' physical conditions and enable medical staff to make better medical judgments through information recording and transmission from it. Considering the accuracy and convenience of detection, Bhat et al. used stretched fabric as a sensor, which was installed at the knee joint, to detect and judge different human activities, including driving, sitting, standing and lying.

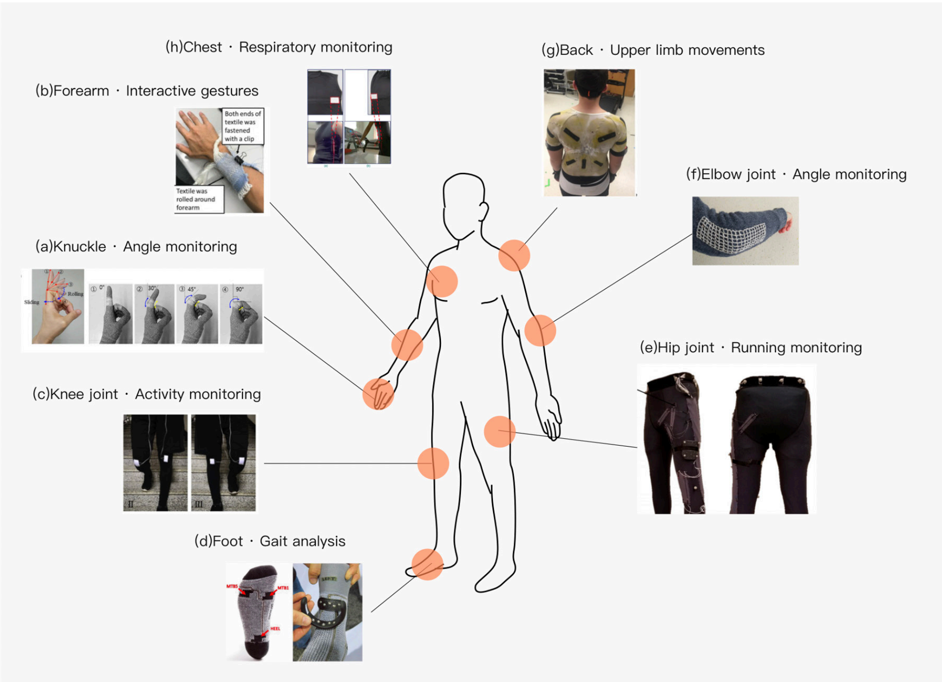


Fig 10. The application of wearable sensing in human body

In the field of sports monitoring, strain textile sensors can do real-time collection of user data, help users to avoid the movement injury caused by the wrong action, improve the user's exercise and training effect. Wearable X developed a series of intelligent yoga clothing, in the monitoring of user movements at the same time to provide feedback for the user guidance, And provide users with more comprehensive sports information services through data storage and Bluetooth transmission combined with the use of mobile APP.

In the field of intelligent protection, Blecha et al. studied and designed a set of wearable system for fire protection, which combined indoor positioning, combustible gas sensing, heart rate monitoring, movement monitoring and other functions.

In the entertainment industry, wearable sensing can bring more dimensions to the user's sensory experience. For example, in virtual reality equipment, Bebop Sensors has developed a set of Forte Data Glove for Oculus Quest equipment. The Glove uses smart fabric to form tactile feedback and simulates the user's tactile feeling in virtual space to improve the user experience of VR equipment.

Fig 11. The different fields of wearable sensing tech.

3.3 The Definition of a Wearable Interaction System

Wearable technology refers to the use of electronic devices that can be worn as accessories, embedded in clothing, implanted in the user's body, or even tattooed on the skin. The devices are hands-free gadgets with practical uses, powered by microprocessors and enhanced with the ability to send and receive data via the Internet.

And when it combines with the ordinary cloth to make it a smart cloth, which enables the cloth to sense stimulus from the environment, to react to them and adapt to them by integration of functionalities in the textile structure. The stimulus as well as the response can have an electrical, thermal, chemical, magnetic or other origin.

When referring to interaction design, especially a complete interaction system, it is usually decomposed and defined into three main modules: user input, system processing module and system output. Our bodies and abilities define how we can "talk" to devices (input). Our sensory system defines how we can "listen" to devices (output).

Understanding this input-output relation (IO relation) is a prerequisite for the design of meaningful interaction. A meaningful IO relation allows the user to know what to do with a system to achieve a certain goal and to evaluate the outcome.

Novel wearable HMI systems must also follow traditional design principles, consisting of four parts, namely users, systems, inputs, and outputs. In this paper, we discuss them from a user perspective, the table bellowed are listed most of the possible inputs and outputs in the human machine interaction, which provides a reference for wearable interaction design. For wearable HMI systems, this process can be interpreted as sensing the physical, electrophysiological, and surrounding signals from the wearers; subsequently, the machine performs specific functions.

Table 5. Interaction Inputs and Outputs

Receive Output Through	Used In...
Seeing	LEDs, screens
Hearing	Sound, voice output
Tactile sensing	Vibration, force feedback, shape
Smell	Scent messaging
Temperature sensing	Temperature output
Input Through	**Used In...**
Touch, Press	Physical contols, touchscreens
Movement and manipulation	Tangible UIs
Speech	Speech recognition
Whole body	Gesture recognition, proximity sensing
Galvanic skin response	Stress detection
Thoughts	Brain-computer interfaces
Heart rate	Determining stress, anxiety, sleep...

3.3.1 The Concept of Input

In wearable interactive system, this input can be user's initiative (such as the user operating the button), or the system can monitor users' behavior (such as detecting the user's state and giving feedback). With the development of sensing technology, users' different states, behaviors can be regarded as the input of information. In this section, the most common input methods are listed based on the user's perspective.

Contact control

This is the most common and well-known input mode. The traditional control including software interface and hardware controller.

To make wearable devices more intelligent and easier to use, this mode has also been applied. For example, Levis's Jacquard-a smart coat has a sensor embedded in the cuff to facilitate users to quickly control the mobile phone while they are riding a bike.

Fig 12. Contact control interaction

Gesture control

Air gestures (non-touch gestures) are a new manner of interaction between a person and a device. They allow a user to conveniently interact with devices without holding or touching them. Air gestures apply to devices such as mobile phones, tablets, automobile head units, smart TVs, speakers, and AR/VR devices. An air gesture is usually a simple action that conforms to the intuition and cultural habits of a user.

Gesture recognition gets rid of the shackles of contact operation, and can capture the gestures of people within a certain distance by means of infrared sensors or cameras. In another way, an acceleration sensor can be placed on the hand, so that gesture can correspond to one certain operation. Gesture technology has been applied in the market, for example, the gesture operation developed by Google for the small screen of smart watch.

Fig 13. Gesture control interaction

Body movement

The movement of the body, trunk and other parts can also be used as an input channel. And this input method gives users a stronger sense of participation and interest, so it is often used in the field of games and sports. For example, in Kinect game, users' actions are captured through the camera and transformed into operations in the games.

Fig 14. Kinect motion game

Voice

Speech recognition is available on most modern smartphones. When it works, it can be a quick way to give complex commands. Setting an alarm using a touchscreen, for example, requires a series of steps that include fiddling around with UI components to select hours and minutes or even doing math to translate the user's way of thinking ("wake me up in 3 hours from now") into the constraints of the UI (set time when alarm should go off). A voice command for the same input can be quicker and easier ("wake me up in 3 hours").

Fig 15. Voice interaction

Facial expression

It is possible to recognize people's mood by his facial expression by using algorithm, so the facial expression can also be used as input. This type of input is hard to be applied in the wearable interaction since it needs the camera to capture users' facial image and also needs a certain distance.

3.3.2 The Concept of Output

Compare to the input, when mentioned output, it is easier to understand through users' perspective, which the output can be concluded into human's five sensing, output can be seen as feedback from the interaction system.

Each sense can correspond to a certain type of information acquisition. Among them, visual, tactile and auditory feedback are more mature, applied and reliable.

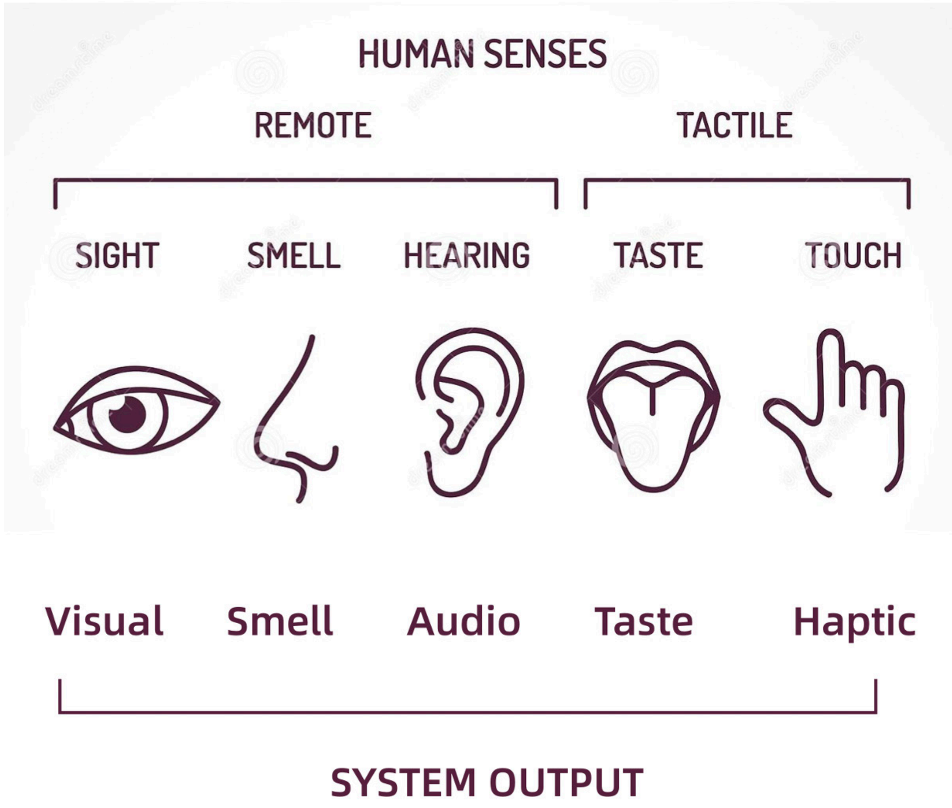


Fig 17. Five sensing and its outputs

Visual Output

Visual feedback is undoubtedly the most effective and widely used output method at present. Most of people obtain information based on visual information. It can also be seen everywhere in the design of interactive system, such as the information in the screen, the information of indicator lights and so on.

Tactile Output

The tactile feedback channel is the primary source of information about the fine shape and surface features of an object. It also contributes to perception of weight, size, and texture. For most interactions, tactile feedback is the most dominant component of haptic perception.

Audio Output

Audio can be a useful output method. Users don't have to look at the device directly and don't even have to be near it. A sound can convey urgency like an ear-piercing high-pitch beep. Or it can convey a sense of satisfaction like a fulfilling swoosh sound when an email is sent.

3.3.3 The Input and Output Modes Used in this Study

In this study, the design of the interaction system applied some of the input and output modes according to the specific characteristics of the users' behavior and their environments, which is to be elaborated in the chapter 5.

Because this study focused on the solution for improving sitting postures, so the input mode is set as people's body movement which is just the posture itself.

For the output modes, which is typically the feedback for the users, this design used multiple output modes to achieve the best correction reminders, including tactile as a fixed mode since its high acceptance and proved effects by other products. And the system also provides visual feedbacks to give a clear instruction by two different ways, it used LED lights when the users are in the school, APP interfaces when they are home.

3.4 Design Method for Wearable Interaction System

In this thesis, the ultimate goal is to explore the possibility of using the strain sensors to build a wearable interaction system.

A framework was provided to assist designers in making choices on how to build composite wearables (Khalaf at el, 2020). Wearable interfaces are expected to combine several modalities (e.g., gesture and speech) to provide wearers with more natural ways of communicating. When compared to a single modality, multidimensional auditory and gestural techniques enable richer and more advanced interactions with wearable technologies and their respective applications.

A human-centered wearable interaction system designing method for smart cloth is constructed here to guide the design process.

According to the ultimate goal of designing a smart cloth to correct sitting posture, its design process can be divided into 3 main stages as shown above.

The first step is to define the scenario clearly, including users' needs and scenarios and material research, user research is a basic information for human-centered-design method. And in this study, the application of a new material is also an innovation part, so material's research is needed. These two parts are well elaborated in chapter 5 & 6.

The second step would be design and prototyping, it's the most important part of the thesis, and they are consisted by connecting the material into the normal cloth to make it sensible of posture change and design input and output to make it a functional interaction system, these two parts can be found in the chapter 6 after the material introduction part.

