Design Research Project-IND402

Name: Kedong Chai

Student ID: 2140058
Xi'an Jiaotong-Liverpool University

Promoting Social Connections and The Inclusiveness of Mixed Reality Technologies by Design

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Abstract

Immersive technologies, such as augmented reality (AR) and virtual reality (VR), have gained widespread adoption, particularly in the fields of education, accessibility, and healthcare. With a rapidly increasing user base, it is expected that these technologies will have a significant impact on human-computer interaction. However, the use of Head Mount Display (HMD) devices by some individuals can lead to isolation and exclusion of non-HMD users, resulting in a separation between the real and digital worlds that can be detrimental to human-computer interaction. This has led to the emergence of a new research direction focused on cross-reality interaction, with an emphasis on the use of physical feedback devices to facilitate interaction between VR users and the natural environment. While some designers and researchers have considered the use of physical feedback to enhance the VR user experience, few have examined the potential for creating novel interactions between different end-users through these devices. The use of physical feedback to facilitate interactions between VR and non-VR users is an important, but challenging, goal. To address this issue, this research project will utilize a Research through Design (RTD) approach to create an interactive cross-reality system with physical feedback devices and asymmetric games. This research is vital for improving cross-reality interactivity for VR/AR users and non-VR users, and will help make VR technology more inclusive for a wide range of user types.

These issues have recently led to a new research direction - cross-reality interaction. Physical feedback devices are also considered an effective means of facilitating interaction between VR users and their natural environment. While many researchers and interaction designers have focused on enhancing the user experience in VR with the help of physical feedback devices, little attention has been paid to the importance of facilitating interactions between different end users by adapting physical feedback devices. Therefore, using the RTD design methodology, I will create an interactive cross-reality system with physical feedback devices. The project will explore how physical feedback and cross-reality interaction affects the asymmetric game design and how VR users interact with regular users. This research project is critical to improving cross-reality interactivity for both VR / AR users and regular users. It will enable VR technology to become more inclusive across many user types.

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Chapter 1

Introduction

1.1 Background

Immersive technology is shown significant promise in various fields and is being employed in a wide range of applications. Despite 40 years of research into Virtual Reality (VR), current VR technology still suffers from three significant drawbacks. Firstly, barriers to game migration are likely to become increasingly common. A study by researchers Professor Frank Steinicke and Professor Gerd Bruder [1] from the University of Hamburg, Germany, found that long-term use of VR devices can lead to volunteers being unable to distinguish between virtual and reality. Secondly, the immersive nature of VR can also create a sense of isolation [2]. Thirdly, while consumers increasingly use VR, simultaneous use of multiple HMDs remains rare due to cost, space required, and potential conflicts between users. There are also insufficient opportunities to increase interaction between VR users and AR users and between users in general.

As such, cross-reality interactions that include enabling non-VR users to access VR experiences are seen as promising ways to increase social interactions between VR users and bystanders (e.g. Gugenheimer et al. 2017 [3]; Lee et al. 2020 [4]). In particular, social aspects of cross-reality VR research are becoming increasingly popular [5]. There has been a proliferation of design and research on virtual reality (VR) that incorporates social interaction as a means of improving cross-reality interactions.

Designers can use these immersions to present endless virtual worlds with countless interactive objects. However, the interactive capabilities are limited because the most popular device for manipulating virtual objects is the controller that the user must carry. While controllers provide a great deal of input capability for VR, output capabilities are still limited. The haptic feedback provided by the controller does not simulate the virtual object's various texture and shape factors. Where products already exist, they are often attached to VR

Fig. 1.1 The widespread use of VR[55].

headsets or used as replacements for VR controllers. This makes them often complex and challenging to use, and the interaction with the user is not very natural. If the user does not have a VR device, they will not be able to use these devices that provide physical feedback to engage with the interaction. Therefore, researchers have conducted extensive research to explore possible approaches.

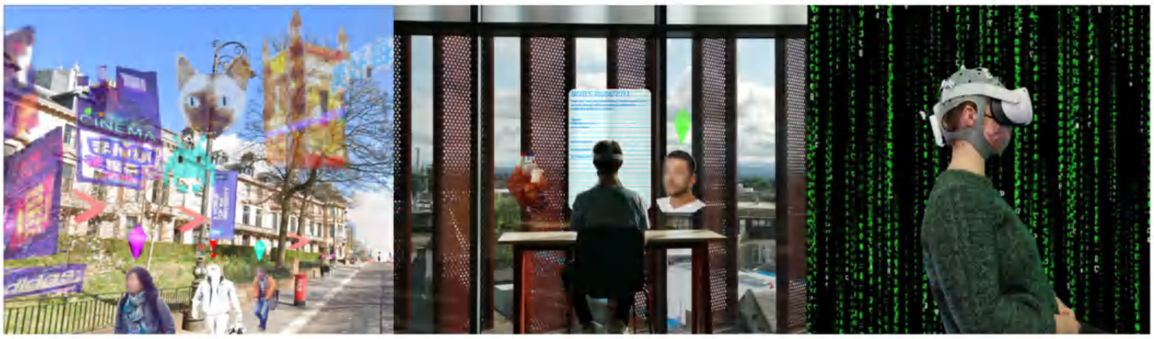


Fig. 1.2 Cross-reality interaction connects the virtual and the real[6].

Current virtual reality and the communications within it are highly focused on sight and sound, neglecting other human sensory experiences. Our eyes and ears are engaged, but an important part of us stays disconnected, our sense of touch. However, the sense of touch is paramount in making a more immersive and realistic VR experience beyond the screen.

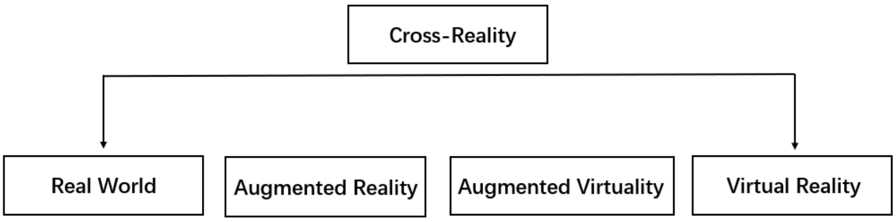


Fig. 1.3 Cross-reality interaction connects the virtual and the real.

1.2 Research Question

Can cross-reality interactions and Haptic feedback devices enhance the user experience and promote social connect?

How to design virtual experiences to benefit our long-term health and well-being?

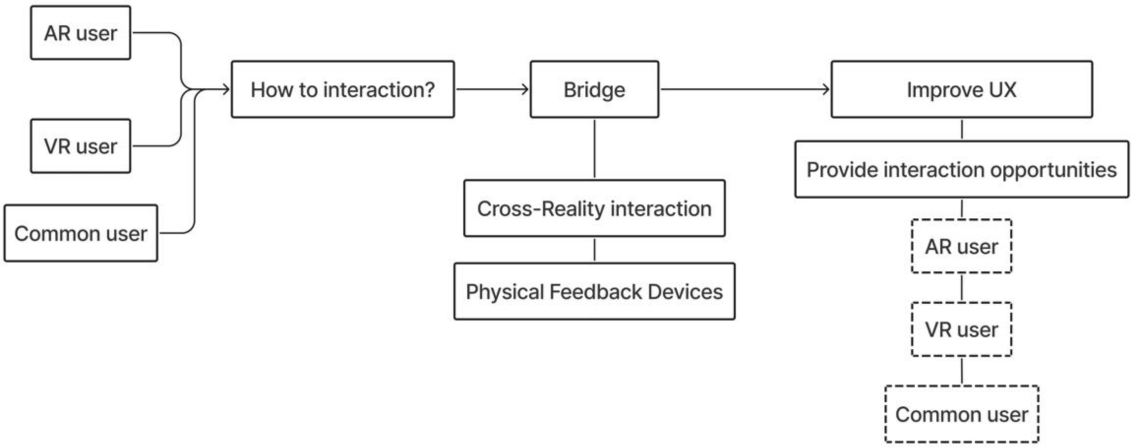


Fig. 1.4 Focus of the research questions

1.3 Research Value

The lessons and frameworks derived from this project through design practice offer possible ways to explore how design can help make mixed reality technologies more equitable and inclusive.