The third step is aimed to prove the system's effectiveness and usability, also to gather the feedback of the participants who used the system so that the thesis can give an overall conclusion of how the system performs, the evaluation method and its implement is described in the chapter 7.

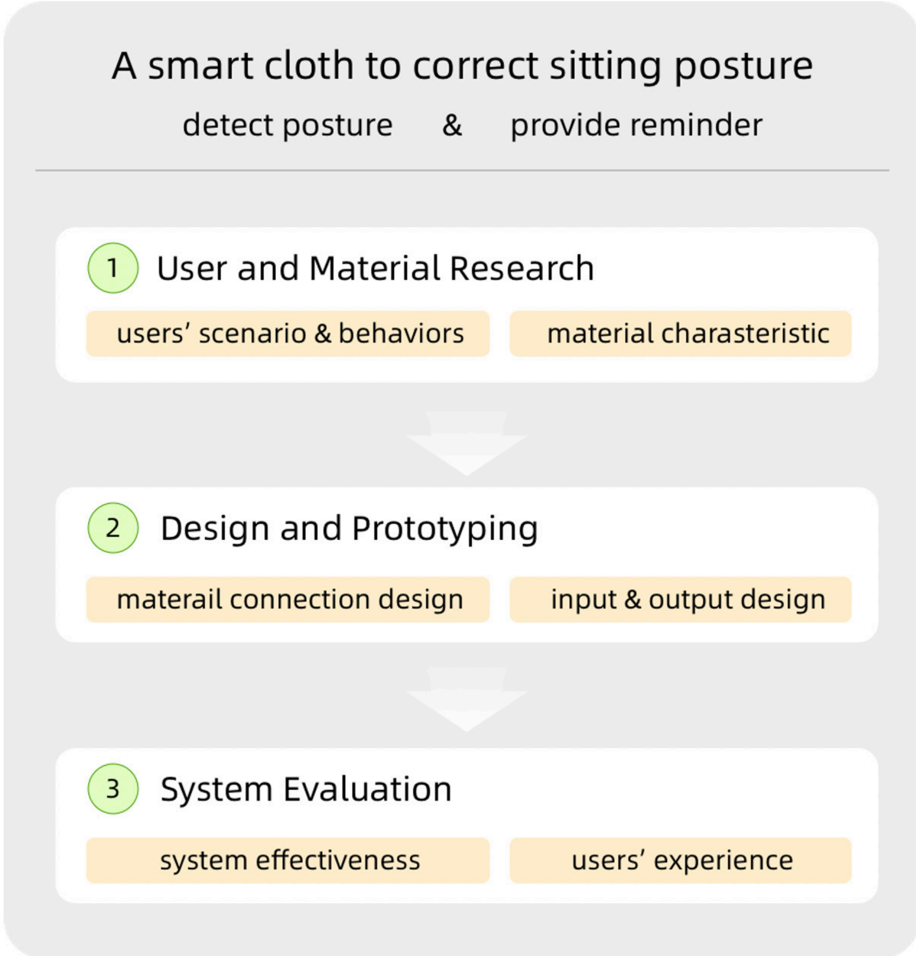


Fig 18. Design process for wearable system used in this thesis

Chapter 4　Wearable Interaction System Design

In this chapter, thesis describe the process of a user-centered design practice by conducting user research, feedback research.
A framework is done to instruct the later design practice.

4.1 Target Users and Scenarios

In this thesis, an in-depth user research was conducted to clarify the sitting posture of our target scenario, and clarify the sitting postures to be detected in the design practice, also it also helps us to understand the user's attitude towards wearable devices, so we can design a better system based on the experience aspect.

Firstly, 55 questionnaire were collected, 3 invalid responses were excluded from the age limitation of the target population and 52 valid questionnaires were recorded. The gender ratio is 17.3% for males and 82.7% for females; the majority of the age structure is the 17 to 19.

Users spend more than 7 hours in sitting a day averagely, and most users have understood the harm caused by incorrect sitting posture. Only 5.8% of users believe that they maintain correct sitting posture most of the time. In daily life, Parents and teachers will act as reminders of sitting posture.

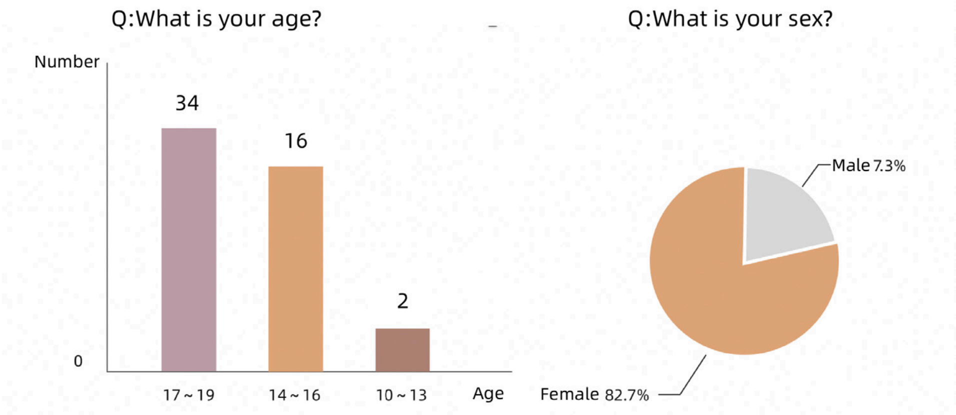


Fig 19. Participants' basic information

More than half of have not used any sitting posture reminder device. During people who have used sitting posture correction product, the most common one is orthopedic belts for external force correction, and the effect is not good. For sitting posture detection and reminding equipment, 59.6% of users choose to use smart detection clothing.

Fig 20. The questionnaire results of people's opinion about posture corrector

Based on the results of the questionnaire, valuable content was extracted and summarized as follows.

1. Participants in the survey have a basic understanding of most sitting posture issues, and believe that it is necessary to have a sitting posture reminder and correct sitting posture. The problem is to keep the right posture after reminding.

2. Among similar sitting posture detection or correction products, the most used is wearable physical correction belts. Regarding its effect and use experience, users mentioned they are not very comfortable, and they thought the correction effect is not so satisfying. Most of the surveyed people have not used any sitting posture detection and correction products.

3. The acceptance for wearable smart detection clothes is relatively high, and the number of people choosing seat cushions is relatively large. The users consider their importances in order as comfort, corrective effect, aesthetics, and fun. It can be seen that users have the highest requirements for the comfort of the equipment, and then is the correction effect. Compared with the light and interface feedback, users are more inclined to tactile feedback, which is a less disruptive feedback method.

4.2 The Settings of Target Sitting Postures

In this thesis, the study refers to the prementioned researches in the chapter 2.1, and follow the physiological comfort and rationality, and make the reference formulation of "standard sitting posture" according to the subdivision of teenagers in their main sitting posture scenes.

The definition of incorrect sitting posture is the extra burden and adverse health effects caused by deviation from the correct sitting posture. In this study, through observations and interviews, we recorded the common sitting postures of adolescents in the above-mentioned sitting situation, and summarized them as the target sitting postures that need to be identified in the research. There are 8 types namely: lean to the right, lean to the left, lean forward, lean back, hunch back, bend over the table, support the cheek on the right, and on the left. In the follow-up stages, the 8 postures and the correct sitting posture, a total of 9 sitting postures will be used as the targets to classify.

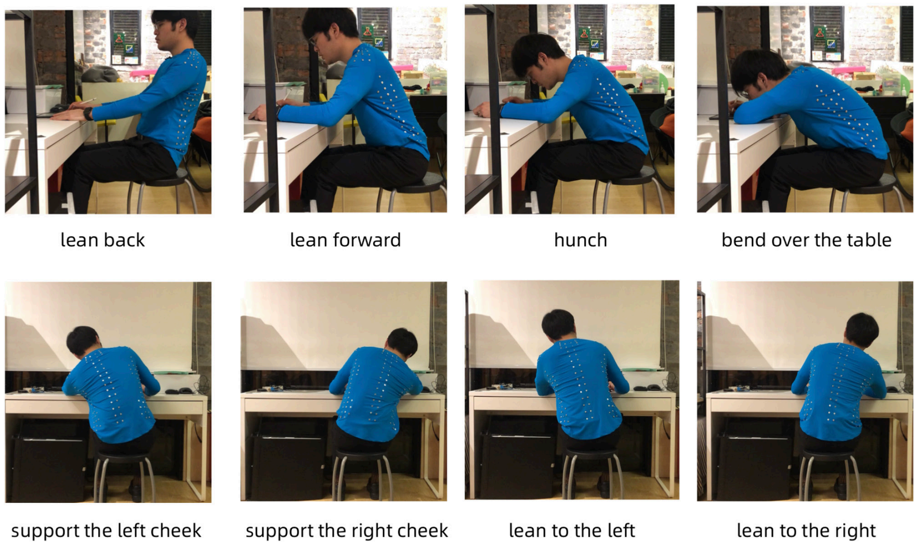


Fig 21. The 8 target sitting postures.

4.3 Interaction Framework for Wearable Sitting Posture Detection System

The whole design procedure follows a way of designing-through-practice, which can be divided into 4 steps. In the first step, the performance of the material experiment needs to be tested to evaluate the performance so to select the right fabric sensors that meets the testing requirements.

The second step is the feasibility experiment of the circuit, that is the selected fabric material is connected to the Arduino through the circuit to detect whether the electrical signal changes caused by stretching of each sensor can be collected. The third step is the experiment of the layout scheme, it is to find the most suitable layout scheme by trying to install the connected sensor circuit on the measuring suit, so as to detect the corresponding posture change most effectively. The fourth step is the attachment method of the sensor experiment, exploring how to properly connect the sensor and clothing. The steps described above are discussed in detail in following passage.

The purpose of design feedback is to guide users to adjust their behaviors. Within the research scope of user behavior persuasion, Fogg proposed FBM(Fogg's Behavior Model), which explained three important influencing factors of human behavior changes, namely motivation, ability and trigger (Fogg, 2009). It provides an important reference for the design of behavior-based feedback research. The principle of feedback design can be referred to it, to find out the user's motivation around the target behavior, to give the user the ability to operate and reduce the difficulty of operation, than make the user start to act through additional trigger points. Meanwhile, in this thesis, the sitting habit of users can be regarded as a learned behavior, it menas behavior that users do not have originally and becomes a habitual action through the action of some mechanism.

The theory of Habit formation methods and steps can be found in related researches (Duhigg,2014). Similarly, Sigrist systematically summarized several feedback modes of motor learning , which is defined as the change of certain behavior after a period of practice, and corresponding design principles for each feedback (Sigrist, 2013).

The feedback's content

In the process of feedback design, the content of feedback should be determined according to the design purpose. According to the statement type of feedback content, feedback can be divided into knowledges of results and knowledges of performance. The former is the content measured during the process. The latter is the certain analysis after the process when the work is finished, for example, after a period of training, the distance the athlete runs and the score are the knowledges of performance. In the previous sitting posture detection system, it is usually based on the user's actions during the wrong action, but lack of performance feedback based on the long time.

In this thesis, users' wrong sitting position should be corrected, so feedback based on user behavior results is essential. In addition, referring to relevant research content, multidimensional and more comprehensive feedbacks can achieve better stimulus effect for user behavior guidance. For technical feasibility, the spread of data processing power makes possible multidimensional visualization of user behavior. Therefore, in this thesis, how to conduct user performance feedback will also be discussed to better realize the purpose of the study and user experience.

The feedback's form

According to the time point of feedback, feedback can be divided into concurrent feedback and terminal feedback. Concurrent feedback refers to the timely output of some feedbacks based on the user's signal input during the user's use, such as providing restorative action guidance feedback for patients during rehabilitation training to achieve more effective rehabilitation effects. Wulf's research and theory point out that the timely feedback plays a high role in promoting the self-consciousness of behavioral learning and can effectively improve the learning efficiency of users in a task.

Terminal feedback is that after collecting user signals for a period of time, the signals are converted by the processor into analyzable data, and some referable data analysis results are provided in summary. With the continuous improvement of data collection and data analysis capabilities, this kind of feedback is more and more common in daily life. For example, after a period of training for athletes, feedback similar to the report can be provided by means of data collection and analysis to improve the effect in the next training.

In the field of medical rehabilitation and health, feedback information is usually provided through the combination of the above two forms, such as sound and vibration feedback reminder by wearing sensors, and more detailed personal information is displayed in computers, mobile phones and other devices.

Considering the goals of this study, it is necessary to provide timely warning of improper posture and to help adolescents develop good posture habits in the long run. Based on the selection of feedback content mentioned above, the two types of feedback content will be displayed respectively in the form of concurrent and terminal feedback.

The feedback's mode

According to users' different perception modes of feedback information, the modes of feedback can be divided into visual, tactile, auditory and multi-modal comprehensive feedback (Wang, 2017). The most common of them is visual feedback, which means information received through two-dimensional or three-dimensional images. For example, in the shoulder rehabilitation training system designed by Semjonova, the user wears the intelligent rehabilitation clothing for rehabilitation training, and the data is collected by the embedded sensors in the clothes, and then the correctness of the action is displayed on the computer screen and the guidance is given (Semjonova, 2020). Auditory feedback is highly dependent on the environment.Tactile feedback can be defined as the transmission and reception of information in the form of pressure, vibration and movement through behaviors. Haptic technology is playing an increasingly obvious role in the previous interaction design, in human-computer interaction, haptic feedback can be used as the visual information supplement for users in the main task, reducing the difficulty of users' operation and improving the efficiency of operation. In a recent study of automobile human-computer interface, the researchers found that by adding gesture and vibration feedback to the original system, users had higher accuracy and response speed in the implementation of the goal setting task during driving. In the entertainment industry, tactile feedback can enrich users' sensory experience. For example, in VR wearable devices, vibration modules in the devices are used to simulate tactile feelings in the virtual game world and make the experience more real.

With the wider use of electronic components, there are more and more studies adopted tactile feedback in the form of information transmission, in the design of Life Chair, the researchers arranged the pressure sensors and vibration motors in the chair, to provide timely feedback to the office users.

Consider the users and the characteristics of the usage scenarios, this study will be integrated with hardware and software of the feedback modes.

In this thesis, the user scenarios are reading, writing and listening states. Considering the user's visual attention on its original mission, when using attractive visual feedback mechanism, it will easily cause interference to the user's original tasks, and have a negative impact.

Among the feedback modes mentioned above, the feedback based on tactile mode is widely applied in classroom and office scenes, which has certain feasibility and good effects after verification. Therefore, in this study, vibration feedback is applied to timely remind posture adjustment.

Chapter 5 The Prototype Development

In this chapter, prototype development is described by textile testing, sensors pattern testing, connection testing and algorithm implementation.
After finishing the detection part, feedback is also compeleted by hardware and APP interfaces.

5.1 Textile Sensor Selection

When it comes to select the right snesors, the first step is to test the performance of the textile sensor. The performance evaluation focus on three aspects, electronic performance and fabric performance and the cross performance including the strain sensitivity of the fabric sensor, resistance linearity, hysteresis of resistance change, repeated use resistance stability, repeated usage length stability, etc.

Based on the desk research, we focused two kinds of strain textile sensors. One is the conductive PPY (polypyrene) textile, three different samples are numbered as A, B, and C with different parameters. The other one is the elastic conductive fabric woven from silver fiber and elastic fiber which is numbered as sample D. The characteristics of the resistance change are also different. The PPY coating material is a form of covering the conductive medium material on the fabric yarn, and the yarn is in a loop-like unit, by stretching, the contact area between the yarns becomes larger, the conductivity increases, and the resistance becomes smaller. The silver fiber conductive material is used in this research to woven the silver fiber and the fabric fiber together in a loop-like unit. When a piece of cloth is stretched, the conductive silver fiber structure is expanded, the contact area between each other becomes smaller, and its resistance becomes correspondingly larger.

We prepared a highly stretchable shirt as testing garment, which is called the body-fitting shirt in the following passage and it will support the sensor deployment experiments. Besides, the stretched length of the material needs to be measured. The fixed points can be used as a mark, and the distance can be observed and recorded.

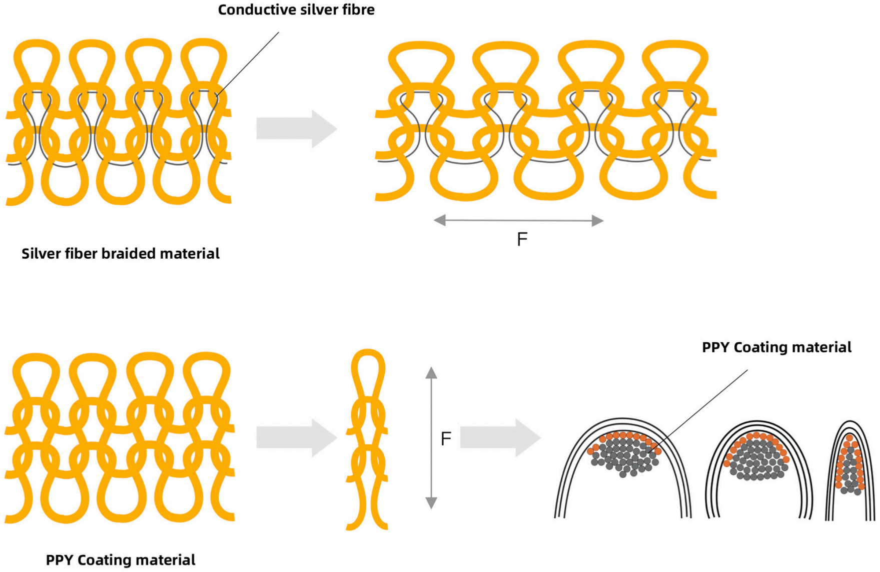


Fig 22. The resistance changes principles

Fig 23. The body-fitting shirt

Participant wears a suit to perform a set of predetermined sitting postures. The measured distance between two adjacent marking points is around 5.9cm, the change is 18.0%, so we set the stretch degree as 20% in the performance test, which means the tested tensile length is 1.0 cm.

To choose the right material for the research purpose, we mainly decide on two indicators—The sensitivity, the Linear stability and the Repetition stability.

Sensitivity indicates whether the change of resistance of fabric material is obvious within the target stretching range. In the scenario of this study, that is, whether the resistance signal caused by the change of sitting posture is significant. The higher the sensitivity, the more obvious the characteristics are in the judgment of sitting posture. The calculation formula of sensitivity is as follows,

$$S = \vartheta R / \vartheta L$$

$$\vartheta R = (R_{max} - R_0) / R_0$$

$$\vartheta L = (L_{max} - L_0) / L_0$$

Where ϑR represents the percentage of the change value of initial resistance when the sensor is stretched to the maximum target, that is, the ratio of the difference between the maximum resistance after stretching [R] _max minus the initial resistance R_0. ϑL represents the difference between the maximum length of the sensor after stretching Lmax minus the initial length L_0, and the ratio of L_0.

Linear stability: indicates whether the resistance of the fabric tends to be linear in a single stretch of a specified length. It is usually used to indicate the stability and uniformity of the sensor in the tensile strain, that is, the linear relationship between the resistance value and the sensor length variable. The more the curve of resistance change fits the ideal linear equation, the more uniform the resistance change is during a single stretch. The calculation formula of linearity is as follows,

$$\sigma = \sigma_{max} + \sigma_{min}$$

$$\sigma_{min} = \sqrt{\frac{1}{N}\sum_{j=1}^{N}\left(r_j - \overline{r_{min}}\right)^2}$$

$$\sigma_{max} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(r_i - \overline{r_{max}})^2}$$

σmax represents the standard deviation of the maximum resistance value during repeated stretching, N is the number of stretching cycles, Ri is the maximum resistance value within each cycle, rmax represents the average of the maximum resistance value within the cycle. Similarly, σmin represents the minimum standard deviation of resistance during repeated stretching. Therefore, the smaller σ is, the higher the repeat stability is during repeated stretching.

In the material test of this study, there are many different kinds of alternative materials, and their initial resistance values are greatly different. Therefore, in the process of comparison, suggestions and comparisons can be made based on their own fluctuation degree,

$$w = w_i + w_j \qquad w_i = \frac{\Delta r_{max}}{r_{max}} \qquad w_j = \frac{\Delta r_{min}}{r_{min}}$$

Where Δ Rmax represents the fluctuation value of the maximum resistance in multiple tensile cycles, rmax represents the maximum output resistance reached in the cycle, Δ Rmin refers to the fluctuation value when the resistance is minimum in multiple stretching cycles, and Rmin refers to the minimum output resistance reached in the cycle. As above, the smaller the fluctuation degree w is, the higher the repetition stability would be.

This research adopts a fixed tensile experiments, using Arduino to control a stepper motor (Figure 2b), and connecting the slide rail for reciprocating movement, the sensor to be measured is fixed on the slide rail and stretch within the specified moving distance interval. The textile sensor was connected to the Arduino analog signal port to read the resistance signal change. The Arduino serial port displays the resistance curve change, and we recorded the value of the signal.

(a) (b)

Fig 24. Stretch fabric to be tested and test equipment

The resistance change curve is as shown in the Figure 25. Among them, the vertical axis represents the resistance value, and the coordinate is converted into a period according to the reciprocating motion, that is, each period unit represents a stretch and recovery of the sensor.

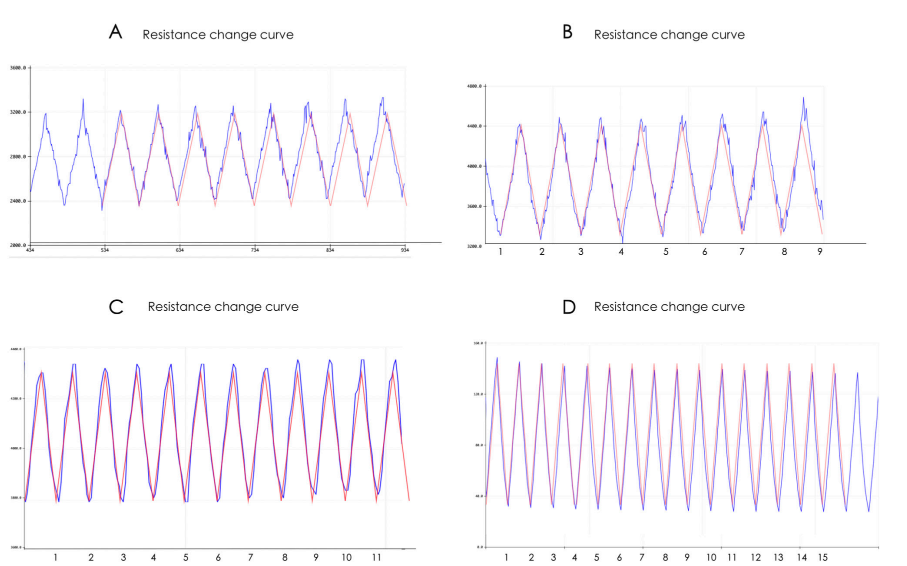


Fig 25. Resistance changes curve of fixed length tensile test of four materials

The blue line in the figure is the actual resistance value, and the red curve is an ideal linear change curve drawn by taking the highest value and the lowest value of the resistance change. According to the above actual and ideal resistance change curves, it can be found that the resistance change curves of material A and material B have greater interference during the repeated stretching process, and exhibit poor linearity.

Among them, material C and material D showed a better linearity. The 20-cycle data of these two materials are counted and calculated, and the table is summarized below.

Table 6. Testing data of Material C and D's repeated stretching

	Maximum resistance	Min resistance at max stretch	Minimum resistance	Max resistance at no stretch	σ	w	s
C	9599.12	8109.75	4562.61	5028.57	548.7	0.25	5.52
D	162.83	152.96	35.75	38.95	3.94	0.14	17.8

Compared with material C, material D has the best repeat stability, and the resistance value fluctuates in a smaller range during the repeated tensile test. When stretched to the maximum extent, its fluctuation range is 9.87 ohms. At the initial length, the fluctuation range is 3.2 ohms. The calculated fluctuation coefficient is 0.14, and the calculated sensitivity is also higher. Considering comprehensively, the material properties of material D are better. Therefore, in the follow-up process of this research, material D will be selected for sensor implementation.

Regarding the conductive properties of stretched fabric, factors include the length and width of a single piece of sensing fabric. Two different length of material D were tested, we extend the length of the sensor to 10cm, and perform a repeated fixed tensile test of the 10cm sensor to compare with the 5cm length sensor. During the test, the stretched length of the 10cm sensor is set to 2cm.

	σ	w	s
5cm	3.94	0.14	17.8
10cm	3.07	0.14	26.9

Comparing the characteristics of the sensor made of two different length materials D, it can be found that the 10cm length of the material D is better than the 5cm length in repeat stability, and it also performed better in sensitivity. Secondly, considering that the sensor with a length of 10cm can monitor a wider range, the material D with a length of 10cm will be used as the tensile strain sensor in the subsequent experiments.

5.2 Sensors Pattern Testing on the Shirt

After selecting the textile with mechanical properties that meet the requirements, the second stage is to initially apply it to the target scene to observe whether the corresponding changes can be detected, and to find the most suitable sensor placements.