Avoiding the isolation of the virtual world from the real world. Reduce the range of social problems caused by the isolation of the real and the virtual, and promote human interaction and connection.

The deep connection of people. People of all classes and ethnicities come together across the virtual and the real to experience new technologies. Not only in terms of gaming and entertainment, but also in terms of learning and much more.

More realistic than VR controllers. Users can enjoy a more realistic and fully immersive experience by having the opportunity to feel the sense of touch at their fingertips. This will greatly improve the pleasure they get from playing in virtual environments and the sense of achievement they get from learning virtually in a virtual experience.

Mixed reality will be more inclusive. The possibility of accessing virtual world experiences for people with disabilities, the elderly, children and those who previously could not enjoy immersive experiences is opened up.

1.4 Methodology

Research through design (RTD) is a cyclical process where explores concepts iteratively to improve the user experience. A method such as Experience Prototyping will be used, where concept prototypes are produced rapidly using existing materials to simulate the experience of using the product. In-depth user research will include questionnaires and semi-structured user interviews.

1.4.1 Research through Design

RTD [7] [8] is the primary design methodology for this design research project, focusing on design iterations. Practices, research, prototyping, testing, and iterations are all designed to implement this incremental model. This design research project will primarily use a research model of interaction design for HCI research proposed by John Zimmerman et al. [9]based on Frayling's [10] research through design.

This design process uses basic research to obtain multiple perspectives on a problem. Ideation is used to generate different possible solutions. A cyclical process of exploring concepts through iteration to improve user experience. Design iterations are considered through reflection. Using this model, interaction design researchers need to combine models and theories from behavioural scientists with technical opportunities demonstrated by engineers. Through an active process of conceptualizing, iterating, and critiquing potential solutions, design researchers continually redefine the problem and explore new solutions. The final output is a problem framework and connections, and a series of models, prototypes, products, and documentation of the design process. The path and deliverables between interaction design researchers and other HCI researchers are illustrated in Figure1.5.

1.4.2 Experience Prototyping

This approach involves the rapid production of concept prototypes using existing materials to simulate the experience of using a product. This is useful for revealing unanticipated problems or needs and for evaluating ideas. This method will be used primarily to understand the experience of different interaction design scenarios for this project. Prototypes will be designed for frequent testing and iteration [11].

1.4.3 Participatory Design Method

A design process iteratively works through possible, probable, and desirable futures [12] to arrive at an optimised vision. Participatory design will be done in the form of workshops. There will be three workshops for different groups of people: computer literate, design literate and mixed multidisciplinary. The three participatory design workshops will be used to brainstorm complete design solutions and design iterations, synthesising the views and needs of stakeholders with different knowledge backgrounds.

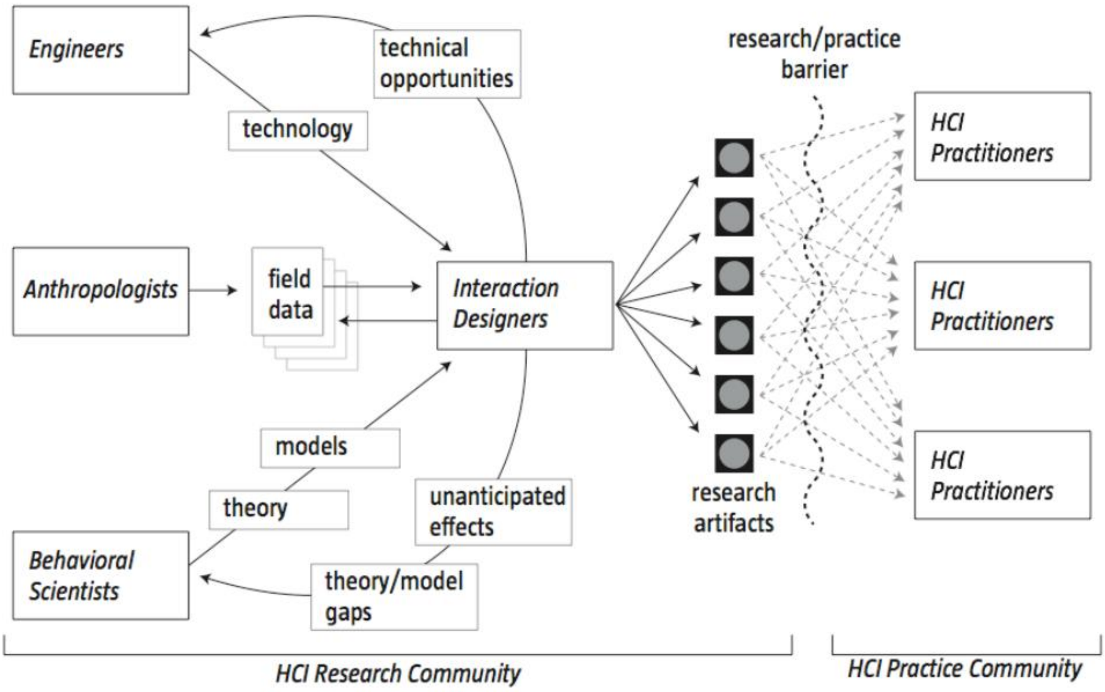


Fig. 1.5 John Zimmerman et al. based on Frayling's research through design.

Each workshop used a stakeholder map to identify the target users. Prototyping and iterating on the brainstormed designs using the IDEA NAPKIN prototype testing methodology.

1.5 Design Objective and Outcome

The output of this design research project is divided into two parts. The first is designing and developing a physical feedback device, including a complete design process based on user research to design the product. The second is interaction design, which will use 3D software and game engines to develop interaction opportunities for VR users, AR users, and general users. The research project will develop a complete system, including physical feedback devices. A range of models, prototypes, products, and design process documentation are also included.

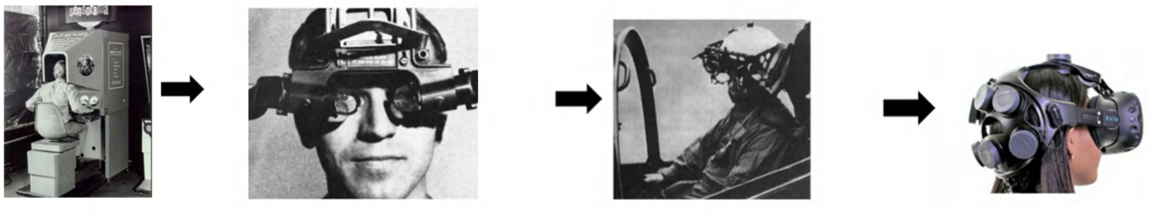
Chapter 2

Literature Review

2.1 Mixed reality

Mixed Reality(MR) experience is one where the user is placed in an interactive setting that is either real with virtual asset augmentation or virtual with real-world augmentation [13]. However, the definition of MR is not very clear. MR, according to Milgram et al.'s continuum, MR is a "stronger" version of AR, MR is a combination of AR and VR (potentially bound to specific hardware or devices), and MR as a synonym for AR [14]. However, the widely used definition of MR is that it encompasses both AR and VR [15].

Virtual Reality (VR), also known as the Spiritual Realm or the Artificial Environment, is the use of computer technology to mimic the production of a closed virtual environment in which the user interacts intuitively with specific input/output devices. VR is the display of the virtual world to your eyes via a terminal device. The present standard refers to the type of virtual world in which you wear a closed device, with immersion and without barriers, similar to virtual reality in its entirety.