In this research, it used a combination of empirical judgments based on references and experiments to try different schemes. Based on the layout plan in previous studies and the stretching distance measurement carried out in the material test, we selected the position with larger variation as the possible layout area. A total of 6 placement positions were selected: vertebrae C5 to T2 and L1 to L3 for spine monitoring,

The areas of the teres minor and infraspinatus on the upper back where the bending deformation is most obvious, and the lower back abdomen and external oblique muscles on both sides.

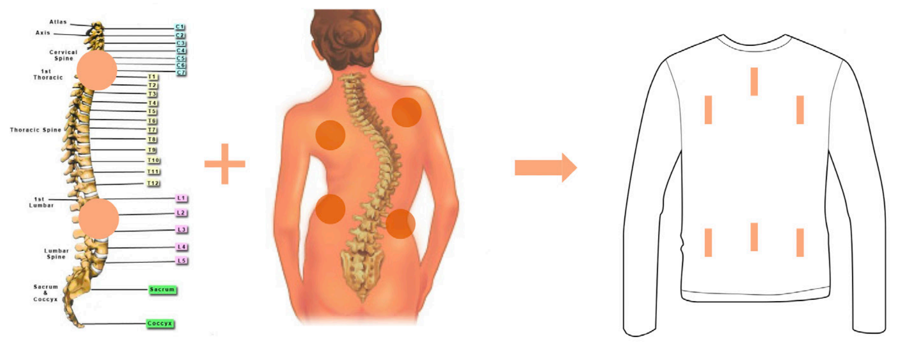


Fig 26. The position of sensor placement

Therefore, the preliminary plan is to try to set up the preliminary circuit with six fabric sensors in the six locations. In this layout scheme, the number of sensors needs six analog signal outputs and several outputs required by the subsequent feedback module. In this study, the Arduino MEGA board is used as a signal processor for experiments and subsequent prototype construction. The specific circuit connection is shown in the figure below. Six sensors to obtain resistance signals are respectively connected to the digital analog port of the Arduino board to obtain resistance signal readings.

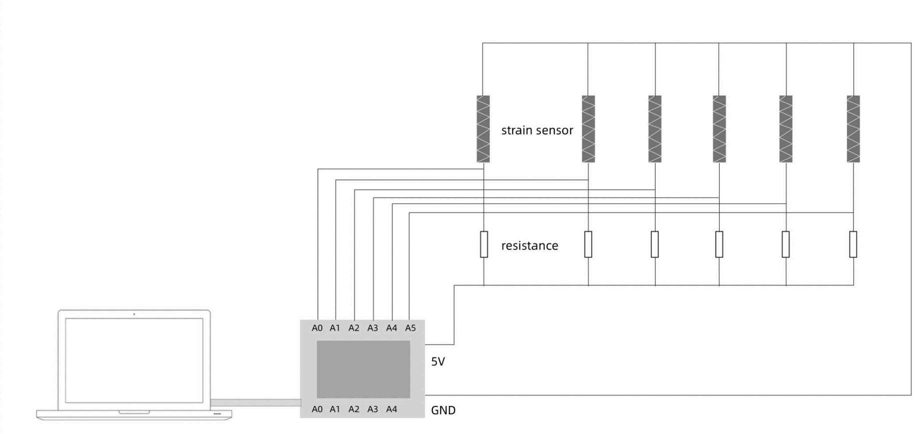


Fig 27. The connection circuit of sensors

Subsequently, all the sensors are connected by snaps to the body-fitting shirt as shown in Figure28 and the resistance changes can be observed when different posture shows.

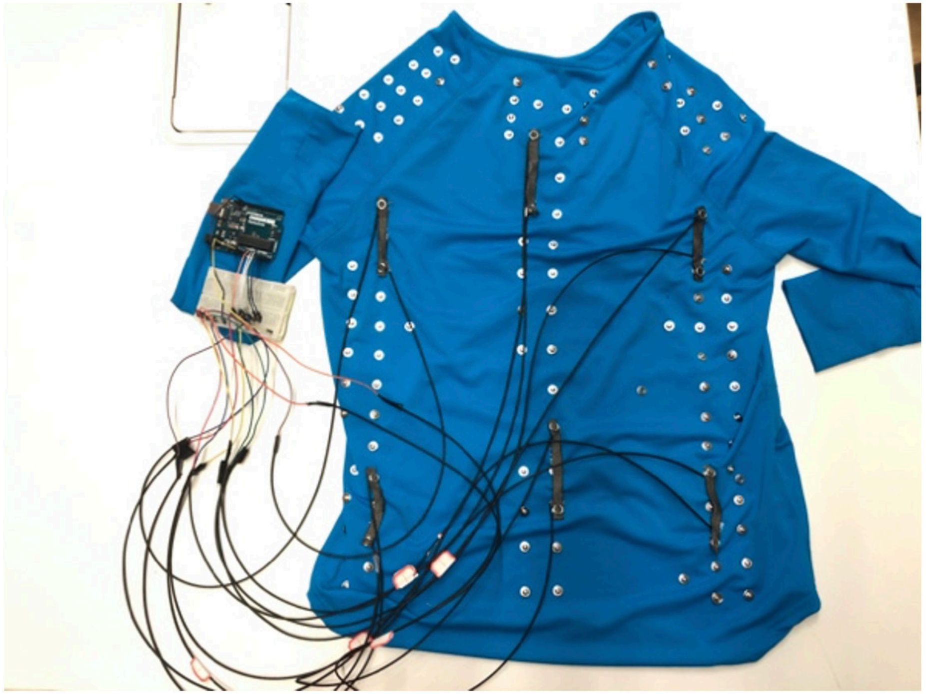


Fig 28. Sensor resistance reading circuit connection

5.3 The Connection Test of the Sensors and the Shirt

In the second iteration, in order to better connect fabric sensors with clothing and improve its practicality and aesthetics, the connection modes between sensor and clothing will be discussed and designed in this chapter.

According to the reversibility of the combination mode, it can be divided into detachable and non-detachable by referring to the way in which the fabric and clothing fabric are connected in existing studies and cases.

The non-detachable connection means that the fabric sensor is directly connected to the clothes.

While the direct connection means includes the common direct stitching, hot pressing, adhesive, hot air welding and so on. Its advantage is that it has good close-fitting, detection effect and comfort and beauty, the disadvantage is that the connection is irreversible, usually one-time processing, poor adjustability.

Detachable connection is realized through the intermediate medium or structured way, make sensors connected to the fabric, with a combination of high flexibility, easy installation. And the components can be separated and protected in situations like laundry, when faced with different requirements, it can choose different functional components, etc.

In the past, the goal of fabric sensor detection was to improve the accuracy of detection methods, so most of them were directly sewn on clothing. In the actual project, the connection mode needs to be considered according to the actual situation of the application scenario. For example, Jacquard, an interactive smart denim garment jointly developed by Levi Strauss and Google, was released in the spring of 2017. Users can perform simple gesture operation on the sleeve to complete the control of mobile phones and facilitate users in cycling and other inconvenient processes. The input module uses conductive fabric sewn onto the sleeve. The transmission module uses a chip clipped on the cuff and a Bluetooth module group, which can be detachable for charging and optional colors.

Based on the above research content, it can be found that the two connection modes have their own advantages and disadvantages. Multiple factors in the application scenario should be considered to select the one suitable for the application scenario.

In this thesis, it can be found from the user's research above that accuracy and effectiveness are the primary considerations. Therefore, the non-detachable connection between the sensor and clothing should be preferred in sensor layout and connection to ensure the collection efficiency.

After determining the connection mode, it is necessary to further determine the specific connection mode. Referring to previous studies, it can be seen that in the research field of fabric sensing, the stitch connection mode has high stability and durability. Therefore, the stitch sewing is given priority in this study. There are many ways to sew small pieces of cloth to large pieces of cloth base for testing and selection. And with the above experimental method, the resistance change was measured after the connection. After the test, it was found that the z-shaped connection method was the closest to the original resistance change curve, so the sensor and clothing will be connected in this way. Then, the conductive wire of the fabric is sewn onto the clothing in the same way.

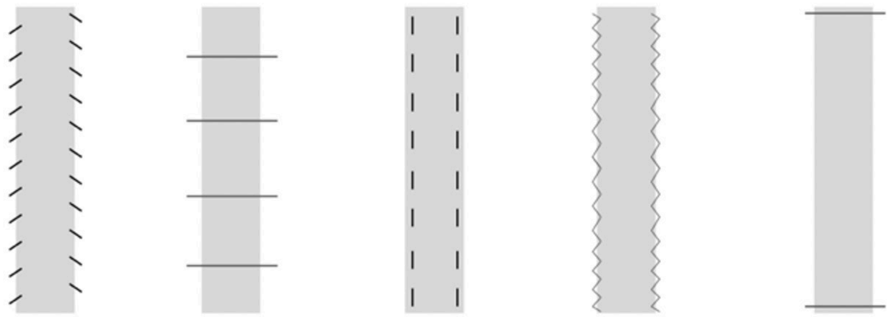


Fig 29. The connection method of textile sensors

5.4 Final Prototyping

In the next stage of this study, the final prototype clothing is made based on aesthetics and comfort, which lays a foundation for data collection and classification model construction in real scenes. The prototype garment was made by stitching sensor circuits onto existing body-building tights. Considering the difficulty of using automatic sewing machine to sew the circuit and the portability of wearing during the test, the fitness jacket with good tensile and close-fitting properties was selected.

The final prototype is designed and implemented by sewing all the textile sensors on predefined locations by conductive yarns, which is the basis for data collection and classification model construction in real scenes.

Fig 30. Prototype clothing circuit sewing inside and outside

When each sitting posture is executed, it will cause the resistance of each sensor in different placements to change. As shown in Figure 32, when the user's body is tilted to the left (including left tilt and left cheek support), the back muscles are stretched, and the sensor located in the area of the teres minor and infraspinatus on the right side of the upper back (green line in the waveform diagram) and the sensor 6 located at the external oblique muscle on the right side of the lower back (indicated by the gray line in the waveform diagram) receives the largest stretch, and its resistance increases accordingly. Among them, the slouch posture is slightly greater than that of the left tilt posture, so the resistance change is more obvious.

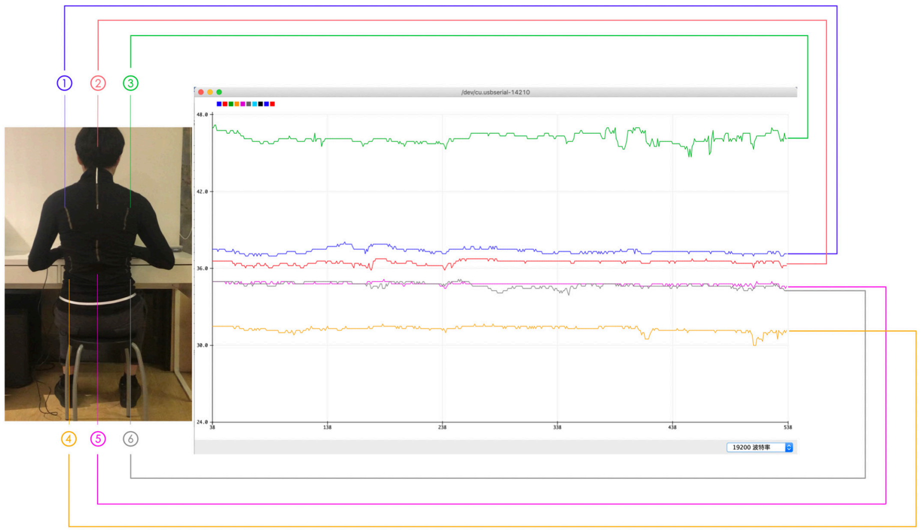


Fig 31. The positions of the corresponding sensors

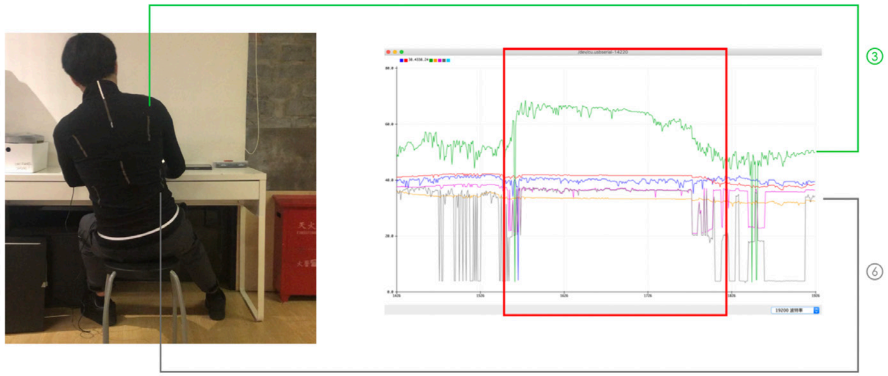


Fig 32. The sensor's resistance changes of the left-leaning sitting posture

When the user's body is leaned to the right (including right tilt and on the right chin), as shown in figure below, the sensor1 located in the area of the teres minor and infraspinatus on the left side of the upper back (indicated by the blue line in the waveform). And the sensor 4 (colored by the yellow line in the waveform diagram)located at the external oblique muscle on the right side of the lower back received the greatest stretch, and its resistance increased accordingly. Among them, the muscle stretching and the corresponding resistance changes in the sitting posture with the cheek supported are more obvious.

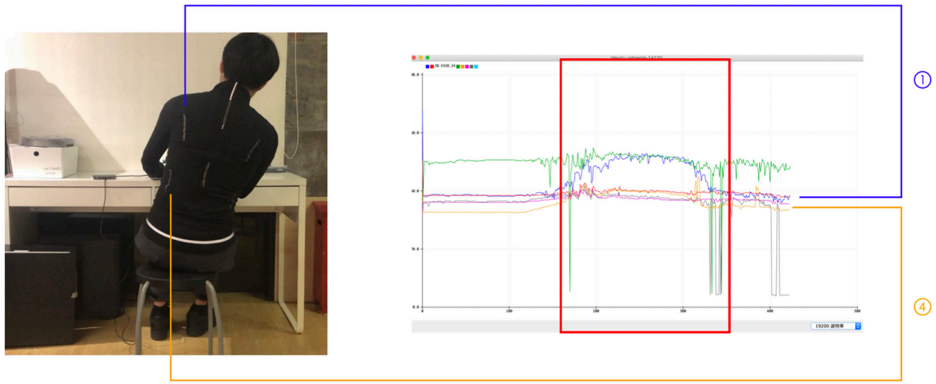


Fig 33. The sensor's resistance changes of the right-leaning sitting posture

When sitting in a slouch posture, the sensor located at the spine has the greatest deformation, so the resistance signals of the sensor 2 and 5 increase at the same time. Besides, sensors in other parts are also deformed and their resistence changes can be observed from the waveform diagram that the sensor signal values at these three positions have increased significantly.

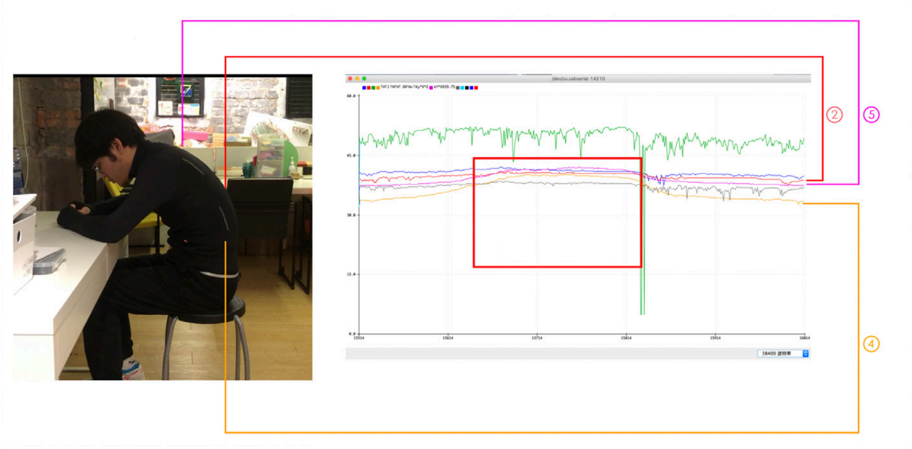


Fig 34. The sensor's resistance changes of the slouch sitting posture

The resistance change value recorded in the process of the above actual operation was analyzed, and the sensor position and its change amount caused by each sitting position were recorded. The maximum value of the resistance change was about 20 ohms (the resistance change value of No.3 when lean on left chin). Resistance variation of the minimum value is approximately 4 ohm resistance, at the same time can be found under each posture, in every position of resistance are slight changes have taken place around (0 ~ 3 ohm), for its posture does not play a decisive role to judge, can be neglected in the criterion, and the other the resistance value of threshold value division, and summarized in the table below, it can be found that for each sitting posture, there is a corresponding different mode from other sitting posture, which can be used as a decision factor in the judgment of sitting posture.

Table 8. The resistance changes value of each sensor corresponding to each sitting positio

	Lean right	Support the right cheek	Lean left	Support the left cheek	Lean forward	Lean backward	Hunch	Bend over the desk
#1	16~20	6~15	0~3	0~3	0~3	0~3	0~3	0~3
#2	0~3	0~3	0~3	0~3	0~3	3~6	4~6	0~3
#3	0~3	0~3	16~20	16~20	0~3	6~15	0~3	0~3
#4	6~15	15~20	0~3	0~3	0~3	0~3	6~15	16~20
#5	0~3	0~3	0~3	0~3	3~6	0~3	6~15	16~20
#6	0~3	0~3	3~6	6~15	0~3	0~3	0~3	0~3

It can be concluded from the above summary that the algorithm processing process is understood as reading each resistance signal and classifying 9 targets according to the generated mode. Referring to the more effective classification methods in the references, MATLAB software is used in the application of the automatic classification algorithm in this study to generate a model that can be applied to the sitting position classification in this study, so as to achieve the final classification goal.

5.5 The Classification through Software based on the Smart Shirt

In this research, MATLAB software is used to apply the automatic classification algorithm to generate a model that can classify the sitting postures. According to the classification principle and algorithm model generation requirements. The data sets contain classification standards and its corresponding multiple sets of training data.

After the circuit is connected, a participant wore the suit and executed the 9 target postures. When each posture is performed, the participant continuously adjusted his sitting posture in the interval of the setting postures for 15 seconds. During the collection process, the collection frequency of the Arduino MEGA board is set to 500hz, so each sitting posture can collect about 7,500 items of data.

After the training data is imported into MATLAB, different algorithm models are used to generated the model for classification. In this study, KNN (K=1 and K=5), Naive Bayes, decision tree, SVM (Support Vector Machine) are the four most commonly used machine learning classification algorithms for data learning and model training. The specific parameter settings are shown in the following.

Table 9. Algorithms and parameters used to train the model

No	Algorithm	Parameter
1	KNN	K=1
2	KNN	K=5
3	Naive Bayes	default
4	Support Vector Machines	RBF，C=1，Degree=3
5	Decision tree	Max split number=100

The data set was divided, 70% were used as the training set of the sitting posture classification model, and the other 30% were used as the validation set. For the trained model, the evaluation and comparison of the following indicators are usually used, which are accuracy, precision, recall, and F-1 value. The KNN algorithm (K-Nearest Neighbor) has the highest accuracy result. When the K value is 1, the accuracy of prediction and judgment is 99.1%, that is, when the model classifies the validation dataset. Its overall performance is also the highest among all. Compared with other types of algorithm models, the KNN (K=1) model exhibits the best performance. Therefore, in the subsequent part of this research, the KNN classification model will be used as a tool for sitting posture classification. Then the trained model is exported from MATLAB to Arduino through Simulink, so that the sensor signal detected on Arduino can be classified by the derived algorithm model, and then returned the classification result.

5.6 Feedback Design and Implementation

This research also aims to build a complete posture detection system including textile sensor and feedback, so they can make adjustments to achieve the correct postures.
The target scenes are mostly classrooms and homes, the user's main activities are reading, writing, and having classes. Therefore, the feedback modalities are designed according to the user's environment: in the classroom environment, the feedback carriers are mainly wearable modes; in the home environment, the carriers of feedback are wearable modules and visual feedback on the APP.
The feedback based on the wearable module can be divided into two parts. One type is the haptic by vibration motors, three vibration motors are respectively arranged on the left, right sides of the lumbar spine and the middle position of the spine.
The working mode of vibration is that when the wearer's body is in a sitting posture that tilts to the right (right cheek support, right tilt), the vibration module located on the left side of the lumbar spine will give a short vibration prompt. When the body is in a sitting posture tilted to the left (left cheek support, left tilt), the vibration module located on the right side of the lumbar spine will give a short vibration prompt. When the body is in a sitting posture tilted back and forth, the module located in the middle of the spine gives a short vibration prompt.
The second type of wearable feedback is the visual feedback which was realized by sewed LEDs. As mentioned in the previous studies, visual feedback is the best for the user's guidance. At the same time, too complex visual feedback may cause interference.
Therefore, we choose to guide the user to correct the sitting posture through weak LED light feedback.

Mobile APP will be used as another main feedback channel for the following considerations.
1. Indicative feedback with more clear and indicative contents to support the users adjust their postures.
2. Display long-term posture data so that users can get more comprehensive personal health information.
3. Social support, target groups mentioned they would be more motivated to participate when their friends around them were doing the same thing.
Based on the analysis of the needs of the above related groups, the APP is divided into the following modules, which are sitting position monitoring module used to observe their sitting position in real time and receive reminders, personal data module used for long-term records, and according to the date of the past data records, equipment control module and feedback module used to control equipment, knowledge community module used for friends to check the sitting position ranking and interactive communication, learning health related knowledge.

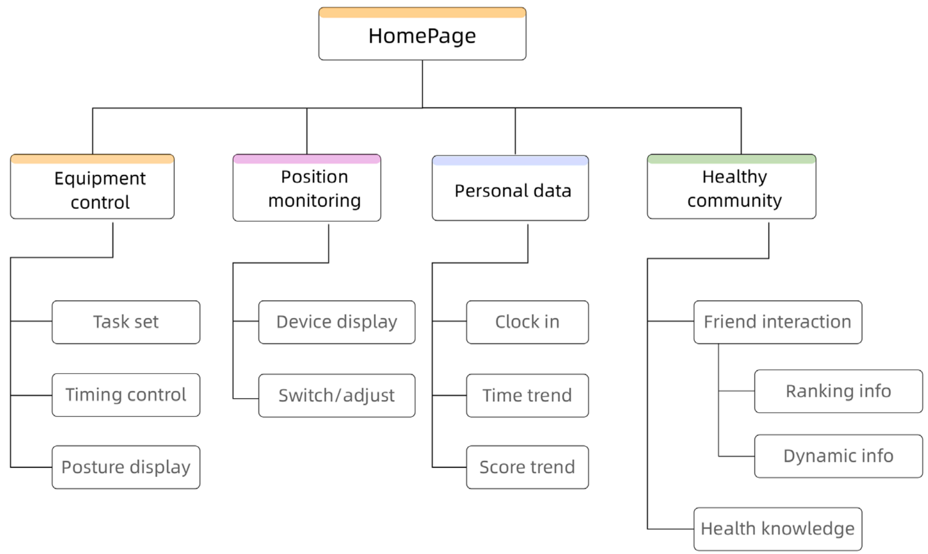


Fig 35. The APP information structure

According to the function stages of sitting posture detection, APP users can be divided into three stages, first, the initialization setting process before use. The second is the process of using APP to monitor and remind sitting position. The third is the information acquisition and interaction based on collected data after detection.

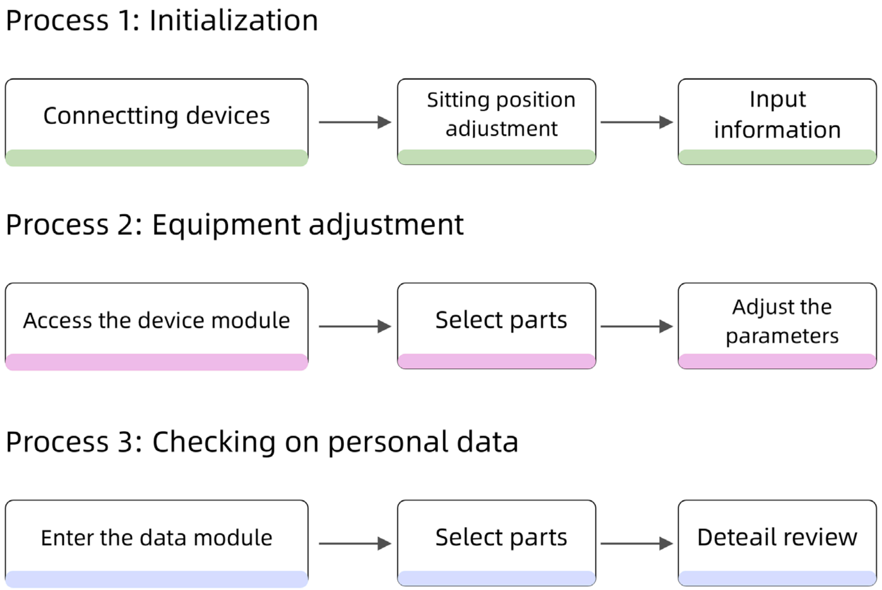


Fig 36. The main process of the APP

Process I refers to the personal information and settings required by users when they use the APP for the first time, including the following parts.