Sensorama VR1956 The Sword of Damocles 1968 VITAL 1979 Neuable 2018

Fig. 2.1 The history of Virtual Reality[56].

Augmented reality (AR) has been around since the 1960s. According to R.T. Azuma, the three key characteristics of AR technology are: merging the real and the virtual, interactive virtual content, and real-time engagement. In recent years, there has been a surge in interest in augmented reality. AR is quickly commercializing, with applications in games, mobile apps, AR for the web, industry applications, and many more areas. AR is the physicalization of the virtual.

EyeTap 1980 Virtual Fixtures 1992 Solider ARC4 2017 AR art LONDON 2021

Fig. 2.2 The history of Augmented Reality[57].

2.2 Haptic feedback

VR and AR technology is being used in a wide range of entertainment applications, games, and simulators on the market. However, most VR/AR apps lack usable user input. The sensation of touch must be replicated in order to perceive physical interaction with the virtual environment, which is a critical component of establishing total immersion. Implementing an accurate touch simulation is a difficult undertaking since it requires describing object properties like form, hardness, weight, texture, and temperature.

Many previous studies have demonstrated the effectiveness of VR-related haptic feedback in enhancing the user experience. AmBioTherm [16] is a wearable headset accessory that provides thermal and wind stimulation. EmoJacket [17] provides thermal feedback at the wrist and neck and vibrotactile feedback at the chest. Nimesha Ranasinghe [18] et al. added odor feedback to wind and temperature feedback and further validated the impact of these feedback factors on user experience by recording physiological signals. However they are often attached to VR headset devices or used as a replacement for VR controllers. This makes them often complex and difficult to use, and less natural to interact with users. For example, AmBioTherm (Figure 3-b). And Lopes et al.[19]: EMS and solenoid condition (Figure 4); Kovacs et al.[20]: catching condition; Steed et al.[21]: free condition. If users do not have VR devices, they will not be able to participate in the interaction using these devices that provide physical feedback.

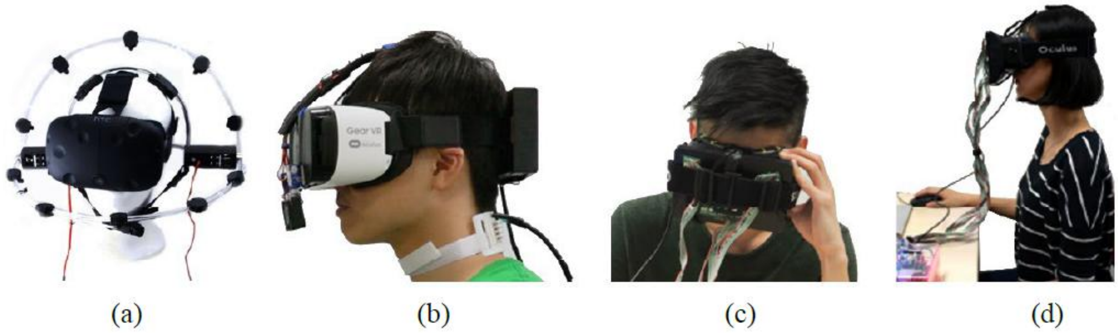


Fig. 2.3 Previous related studies.(a) [22] (b) [16] (c) [23](d) [24]

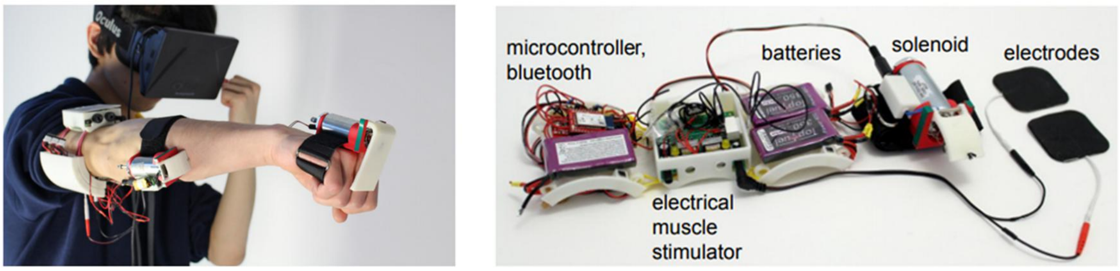


Fig. 2.4 Impacto: Simulating physical impact by combining tactile stimulation with electrical muscle stimulation[19].

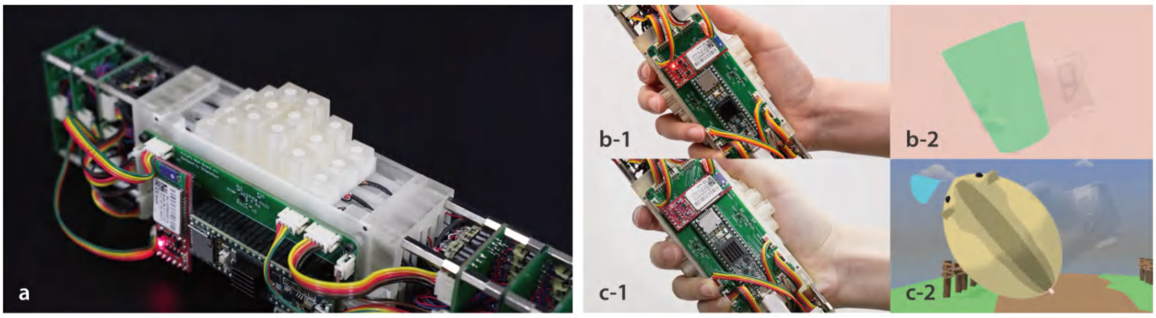


Fig. 2.5 PoCoPo: Handheld Pin-based Shape Display for Haptic Rendering in Virtual Reality Shigeo Yoshida;Yuqian Sun;Hideaki Kuzuoka [25]

Immersive user engagement is critical in AR and VR. Many AR/VR technologies rely on controllers to facilitate user engagement with digital material. However, controllers are not only difficult to transport, but they may also disturb immersion, making interactions feel less natural and fluid.

2.3 Soft Robotics

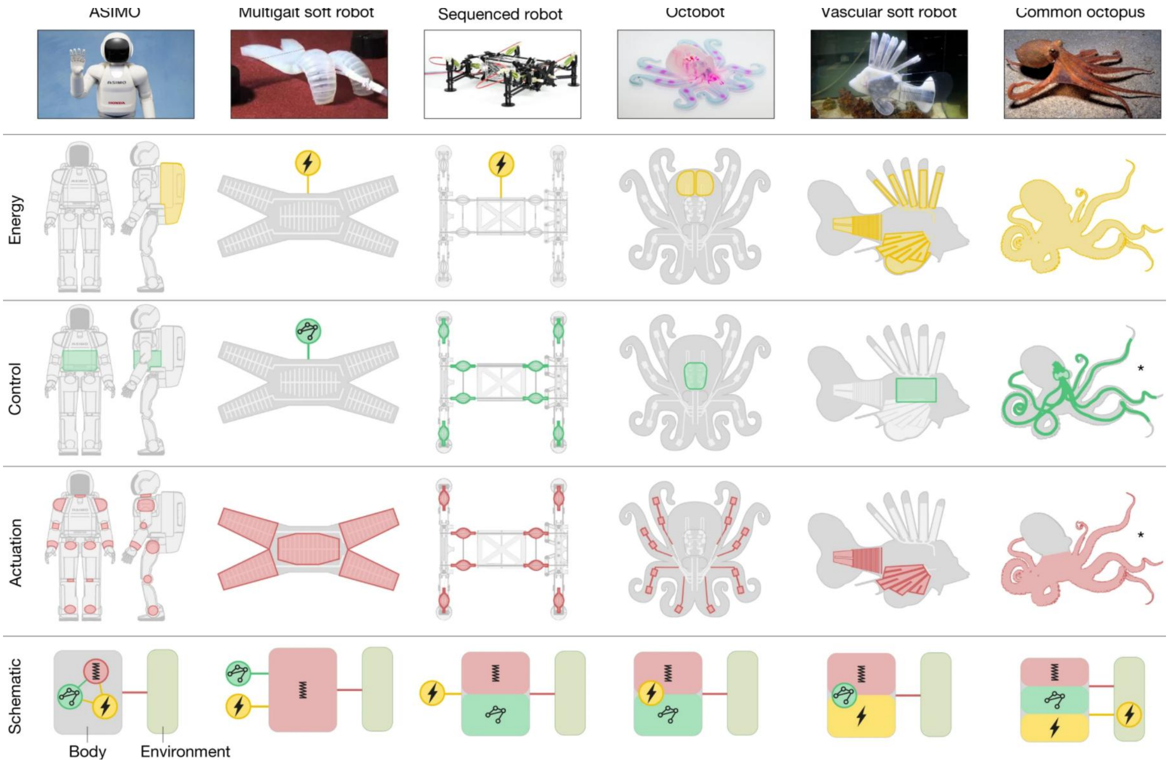


Fig. 2.6 Soft robotics application[26].