1. Role selection is when users need to select roles according to their identity when they first use it. The core users of this APP are teenagers who need to develop good sitting habits. Other users include parents, teachers and physiotherapists, etc. Therefore, the information content displayed by the APP varies according to the user attributes.

2. Self-image creationis when users can choose their own image and define themselves when using it for the first time. When creating their own image, it can effectively improve the interest and user participation, better map the role in the subsequent APP to themselves, and have a better sense of inclusion when reminding them.

3. Equipment adaptation is where after putting on the detection clothes, the equipment adaptation step is carried out. The purpose of this step is to set the initial value of the sensor. As the detection principle mentioned above, even if the height and weight of the same standard and the clothes of the same size are worn, the initial resistance measured will be different due to slight differences. Therefore, after wearing the clothes, you need to sit and wait for the setting of the initial value according to the guidance on the interface.

4. Device Settings is where the user's can use interface to set feedbacks mode for the wearable part. In this section, the interface displays the feedback signal of the adaptive device. Users adjust the feedback strength by sliding, and switch between feedback modules through buttons.

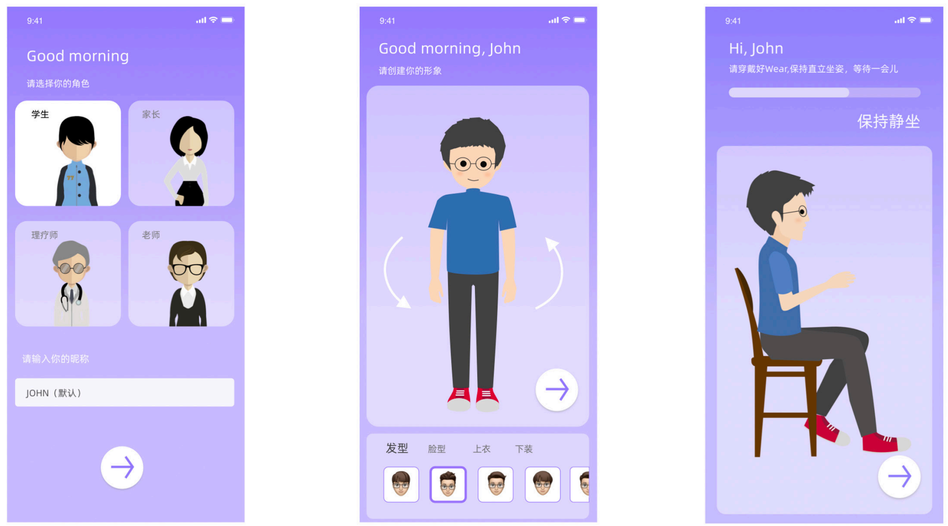


Fig 37. The initial process of the APP

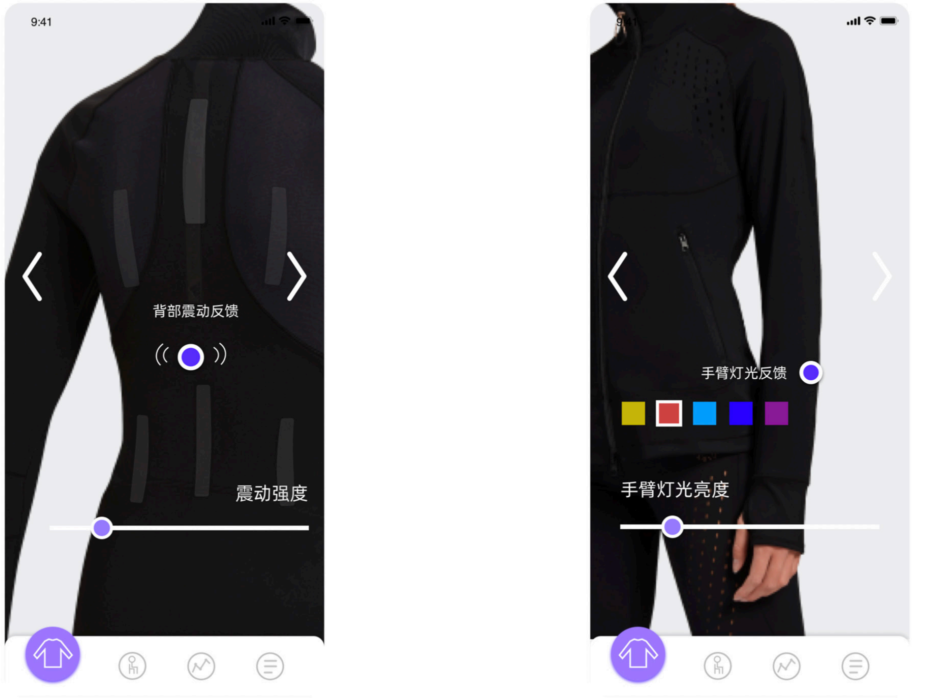


Fig 38. The equipment control interface of the APP

Process 2 is the most important process in the APP, which is to display the real-time sitting position of the user and provide timely reminders. The user status and interface are shown as follows. When the APP is started, the interface begins to connect the device to synchronize the user's sitting position and guide the user to keep the correct sitting position. It offers the always-on capability and when the user has a wrong sitting position, the screen will automatically light up to show the user the sitting position and give adjustment instructions.

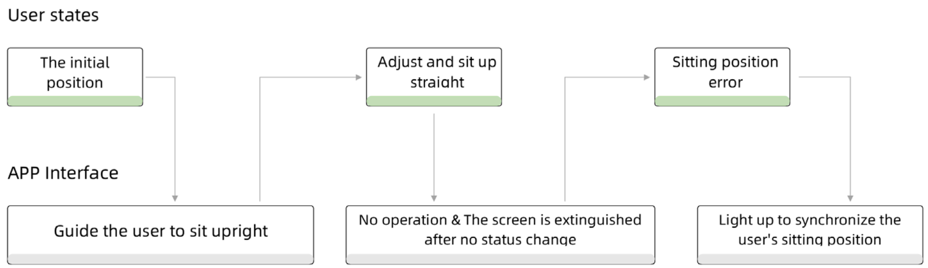


Fig 39. The reminding process of the APP

The specific sitting posture adjustment feedback interfaces are as follows, when the user sits in a wrong way, the cartoon character will appear in the corresponding state simultaneously, it has four wrong sitting postures, forward, backward, hunchback, and prone writing. A prompt to adjust the sitting posture appears in the interface, as well as a background adjustment in auxiliary scale circle.

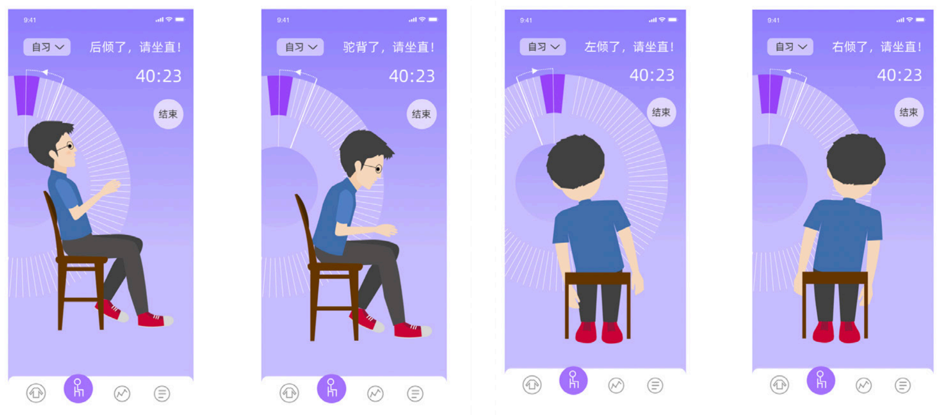


Fig 40. APP interface for posturing reminding1

When left and right tilt error postures occurres, the interfaces present the characters by the view from the behind. So it would be clear to see the wrong postures.

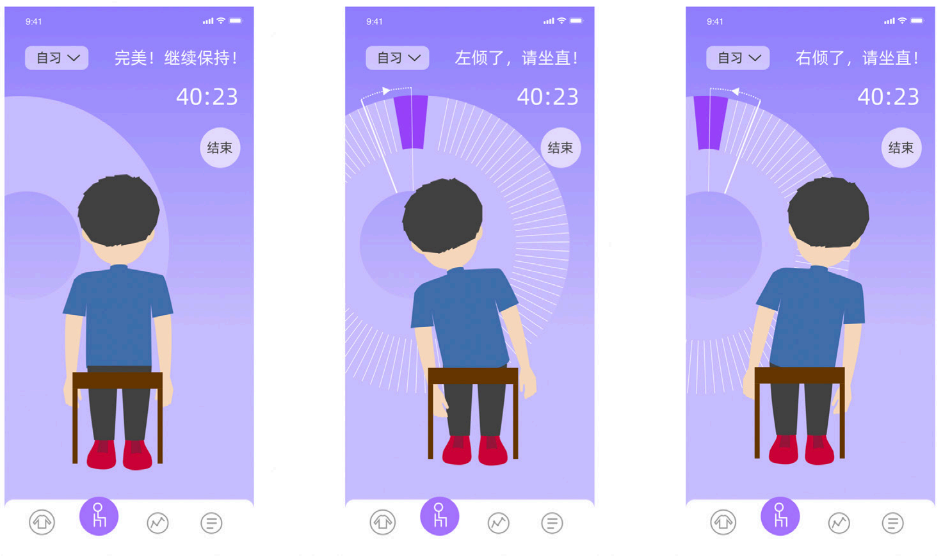


Fig41. APP interface for posturing reminding2

Chapter 6　Testing and Validation

In this chapter, different methods were carried out to make a complete evaluation to prove the system's effectiveness and usability.
A total of three testing mrthods are introduced and their reslults are all quantified to show system's performance.

6.1 Evaluation Planning of the Wearable Interaction System

In this study, different methods are carried out to make a complete evaluation. For the wearable monitoring and feedback, effectiveness and user experience were evaluated. For the APP interface design, usability test was conducted.

For a complete intelligent wearable device, mechanical performance test, usability test and clinical test are to be conducted according to different stage of users' participation.

The purpose of mechanical performance test is to see whether if the system has the preset function and whether the corresponding function can achieve the desired effect in the target scene.

Usability testing is a user-centered method, it requires the users to give the scores and tell the deficiencies of experience. It is a quantitative testing method based on subjective feelings.

The purpose of clinical testing is to make a more rigorous evaluation. Based on the rehabilitation theory, the users are allowed to use the system, and then evaluated by scientific methods. Such as the CKCUES Test (Closed Kinetic Chain Upper Extremity Stability Test). The effectiveness of the system can be measured by CEQ (The Credibility/Expectancy Questionnaire), through which users will rate the system from the dimensions of trust and expectation after using the system. The IMI (Intrinsic Motivation Inventory) is another measurement of user operating experience based on self-determined motivation theory, which can be used in system evaluation to score system operating experience in multiple dimensions.

In this study, different test methods were formulated according to the different emphasis of the design contents.

1. For the part of wearable monitoring and feedback, it focused on the effectiveness and multidimensional experience. By setting up simulation scenarios and using the methods of usability and comparative experimental testing, the subjects were invited to have short-term experience, then the prototype was comprehensively evaluated and analyzed.

2. For APP interface feedback, it focused on visual information display. Three testing methods were combined to evaluate its performance, which are usability test, heuristic evaluation and real-scene test, the former two are more about the UI perspective and the last one is about the combination experience used with the wearable device.

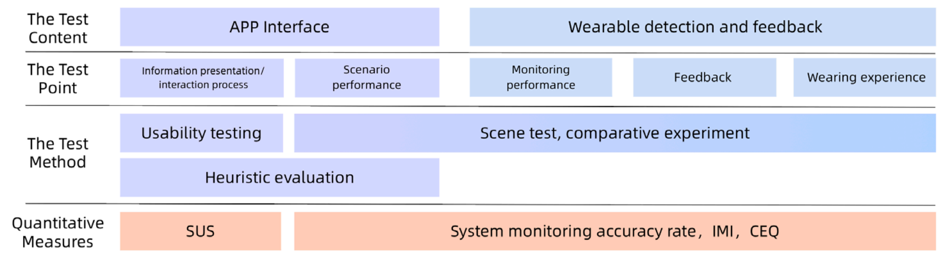


Fig 42. Evaluation planning for system use experience

6.2 User Testing of the APP Interface

6.2.1 Heuristic Evaluation

The heuristic evaluation is based on the use of APP by users who has professional knowledges, to find out the existing deficiencies, point out improvement points and some suggestions. The principles followed is based on the ten usability items of heuristic evaluation.

In this study, four professional graduate students were invited to use and evaluate the APP interface according to the principles. The problems found are rated by severity scores, expressed by 1 to 5 from light to severe. The average score of each question was taken as the final severity score, and the results are summarized in the table below.

Table 10. Problems from Heuristic evaluation

Problem	Principle	Severity
In application scenarios, it is difficult to obtain interface information	Recognition rather than recall	4
Lack of user guidance during initial setup	Visibility of system status	4
Elements of the feedback setup interface are not strongly related to the hardware part	Match between system and the real world	2
Think the module of sitting position ranking is redundant and has no connection with others	Consistency and standards	3
The perception of personal data has a learning cost	Recognition rather than recall	2

The problems detailly mentioned are classified and analyzed according to the 5 elements of user experience (Garrett, 2003).

In terms of the interaction information, users mentioned it lacks the guidance when they used the app for the first time, it would be difficult to understand how to start. And when setting the feedback modes, users have doubts about the connection between the operation on the app interface and the feedback on the wearable device.

In terms of the visual expression, users mentioned that in the real scene, they want to know their sitting state with just a glance, but not keep looking at it.

The visual appeal of the interface and the simplicity of interaction were good points users all agree with.

6.2.2 Usability Test

In the usability test, the information presentation and the smoothness of the user's operation were the main points.

In this thesis, 12 test samples were collected, the age of the tested users is between 12 and 18 years old (M=15.84, SD=1.61), and the sex ratio is 2:10.

Table 11. User score of SUS questionnaire

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
P1	4	2	3	2	4	2	4	1	5	3	75
P2	4	1	3	1	4	1	4	2	4	1	82.5
P3	4	3	5	3	3	1	3	2	4	5	62.5
P4	3	4	3	2	4	1	4	1	4	3	67.5
P5	5	5	1	1	4	1	5	1	5	1	85
P6	4	1	5	1	5	2	4	2	4	2	77.5
P7	4	1	4	3	4	2	3	2	5	1	77.5
P8	4	1	5	1	4	1	5	1	4	2	90
P9	4	1	4	2	4	3	5	1	5	1	85
P10	4	2	4	1	4	1	5	1	5	1	90
P11	5	2	4	1	4	3	4	2	4	2	77.5
P12	5	1	5	1	5	2	4	1	5	1	95
M	4.1	2.2	3.7	1.7	4.1	1.7	4.1	1.5	4.3	2.1	77.9

After the user completes the interface operation, the average score of the SUS scale is 77.9 points, and the standard deviation of the score is 12.282. It can be found that the complexity and learning cost of the APP are high, which means guidance may need to be improved.

6.3 Effectiveness Test of the System

6.3.1 The Content and Procedure of the Test

In this section, the goal of the experiment is to evaluate the feasibility and effectiveness of the system, and the user's experience in the real environment.

A comparative observation experiment method was conducted. By controlling the state of the system as a variable factor, it can be observed that the different states of users when they performed the same task. As did in the previous testing, subjective feelings were collected after they used the system, in the form of questionnaires and interviews.

The scene was set to simulate teenagers' daily home/classroom environment. A simulation of the real environment was prepared for performing learning tasks, and the entire process of the test was recorded through video equipment.

Because the shirt has a size limit, three users aged from 19 to 23 (M= 22.3, SD = 2.31) with similar heights (M = 161cm, SD = 1cm) and weights were selected when recruiting volunteers for the study.

The detailed participants information are as follows.

Participant 1 is a 19-year-old freshman with a height of 161cm and a weight of 49kg. She has not used a sitting posture correction device before, and the task was writing.

Participant 2 is a 23-year-old graduate student with a height of 162cm and a weight of 46kg. She has not used a sitting posture correction device before, and the task was to use a computer.

Participant 3 is a 23-year-old graduate student with a height of 160cm and a weight of 44kg. She has used a sitting posture correction belt before, and the task was to read.

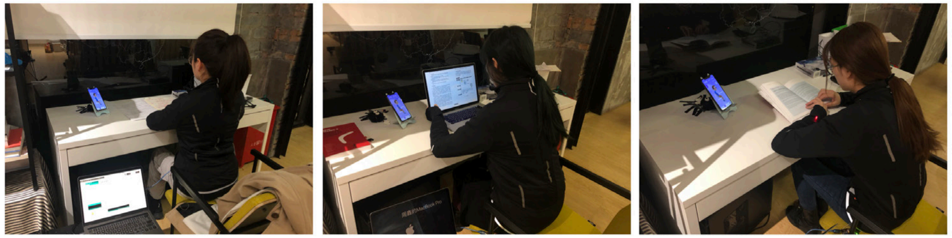


Fig 43. The three participants used in this study

This testing study followed four stages, in each condition the smart shirt was worn and other variables were controlled. Each stage lasts for 30 minutes.

The first stage would be the baseline, that is, without any sitting posture reminder, and the sitting posture data of the natural state was collected for comparison. In the second stage, the wearable feedbacks was provided, when the user's sitting posture was wrong, the vibration module and the LED module would offer reminders. In the third stage, the mobile phone was placed on the desktop, the APP feedback was also provided together with the wearable feedbacks. Finally, in the last stage, only APP interface was provided.

Table 12. Task schedule for participants.

	Stage 1 No Feedback	Stage 2 Wearable Feedback	Stage 2 Wearable & APP Feedback	Stage 4 APP Feedback
Participant 1	Writing for 30 mins	Writing for 30 mins	Writing for 30 mins	Writing for 30 mins
Participant 2	Using computer for 30 mins	Using computer for 30 mins	Using computer for 30 mins	Using computer for 30 mins
Participant 3	Reading books for 30 mins	Reading books for 30 mins	Reading books for 30 mins	Reading books for 30 mins

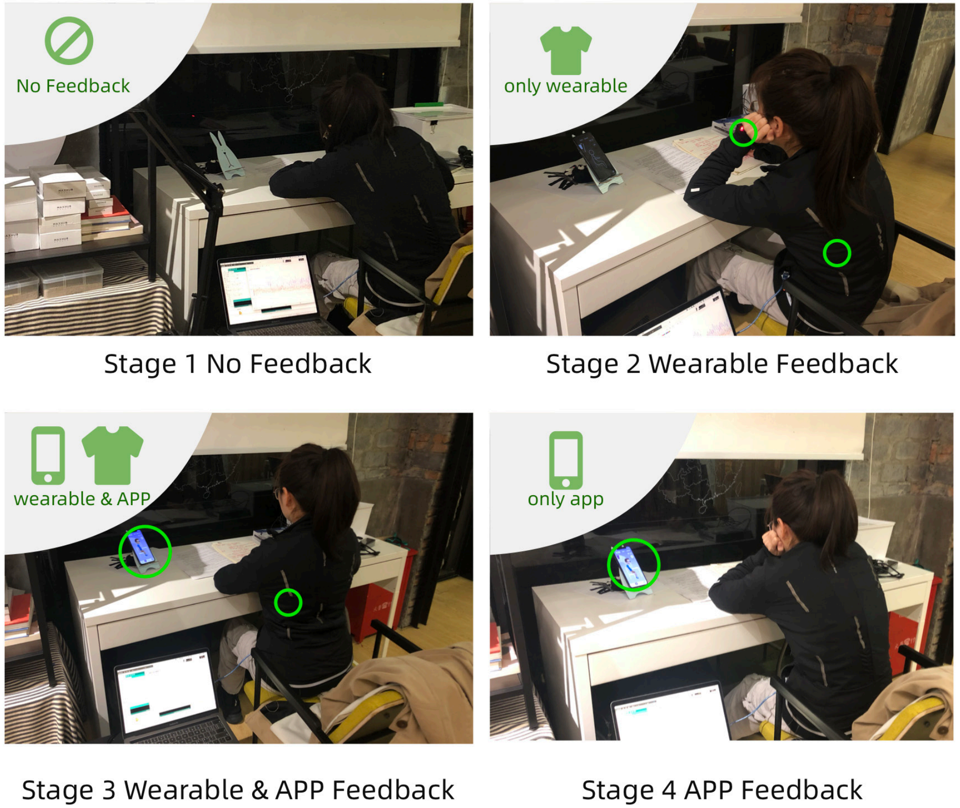


Fig 44. Four stages with different feedbacks of the test

After the test, users' subjective evaluation and objective data are taken to comprehensively evaluate the effectiveness of the system. Users were asked to fill in the evaluation questionnaire and they were interviewed about their feelings.

By observing the video of the user's test process, with the detection of changes, the user's correct sitting posture and incorrect sitting posture times can be calculated, as well as the number of sitting errors.

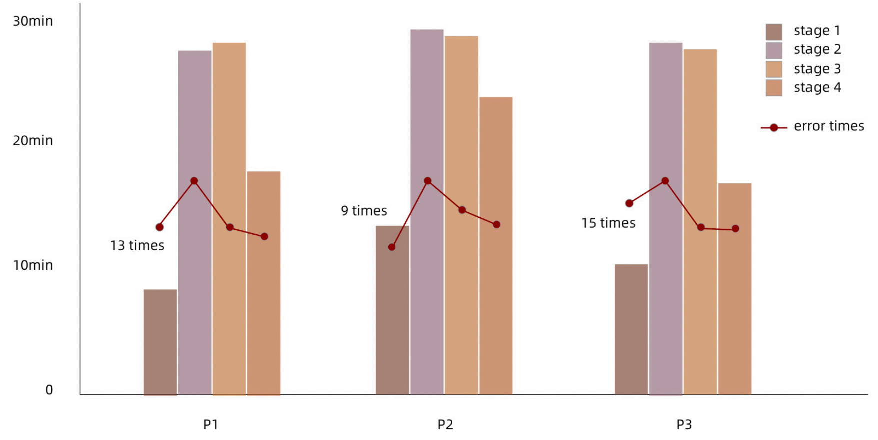


Fig 45. The user's correct sitting time and the incorrect sittings posture times

6.3.2 The Result and Analysis of the Effectiveness Test

It can be calculated that the number of incorrect sitting postures detected by the three users is totally 98 times, while the number of times calculated from actual observation is 103 times, recognition rate of the system for incorrect sitting postures was 95.1%. Among the sitting postures that have not been successfully recognized, they were mainly lean left and forward. The reason is that when those types of sitting posture occurred, the back is straight and the tension on the sensors is similar with when they are in the right posture.

According to the statistical results, the user's correct sitting posture takes less time especially in writing and reading tasks. In the following three stages, with the feedback provided when the sitting posture is wrong, the probability of users in the correct sitting posture has been greatly improved, the number of wrong sitting postures is reduced, and the number of sitting errors in the natural state also reduced. At the same time, it was mentioned in the interview process that there was a certain awareness in the later test.

In the fourth stage, when the wearable feedback is turned off, the user's correct sitting time has decreased compared with the second and third stages. During the interview with the users, it can be found that the user is performing his reading work, the feedback of the APP interface is not easy to be noticed. In the last tasks, situation gets better because that the user's visual area can easily observe the mobile APP interface.

In this study, two types of questionnaires were used to carry out systematic evaluation from different perspectives, which were conducted after stage 2, 3 and 4 respectively. The CEQ questionnaire is used as a quantitative means to evaluate the effectiveness of the system including the users' trust and expectation of the system.

The intrinsic motivation scale is used for systematic experience evaluation. The activities referred to in the scale used in this study are wearing devices and using APP. Based on users' experience of wearing and operating, the scale evaluates users' sense of enjoyment, sense of completion, sense of engagement, sense of pressure, sense of value and sense of intimacy.

The research calculated the data of CEQ questionnaire and found the trust level was 32.7 in stage 2, 34 in stage 3 and 26 in stage 4. The expected value was 15.3 in stage 2, 18 in stage 3 and 14 in stage 4.

Combined with the user's interview information, it can be found that in the process of using the APP, the sitting state of the user can be displayed in real time, the user feel closer connection with the device, therefore, the expectation is slightly higher than that in stage 2.

Table 13. Three stages of trust and expectation statistics

	Stage2		Stage3		Stage4	
	credibility	expectation	credibility	expectation	credibility	expectation
P1	36	17	34	18	37	19
P2	29	14	33	18	21	12
P3	33	15	35	18	20	11
M	32.7	15.3	34	18	26	14
SD	3.5	1.53	1	0	9.5	4.4

The Intrinsic Motivation Scale was used as a questionnaire to evaluate the system experience. The scale is based on the user's experience of wearing and operating, and the user's sense of enjoyment and completion Six aspects are evaluated (Interest/Enjoyment, Perceived Competence, Effort/Importance, Pressure/Tension, Value/Usefulness, Relatedness).