Pneumatically actuated soft materials have garnered significant attention in the fields of human-computer interaction (HCI) and robotics due to their unique capability for deformation, movement, and flexibility. This enables them to exhibit a wide range of shape-changing capabilities and functions. One major advantage of using materials with pliability similar to that of soft biological materials is the potential for reducing injuries caused by robotic systems (as demonstrated by rigid robots with pliable joints [27]), increasing their potential for interaction with humans.

One challenge in the design of soft robots is the control of their extension and deformation, which determines their movement. Unlike rigid robots that move in a fixed manner based on joints, the materials in soft robots have the potential to move and expand in a virtually limitless range of ways.

Currently, the most common methods for constructing soft robots include the use of TPU airbags and silicone airbags. The former often employs thermo-compression moulding and infrared sewing techniques to create airtight airbags, while the latter utilizes 3D printing and CNC moulding to create moulds that are then used to create silicone airbags. Both methods utilize changes in air pressure, controlled by an air pump, to regulate the deformation and movement of the robot. The primary difference between these two approaches is that TPU soft robots are typically created with multiple air chambers that are controlled through thermoforming or infrared sewing technology, while soft silicone robots are designed with air-tight chambers when the mould is created and are moulded in a single piece using silicone.

2.4 Interdependent Wearable

Most current wearable devices are designed to ignore social interaction. They are still designed to focus on self-improvement, such as personal exercise data tracking and management, healthcare support to help diagnose, monitor or provide treatment recommendations, or on connected communication. Neither of them focuses on support for social interactions between people.

However, social interaction and interdependent wearable devices have recently received increasing attention from HCI researchers and designers, who have recently proposed to the academic community to guide future technological developments by focusing on the human-to-human experience space and deploying computing to enhance social interaction.[28].

The integration of interdependence between users in interaction design may facilitate pro-social behaviour, such as cooperation, coordination, and mutual concern [29**?**]. This aligns with the argument made by interaction designers that these qualities can be effectively encoded into the design context to establish the necessity of interaction with technology.

2.5 Cross reality user interaction

Computing has progressed beyond the desktop computer since then. Pervasive computing differs from traditional computing in that it requires perceptual information about the environment. The pervasive computing framework strives to immerse the user in a ubiquitous computer realm.

Human-computer interaction, the most recent study in ubiquitous computing, is indisputably ubiquitous computing (Ubicomp). This phrase, along with ambient intelligence and pervasive computing, is frequently used interchangeably to allude to the ultimate approach to human-computer interaction [30].

Current VR systems prioritize immersion and enjoyment for individuals wearing HMDs (HMD users), excluding all onlookers (non-HMD users) from experience. Share VR [3] is a proof-of-concept prototype that visualizes the virtual world for non-HMD users via floor projection and mobile displays paired with positional tracking, allowing them to interact with HMD users and become a part of the VR experience. They conducted user research (n = 16) comparing ShareVR to the baseline condition and discovered that utilizing ShareVR boosted presence and social engagement.

Fig. 2.7 ShareVR, Experiences for Virtual Reality between HMD and Non-HMD Users[3].

In addition to display-supported sharing of virtual content, the researchers also believe that the sharing of sensory information beyond the visual is important for deeper connections. This can help people move from a deep connection to technology to a deep connection with emotions. These efforts are all aimed at addressing isolation and facilitating social interaction. Tactile sharing (also known as tactile interaction) is the process of using technology to transfer tactile information from one person to another. This technology can be implemented in a variety of ways, including haptic input devices and haptic output devices.

Haptic sharing technology can facilitate social interaction because it allows people to feel each other's tactile information, thus enhancing human interaction. For example, when two people use haptic sharing technology to interact across realities, i.e. the audience can also feel the haptic sensations of the VR user. In this way, people can create richer and more interesting interactions and more intimate connections with each other.

Chapter 3

User Research

3.1 Participatory Design

3.1.1 Participatory Design Workshop

Participatory design strategically engages stakeholders by involving key stakeholders, mapping roles and relationships in a 'people-centred system' view, making assumptions transparent and revealing motivations and concerns.

Two participatory design workshops were organised, the first with participants from computer and engineering backgrounds, and the second with participants from design backgrounds.

At the beginning of the workshop, I gave a brief introduction to the background of the whole project and the purpose and significance of the research. Some knowledge and research related to immersive technology, haptic devices and wearable devices were also introduced. We then had a brainstorming session to first identify the stakeholders related to the research questions of the project. We used a stakeholder map to classify the target audience: Target Audience, Direct Stakeholder, Indirect Stakeholder and the classification of users is shown in Figure 3.2.

Participants from design backgrounds (N=8) were very diffuse and active in brainstorming solutions for this project. The ideas they mentioned more often were limb sensing and haptic synchronisation (N=4). They designed virtual experiences for multiple users, using projector devices or large screen displays, creating opportunities for multiple users to interact with the experience in the same scene. As shown in Figure 3.3.

Participants from computer and engineering backgrounds assessed the feasibility of implementing ideas from a more technical point of view. In addition to projectors and screen displays, they introduced interactive and dome-like immersive displays for visual tracking and positioning. They designed multi-user types of virtual experiences and also mentioned multi-device types of communication and shared experiences.

Fig. 3.1 Workshop Sciences.