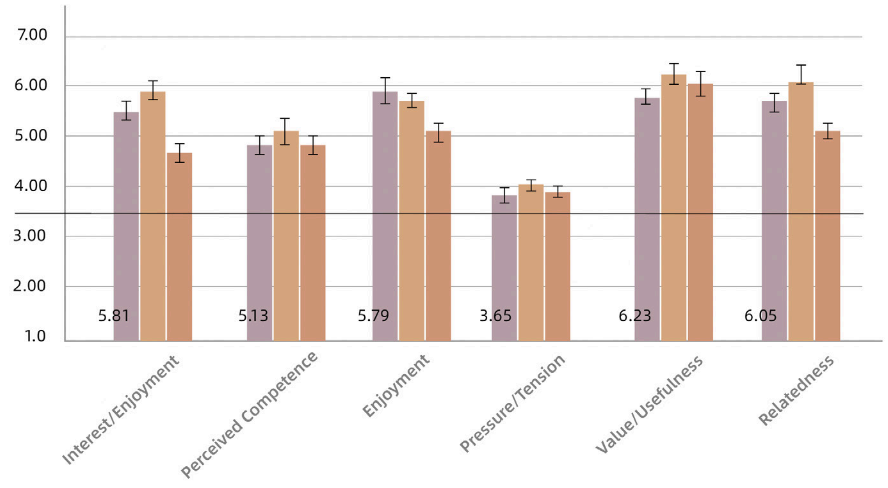


Fig 46. The scores of IMI questionnaire

The highest is value or usefulness, which reached a score of 6.23. In the interview, all the participant said they felt that their posture has become better when using the system. Participant 1 also mentioned that sitting in a right way can improve the working efficiency, especially when they felt tired before using it. It is verified that the system can prompt the user to maintain a good physical posture, thereby making the user feel the value from the psychological level.

The second score is the sense of intimacy, the user mentioned that when using the APP, they can feel the connection between themselves and the product. It is new for the participants that the character creation of the APP and the change of the sitting posture of the character have also occurred simultaneously.

In terms of negative factors, users gave a high score on the sense of stress, reasons could be the physical discomfort, and when the two types of feedback modes are turned on at the same time, they felt nervous some time.

The comfort of the product is the most deficiencies mentioned, followed by interference. This is partly because the detection of the fabric sensor needs to be close to the human body, so a tight jacket was selected, which has a negative feel on wearing.

Chapter 7　Conclusion and Future Development

In this chapter, a conclusion is written about the research and design. It summaries what have been done in this thesis and its contribution and dificiency.
In the last, it explains the pratical value to specific groups and potentials to further achieve.

Chapter7 Conclusion and Future Development

7.1 Conclusions from the Design Research

This thesis paid attention to the health problems of sitting posture of teenagers, it started from fabric sensing technology, exploring how to rationally apply fabric sensing technology through the design of interactive system to solve the former problems. By summarizing the research status of the problem, the study of the crowd, the existing technology and the relevant theory, the fabric sensing interaction system architecture was proposed. Through the design practice, the framework is demonstrated in the form of design concept and prototype, and the design scheme is verified through the usability and effectiveness test of the system.

The problems of this study are derived from the actual scenes and needs, and the needs and scenes are clarified through the investigation of the target population. At the same time, the characteristics and research status of fabric sensing technology are summarized, and the shortcomings of research are pointed out from the professional perspective of interaction design. In this paper, the design steps and flow of interactive system are proposed for the target scene, and the design practice is carried out.

The main work done in this thesis can be summarized as follows:

1. This paper summarizes the current research progress of posture detection and fabric sensing technology, and proposes and confirms the possibility of applying the technology to practical problems.
2. Conducted research on the target population and disassembled and analyzed the problems, further defined the content of the problems to be solved, and pointed out the reasonable path of design and research according to their needs.
3. The research on fabric materials is related to the demand of sitting posture detection, material testing and the production of sensing units are carried out in an appropriate way, and the design and production of detection clothes based on fabric sensors are carried out in combination with the use scene and crowd.
4. From the perspective of interactive design system, the complete interactive closed loop of the detection clothing is designed to build an interactive system of sitting posture detection, and appropriate feedback mechanism is designed to promote teenagers to adjust their sitting posture.
5. A system test based on the real scene was carried out to verify the effectiveness and interactive usability of the system and summarize the deficiencies and areas for improvement.

And through the above research process, conclusions can be draw that the overall performance of the system is well, which can be seen in chapter 6, the usability of the APP interfaces is easy to understand (seen in table 11), the instructions is clear and readable (seen in fig 40 & 41), since in the interface design, two different perspectives from back and side are combined to show the real-time postures.

It also shows better acceptance and inclusiveness compared to the existing products, when participants talked about their feelings of using the system, the most mentioned is convenient and flexible since our system provides several different modes and users are able to select one or multiple based on their needs. It means that users are more pleasant to set and use the feedback so they will get more precise instructions on posture correction, this effect can be seen from the chapter 6.3 and the scores are high and persuasive.

7.2 The interaction system's prototype

In this thesis, a wearable sitting posture correction system based on new material was developed. The prototype is consisted of two main parts, one is the smart jacket which is able to detect user's posture change and provide tactile feedback as mentioned in the thesis. Its transmission structure can be seen from the linins connected by conductive threads and Arduino processing module. The textile sensors are sewed on the outside as it can be seen as decorations. But there is no difference with a normal jacket when users are wearing it.

The other part is the APP which mainly provide visual feedback to the users, it has the advantages of clear indications and long-term tracking data display. It also can be a controller of the wearable feedback with further development. When using the system, the phone can be placed on the table so it's easier to get information from it.

Fig 47. The introduction of the system's prototype

7.3 Potential application and its beneficial stakeholders

In this thesis, a wearable sitting posture correction system based on new material was developed through the designing method and practice, more importantly, the system is proved to be well-functioned.

From the research perspective, the designing method of applying textile sensors to design a wearable system can be a reference for the designer who wants to explore in such area.

The functional prototype can be widely used in school for improving children's sitting posture so to make them a healthier habit, as it is the main purpose.

In the similar way, the prototype can be used in the sitting posture correction for other long-sitting groups like the white-collars, it only needs to change the size of the cloth and the initial settings.

The current system used the strain textile on the back so it could detect back's posture, but if they are put into other parts of the body to detect other postures, it will get a broader application field, like detecting arm or leg posture, so rehabilitation facilities and hospitals can have a better way to do health treatment and evaluate it.

Further possible application can be the detection of movements since the movement can be seen as a certain sequence of static postures, so by upgrading the algorithm to be capable of mapping a sequence of postures into a certain kind of movement, though it is not fulfilled in this thesis, it is still a theoretically feasible.

Except for the value of the already done prototype, when in the process of design practice, the following contents that can be further optimized.

1. In the material testing and decision stage, better and high-quality solutions can be found through tests of more types of materials. Due to limited resources in this study, several materials to be selected are actually similar stretched conductive fabrics, other kinds of feasible materials are not tested here.

2. In the later stage of design, deeper and diversified test feedback can be obtained through more detailed and higher degree of restoration system test. In the test of this study, the user's experience evaluation is mainly obtained through the way of simulating the scene. Although the aspects we focus on are key, they still need to be further subdivided to obtain a clearer direction of design optimization. The prototype of this study is used to verify the feasibility of the overall design idea and results, and there is still a large room for improvement in the comfort and aesthetics of wearing.

References

Brown RA. (2016) Spinal Health: The Backbone of Chiropractic's Identity. J Chiropr Humanit.

Carolin Bontrup.(2019) Low back pain and its relationship with sitting behaviour among sedentary office workers,Applied Ergonomics

da Costa, B.R. and Vieira, E.R. (2010), Risk factors for work related musculoskeletal disorders: a systematic review of recent longitudinal studies.

Drzał-Grabiec, Justyna et al.(2015) 'Effects of the Sitting Position on the Body Posture of Children Aged 11 to 13 Years'.

Sedrez. (2015). Fatores de risco associados a alterações posturais estruturais da coluna vertebral em crianças e adolescentes.

Alibegović. (2020). School Furniture Ergonomics in Prevention of Pupils' Poor Sitting Posture

Korakakis V.(2019).Physiotherapist perceptions of optimal sitting and standing posture.

Kazuhiro.(2018)."Sitting posture analysis by pressure sensors," 2008 19th International Conference on Pattern Recognition.

Skach. (2013).Intelligent Chair Sensor.

W. Xu.(2011).eCushion: An eTextile Device for Sitting Posture Monitoring.

Sedrez. (2015).Risk factors associated with structural postural changes in the spinal column of children and adolescents.

Sophie.(2018).Smart Arse: Posture Classification with Textile Sensors in Trousers.

Chen, K(2019)."Sitting Posture Recognition Based on OpenPose."

Wang W-J.(2016).Human Posture Recognition Based on Images Captured by the Kinect Sensor.

Fraden J. (2016).Physical Principles of Sensing. In: Handbook of Modern Sensors.

Toprakci H.A.K., Ghosh T.K. (2015) Textile Sensors. In: Tao X. (eds) Handbook of Smart Textiles.

Greenwood, James. (1966). Constriction Resistance and the Real Area of Contact.

Wang, Qi & Toeters, Marina & Chen, Wei & Timmermans, Annick & Markopoulos, Panos. (2016). Zishi: A Smart Garment for Posture Monitoring.

G. Bhat, R.(2018)."Online Human Activity Recognition using Low-Power Wearable Devices"

Ryu, Hochung. (2018)."A knitted glove sensing system. with compression strain for finger movements."

Patrick Parzer. (2017).SmartSleeve: Real-time Sensing of Surface and Deformation Gestures on Flexible.

Shaowei Lu.(2019).Wearable graphene film strain sensors encapsulated with nylon fabric for human motion monitoring.

L. Iuppariello et al(2016)."Effects of wavelets analysis on power spectral distributions in posturographic signal processing".

Gholami M.(2019).Kinematics Monitoring in Running Using Fabric-Based Wearable Sensors and Deep Convolutional Neural Networks.

M. Bobin.(2017)."SVM based approach for the assessment of elbow flexion with smart textile sensor".

N. A. Choudhry.(2020)."Design, Development and Characterization of Textile Stitch-Based Piezoresistive Sensors for Wearable Monitoring".

P. Randhawa.(2017)."A review on applied machine learning in wearable technology and its applications".

Tavassolian. (2020).Textile Based Inductive Soft Strain Sensors for Fast Frequency Movement and Their Application in Wearable Devices Measuring Multiaxial Hip Joint Angles during Running

N. Mezghani.(2017)."Context aware adaptable approach for fall detection bases on smart textile,"

Jiang.(2021)Head motion classification using thread-based sensor and machine learning algorithm.

M. Bobin.(2017). "SVM based approach for the assessment of elbow flexion with smart textile sensor".

Maxence Bobin.(2017).DNN based Approach for the Assessment of Elbow Flexion with Smart Textile Sensor.

O'Sullivan K.(2013).Investigating the effect of real-time spinal postural biofeedback on seated discomfort in people with non-specific chronic low back pain.

Guo.(2010).“Textile Strain Sensors Characterization- Sensitivity, Linearity, Stability and Hysteresis.”

Mokhlespour.(2017).Trunk Motion System (TMS) Using Printed Body Worn Sensor (BWS) via Data Fusion Approach.

Andrew P.(2009).Is ‘ideal’ sitting posture real?:Measurement of spinal curves in four sitting postures

Fogg, BJ. (2009). A behavior model for persuasive design.

Duhigg.(2014).The Power of Habit : Why We Do What We Do in Life and Business.

Eyal, N., & Hoover, R. (2014). Hooked: How to build habit-forming products.

Sigrist, R. (2013).Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review.

Schmidt RA.(1997) Continuous concurrent feedback degrades skill learning: implications for training and simulation.

Chiviacowsky. (2010).Frequent External-Focus Feedback Enhances Motor Learning.

Wang Q. (2017).Interactive wearable systems for upper body rehabilitation: a systematic review.

Semjonova G.(2020).Improving the Recovery of Patients with Subacromial Pain Syndrome with the DAid Smart Textile Shirt.

Ishac K.(2018).LifeChair: A Conductive Fabric Sensor-Based Smart Cushion for Actively Shaping Sitting Posture.

Tucci HT.(2014). Closed Kinetic Chain Upper Extremity Stability test (CKCUES test): a reliability study in persons with and without shoulder impingement syndrome.

Devilly. (2000). Psychometric properties of the Credibility/Expectancy Questionnaire.

Garrett, Jesse. (2010). The Elements of User Experience: User-Centered Design. for the Web and Beyond.

Bastien, J.(2009). Usability testing: A review of some methodological and. technical aspects of the method.

Giles Colborne.(2010).Simple and usable web, mobile, and interaction design. New Riders. Berkeley, USA.