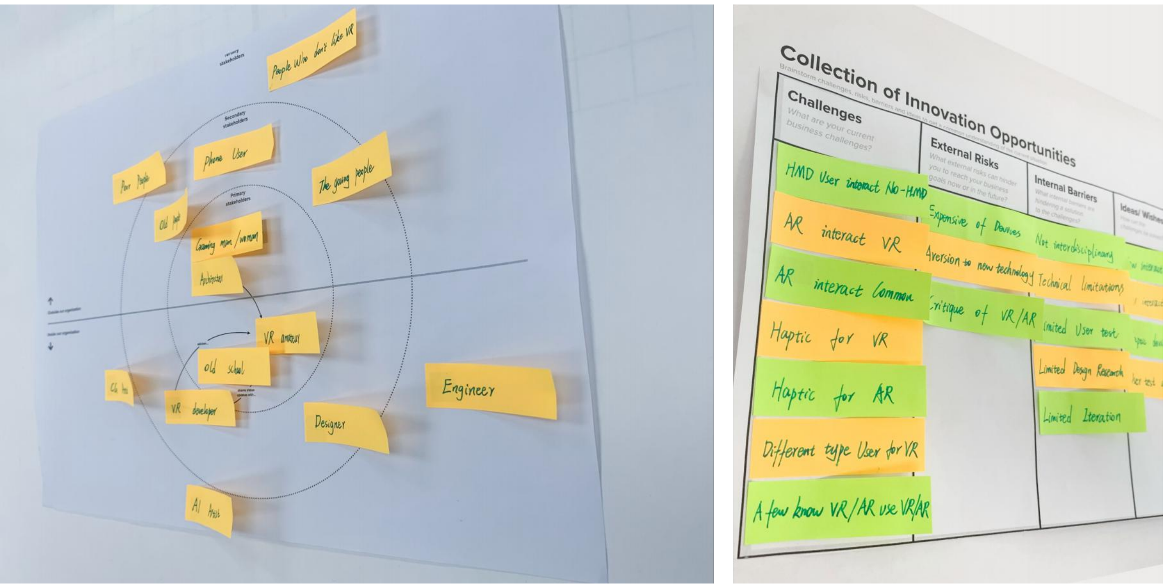
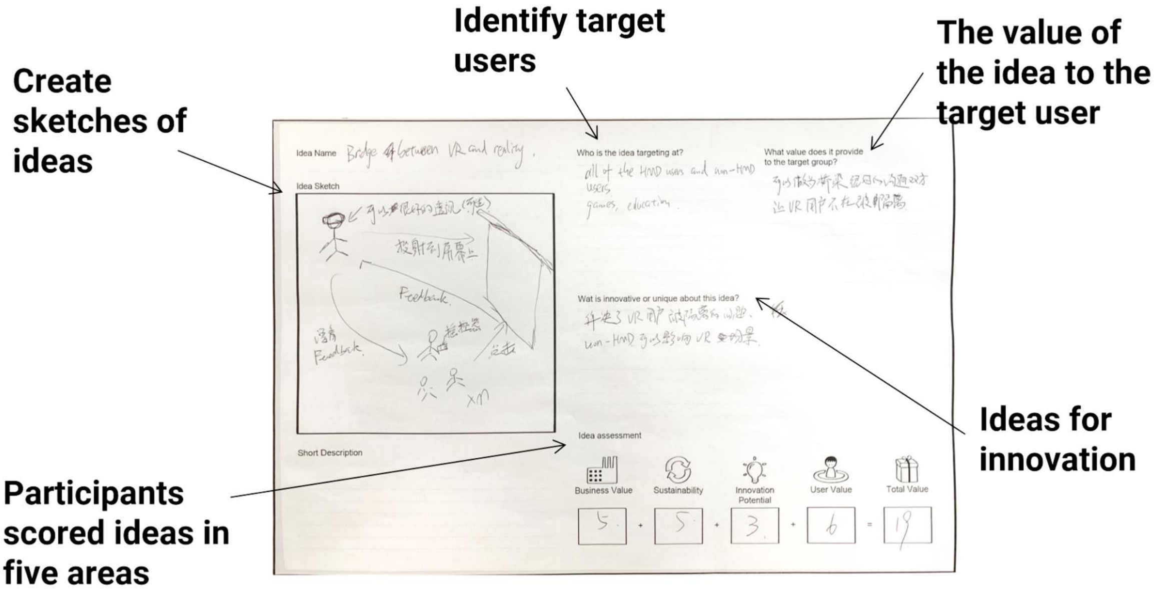


Fig. 3.2 Stakeholder map and Innovation Opportunities map.



Idea Name Bridge between VR and reality.

Idea Sketch

Who is the idea targeting at?
all of the HMD users and non-HMD users
games, education.

What value does it provide to the target group?
可以做为桥梁 纽用户沟通双方 让VR用户不在被隔离

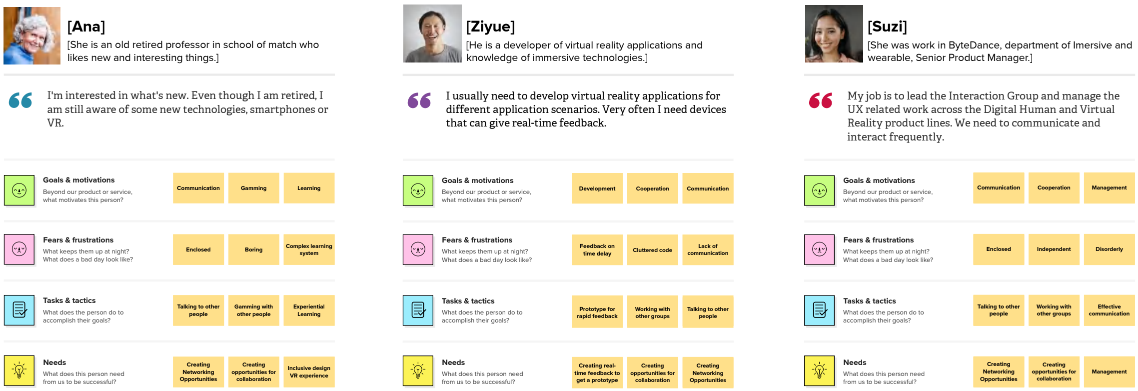
Wat is innovative or unique about this idea?
解决了VR用户被隔离的问题.
non-HMD 可以影响 VR 的结果.

Short Description

Idea assessment

Business Value		Sustainability		Innovation Potential		User Value		Total Value
5.	+	5.	+	3.	+	6	=	19

Fig. 3.3 Idea test.



[Ana]
[She is an old retired professor in school of match who likes new and interesting things.]

> I'm interested in what's new. Even though I am retired, I am still aware of some new technologies, smartphones or VR.

Goals & motivations	Beyond our product or service, what motivates this person?	Communication	Gamming	Learning
Fears & frustrations	What keeps them up at night? What does a bad day look like?	Enclosed	Boring	Complex learning system
Tasks & tactics	What does the person do to accomplish their goals?	Talking to other people	Gamming with other people	Experiential Learning
Needs	What does this person need from us to be successful?	Creating Networking Opportunities	Creating opportunities for collaboration	Inclusive design VR experience

[Ziyue]
[He is a developer of virtual reality applications and knowledge of immersive technologies.]

> I usually need to develop virtual reality applications for different application scenarios. Very often I need devices that can give real-time feedback.

Goals & motivations	Beyond our product or service, what motivates this person?	Development	Cooperation	Communication
Fears & frustrations	What keeps them up at night? What does a bad day look like?	Feedback on time delay	Cluttered code	Lack of communication
Tasks & tactics	What does the person do to accomplish their goals?	Prototype for rapid feedback	Working with other groups	Talking to other people
Needs	What does this person need from us to be successful?	Creating real-time feedback to get a prototype	Creating opportunities for collaboration	Creating Networking Opportunities

[Suzi]
[She was work in ByteDance, department of Imersive and wearable, Senior Product Manager.]

> My job is to lead the Interaction Group and manage the UX related work across the Digital Human and Virtual Reality product lines. We need to communicate and interact frequently.

Goals & motivations	Beyond our product or service, what motivates this person?	Communication	Cooperation	Management
Fears & frustrations	What keeps them up at night? What does a bad day look like?	Enclosed	Independent	Disorderly
Tasks & tactics	What does the person do to accomplish their goals?	Talking to other people	Working with other groups	Effective communication
Needs	What does this person need from us to be successful?	Creating Networking Opportunities	Creating opportunities for collaboration	Management

Fig. 3.4 Three main kind persona.

In this study, we conducted user profiling for three different types of user personas. A persona is a fictional representation of a real user, based on actual data, and serves as a model for designing interactions with a specific target user in mind. In short, personas allow us to focus on the motivations and behaviours of our target users during the brainstorming process, rather than personal preferences.

Additionally, in order to better understand our users, we also employed empathy mapping during the workshop to establish empathy for our end users. Empathy mapping helps us to consider the thoughts and feelings of others. It can assist us in shifting our focus from behaviour to the emotions and experiences of our users.

Fig. 3.5 Emapthy map for persona.

During a comprehensive post-workshop with our stakeholders, we added a turning point to this technology by focusing on personas. We adapted a method from Nikki Knox's user research, simplifying it into three main components: thinking, feeling, and doing, and we focused on the pain points and challenges currently identified in our study.

3.1.2 Pain point

Current virtual reality and the communications within it are highly focused on sight and sound, neglecting other human sensory experiences. Our eyes and ears are engaged, but an important part of us stays disconnected, our sense of touch.

Game Migration Disorder The barriers to game migration may become increasingly common. A study by researchers Prof. Frank Steinicke and Prof. Gerd Bruder [1] at the University of Hamburg in Germany found that prolonged use of VR devices can cause volunteers to be unable to distinguish between virtual and reality.

Addiction and Isolation Immersive technologies such as augmented reality (AR) and virtual reality (VR) are already widely used. However, these technologies pose the problem of isolation of Head Mount Display users (HMD users) and exclusion of bystanders (non-HMD users). The separation between the real and digital worlds has become an issue, especially in human-computer interaction. It is crucial to stay connected and interact with natural environments and objects.

Lack of Interaction Even though consumers have increased access to VR, using multiple Head Mount Display (HMDs) simultaneously is still rare due to cost and the possibility of conflict between users [2].

In summary, through a series of workshop, I have identified the following design opportunities.

1. People incorporate tactile evidence when touching.
2. People usually use their hands to feel the sense of touch.

3. Older people, who cannot afford the price of immersive devices, want to experience this new technology.
4. Users want to be able to interact with different types of users when experiencing an immersive environment.
5. Haptic, wearable, and projection devices may be one effective way to create this interaction.
6. Immersive technology experiences need to be designed to be inclusive, affordable and easy to use out of the lab.

3.2 Expert Interview

To gain a deeper understanding of the needs and opportunities for supporting haptic wearables, we first engaged in discussions with five researchers from the fields of Human-Computer Interaction and Interaction Design, Innovation Design. The target group for the user interviews came from two professional fields, computing and design. They all have extensive experience in human-computer interaction, virtual reality, tangible interaction and haptic feedback. Not only are there specialist researchers, but also experienced interaction designers.

3.2.1 Expert Interview with Interaction Designer

To delve further into wearable haptic devices, I conducted an interview with experts who are veterans in the field and have a wealth of experience.

E1, who is an associate professor of design at a university. She has been involved in research in this field since 2015. Her research has been vocal around inclusive design and she then met some of the companies working on this technology, from sensors to wearables. She combined her experience with that of this company. The project they worked on together received European funding. She is also exploring the intersection of wearables and immersive technologies, although these are still very experimental. Although we still don't have a commercial product, these haptic and immersive technologies are now being experimented with in different areas," she says. Even in the healthcare sector, which I think is one of the most important sectors. There are apps and wearables designed for training. Like the personnel there. Immersive technology that trains doctors or immersive technology that even helps patients, especially children, rather than entertaining."

When asked: " Currently most haptic devices are used in laboratory environments, what solutions do you think we can take to promote the popularity of haptic devices? Popularity of haptic devices?"

She said." So there are two aspects. One aspect is based on the development of technology, when technology will be more flexible and miniaturised. Integrated, no cleaning problems. It will be easier to make them commercially available to writers. They are using labs as there are still. The complexity of you know like that."

She highlights the potential of immersive technology for the care of older people. " I think immersive technology will be very important for older people in China. Yes, you know. There are countries with an elderly population. It's important, not like in Italy, so how can we help older people? By this tactile right to enjoy their lives or support their daily needs, sometimes with even weaker senses. So it's an interesting regional survey. So I mean, I don't know what you really want to do now because you have to know what, but I think there are things that you would really enjoy if you worked with older people? You have people you can talk to and the most important thing in design is to work with the users involved, the users develop your project so you can talk to specific categories. What are the other difficulties with enhancing cocaine? Sometimes, by talking to people you know, what you really need, it can be an opportunity for designers to, you know so what? What can I do? I want to design something for my grandfather because? Some reason oh yeah, so. Well, why not something very interesting and very useful like in the UK. There isn't even an association in Asia. Older people were design for older people. No, so the most important thing is to talk to the people who need it. Because we can guess, but when you don't talk to the person. You never know."

When asked, "How do users expect to react to multi-person control of wearable haptic devices? And will this enhance the social experience?" "It depends on the specific use case. For example, people with disabilities who can't control anything, they may need a person interacting with the wearable to activate the wearable or controlled available in some way. Or as far as safety is concerned, there will be a third person to take control." However, she also highlighted issues regarding safety and ethics. "Terms and rules need to be made clear. I think it's very important to specify those rules."

E2, He is an expert in socially innovative design and forward-looking speculative design. He works as an associate professor in a university's design programme. With nine years of experience in the field, he focuses on improving communities and society through design.

When asked: " What are the main limitations currently preventing the widespread adoption of immersive technologies?" he said: "First of all, it's the equipment. I think the equipment is still bulky and expensive, it requires cables, the head-mounted displays are heavy to wear and still very uncomfortable and not easy to wear."

When asked, " What do you think is the reason for the immersive technology that some people believe reduces human interaction?" He stated, " I firmly believe that I was anchored to a large extent in the 20th century and I think the way we use technology, especially you know virtual technology or technology that enables you to enter these spaces. In the end, it created a separation between the people we know and the people we know, especially with very young generations born on the internet and mobile phones. For these people, they spend more time in virtual environments or using computers or their reality. The tangible reality of everyday life is. They spend less time in fasting, creating for them the main reality. For me it is virtual. This is going to be very problematic in the future. That is my belief. I think we are creating and you are. If we are. We can say that sometimes humans are a new form of humanity that is developing very fast and we don't know yet how it will turn out, and yes, I have discovered a very scary phenomenon. To be honest."

He stresses:"For me, I think we have to find a balance between the tangible reality The everyday reality of tangible objects and the interactions between people."

He expressed concern about virtual technology that transcends reality. He believes that going beyond the real to the virtual can be addictive for many people. "In general, I think the isolation that is ultimately created is a form of addiction because you know you have your own space in the virtual world. You can know everything you need to know and then your stimulation is always switched on? Yes, your stimulus, and then you can't find the explicit metaphor in the real world because the real goal is: generally speaking, these things, yes, are much more difficult. You have to work. You have to work. You have to deal with things in those environments, and usually that's the environment that companies provide. You control, yes, so what happens is almost always positive or good and you know the feeling will make you feel better because that's how they sell this, obviously, you don't want to have anything to do with the world because the world is difficult and unexpected."

When asked, "What impact do you think variable devices have on the immersive experience or haptic devices on the immersive experience? Are they important?"

He stressed that we need to cater for more people and make the new technology more inclusive: "Well, right now we're talking about how many people will wear them. Those are, yeah, at the moment. You know, or the fact that technology doesn't always depend on whether you can afford it or not. Yeah, yeah, so when we talk about topics like that. We have to take into account that you know poor people can't access these technologies because there's going to be a special, yeah, so people will have an impact. The elite are the ones who can afford this new technology. Yes, that's the point I found, so the impact could be huge, but before this technology, it would be on very few people. We can be so cheap and so affordable that anyone can have it. So it's just for comparison it's like a personal computer, yeah, yeah.

The first time I bought a computer was 20 years ago. It was super expensive. Not everybody had, yeah, spent so much money on it. Now, in most you know developed countries, almost anyone can use a computer for very little money, so it's exactly the same thing. The impact will depend on how cheap it is. These technologies become all about the cost base, all about the money."

E3, She is an assistant professor of design at a university and has more than ten years of experience in the field of design communication, mostly from corporate and practical work. She also works with people in artificial intelligence and information systems, and her main research interests are in exploring ways to enhance communication with user objects.

When asked: "What kind of design do you think will allow more people to be included in this immersive and interactive experience?"

3.2.2 Expert Interview with HCI Researcher

E4, He is a senior researcher in the field of human-computer interaction and an assistant professor of computer science at a university. His main research interest is in organisational work and then using computer systems to support organisational work, in other words called CSCW. He has 10 years of experience in this field. When asked: " What do you think are the main limitations that are currently preventing the widespread application of this immersive technology?" He believes that the main limitations are: 1. The device is bulky and uncomfortable to wear. 2. vertigo, although some technologies are exploring ways to mitigate motion sickness, it is still a very impressive user experience. 3. The application scenario is too narrow. Immersive technology is not being used on a large scale.

E5, She is a senior researcher in the field of human-computer interaction and works as an associate professor in the computer science department of a university. She has 14 years of experience in the field of human-computer interaction. Her research interests are mainly designing imagery and natural interaction techniques to help users explore complex scientific data.

I think in an immersive environment, the first thing is that the person and the data are in the same space, and the other thing is that you are in the same space with other people who are collaborating with you. Then when you're all exploring the data in the same space, there's a need to exchange information or discuss insights. So this is a very good space, a virtual space or a space to enhance some information. Then everyone can discover some issues together."

3.2.3 Conclusion of Expert Interview

Particularly in the context of immersive technologies such as virtual reality (VR) and augmented reality (AR). The use of haptic technology can enhance the user experience in games and could be easily spread to individuals with disabilities. However, there may be resistance to accepting the need for this kind of support, and it may take time for different stakeholders to become involved. Wearable devices in healthcare, such as training and support for doctors, may also be important areas to consider. In countries with large elderly populations, haptic technology could be used to help elderly individuals enjoy their lives and meet their daily needs, as their senses may be weaker. It is important to work with users in the design process and to consider the specific needs and challenges of different groups. There may be difficulties in implementing haptic technology, such as the cost and technical challenges, as well as cultural and psychological barriers. It is also important to consider the ethical implications of using haptic technology and to ensure that it is used in a way that is respectful and sensitive to the needs of all users.

The variable and haptic devices can have a significant impact on the immersive experience, but their effectiveness depends on how widely they are available and how affordable they are. They argue that if these technologies are only accessible to a select group of people, the impact will be limited, but if they are made more affordable and accessible to everyone, the impact could be huge. The speaker uses the example of personal computers, which were once expensive and only accessible to a small group of people, but are now widely available and affordable for most people in developed countries. The speaker believes that the cost of these technologies will ultimately determine their impact.

In summary, through a series of Expert Interview, I have identified the following design opportunities.

1. Current haptic interfaces are usually complex, large and heavy in overall weight, which affects the user experience.

2. Current haptic feedback devices usually require a wired connection to a computer for serial communication to control how the haptic feedback works, which greatly limits movement when using VR.

3. Current haptic feedback devices are limited in form and not flexible enough to enhance the user experience.

3.3 Primary Evaluate Haptic

3.3.1 Finger or Palm

Previous work on haptic feedback has been less in-depth in the study of very precise sensory areas. This is particularly true for the hand, a region that is closely associated with human tactile sensation. Humans rely on their dexterous hands to explore new things and to feel the touch of materials, but what has not been explored in depth is which area of the finger or palm is more sensitive to haptic sensations. This question is crucial to the haptic experience associated with immersive technologies and has profound implications for the haptic experience in human reality.

I conducted a user experiment to investigate the effect of different feedback locations on the hand on the user's haptic experience, both in terms of haptic perception and preference of haptic experience location.

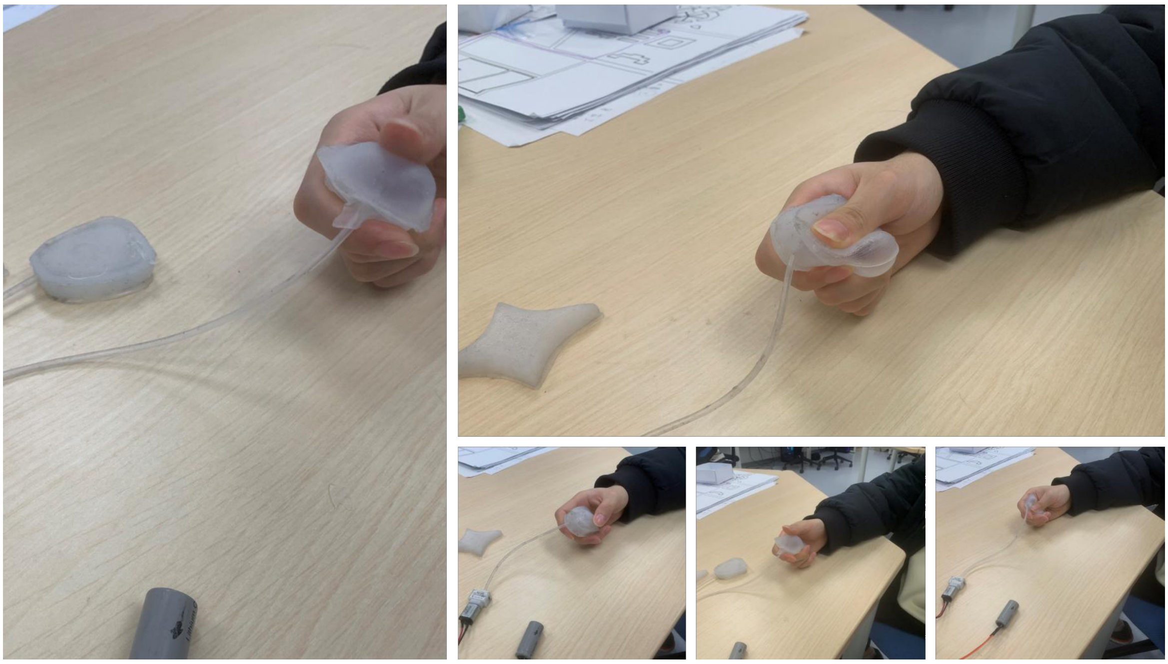


Fig. 3.6 Iteration of the design of the control system. Added air outlet for odour feedback.

Participants

We recruited participants (n=10) to participate in this experiment, where the order of different voltages and feedback positions was randomised. The mean age of the participants was 22.5, with six males and four females.

Procedure

The study was conducted in a comfortable laboratory environment. Participants wore the soft robot in each of the six positions on the hand as shown in Figure 3.7.

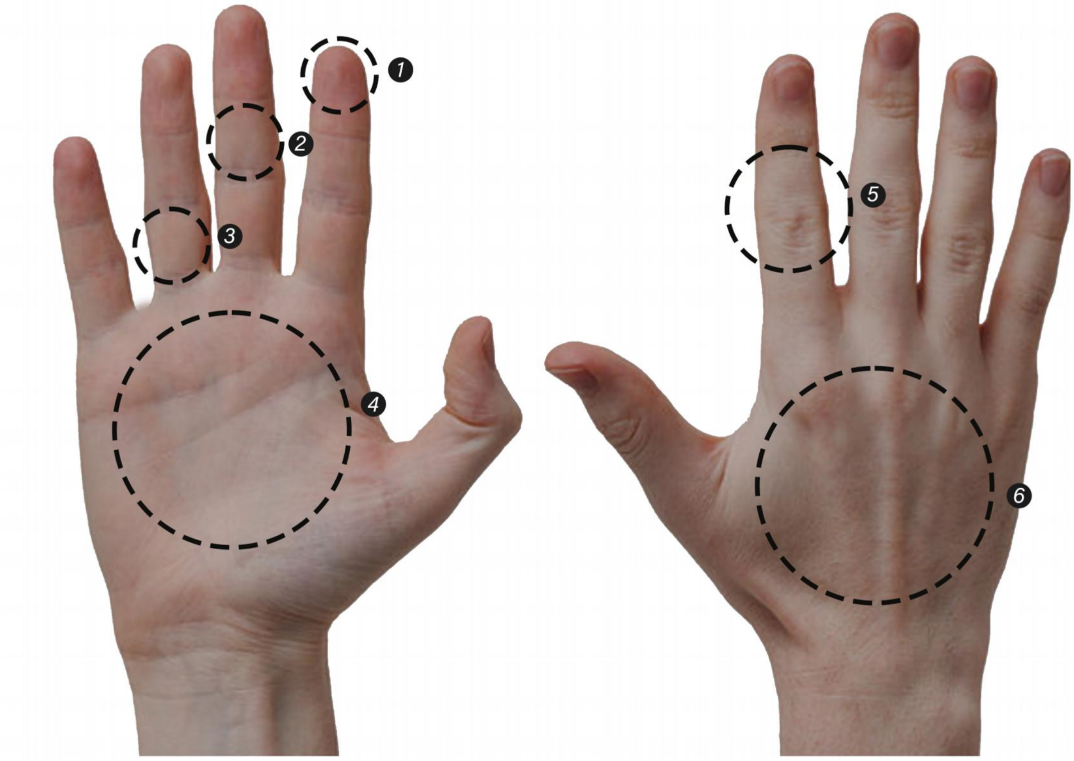


Fig. 3.7 Prototype test.

Experienced haptic feedback at different feedback locations. Participants answered two questions about the haptic experience after each experience: "Do you think the touch feels strong?" "Do you like this experience of haptic feedback in this position?" . From a minimum score of 1 to a maximum score of 7, each participant was rated 12 times.

Result

The haptic perception scores of participants were collected and the experimental results were analyzed. The feedback position has a significant impact on the user's touch and comfort. Among all six positions, positions 1, 2, 3 and 4 have higher scores. Position 4, palm area, obtained the highest Likert score.

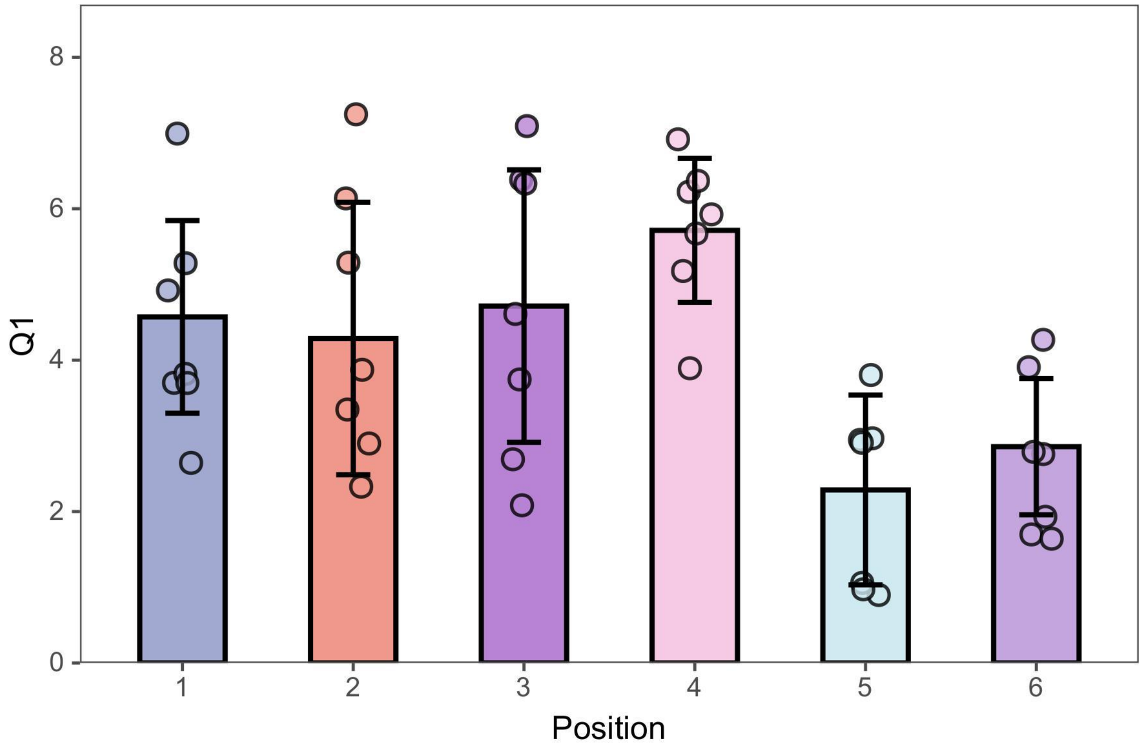


Fig. 3.8 Result of Likrt score in different position.

User interviews

After the experiment, we conducted user interviews with the participants and when asked: "Do you think the haptic feedback is more pronounced in the fingers or in the palm of the hand?" the majority of participants said that the tactile feedback was more pronounced in the fingers. I also asked an open-ended interview question, "Please talk about your experience of experiencing haptic feedback in your hands?" They indicate that: "It has been noted that, although the tactile changes are quite subtle, they can be easily perceived in the palm of the hand."

3.3.2 Summary of the Design Opportunities

In summary, through a series of user studies, I have identified the following design opportunities.

1. Current haptic interfaces are usually complex, large and heavy in overall weight, which affects the user experience.

2. Current haptic feedback devices usually require a wired connection to a computer for serial communication to control how the haptic feedback works, which greatly limits movement when using VR.
3. Current haptic feedback devices are limited in form and not flexible enough to enhance the user experience.
4. Current haptic feedback devices rarely create interactions between different users.

Chapter 4

Design Process

4.1 Design Phase I: One-way interaction

4.1.1 Concept Generation

In the past, haptic devices often required large control systems and complex communication mechanisms, and they were confined to laboratory environments. Most existing tools use rigid components (e.g. accelerometers or strain sensors) or external tracking systems (e.g. cameras and markers) to detect deformation. These rigid materials undermine the benefits of soft touch, and external sensors require complex setups and pose other problems, such as masking or fixation. Their mechanical construction makes them difficult to use as lightweight, portable wearable devices in a wider range of environments. Users need a portable, ergonomic and soft haptic wearable device.

The advancement of soft robotics is also facilitating soft wearable devices that provide haptic feedback to the user. They can react quickly to apply forces on the skin while maintaining safety and flexibility [31]. Compared to traditional rigid materials, soft materials have unique deformation, movement and flexibility capabilities that give shape changing physical objects a wealth of expression and functionality.

An early design concept is shown in Figure 4.2. The control system is worn on the arm. The tactile part is made of soft materials and connected to the fingers and palms.

Fig. 4.1 Inspiration Board[32]

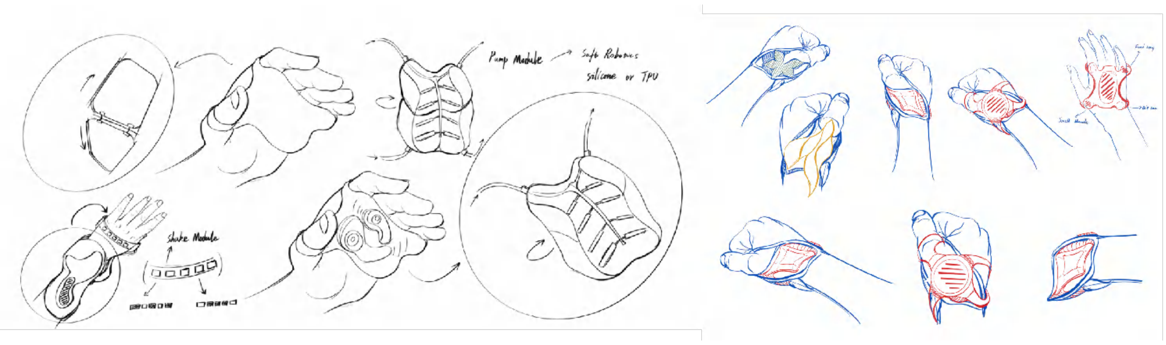


Fig. 4.2 Concept Sketch.

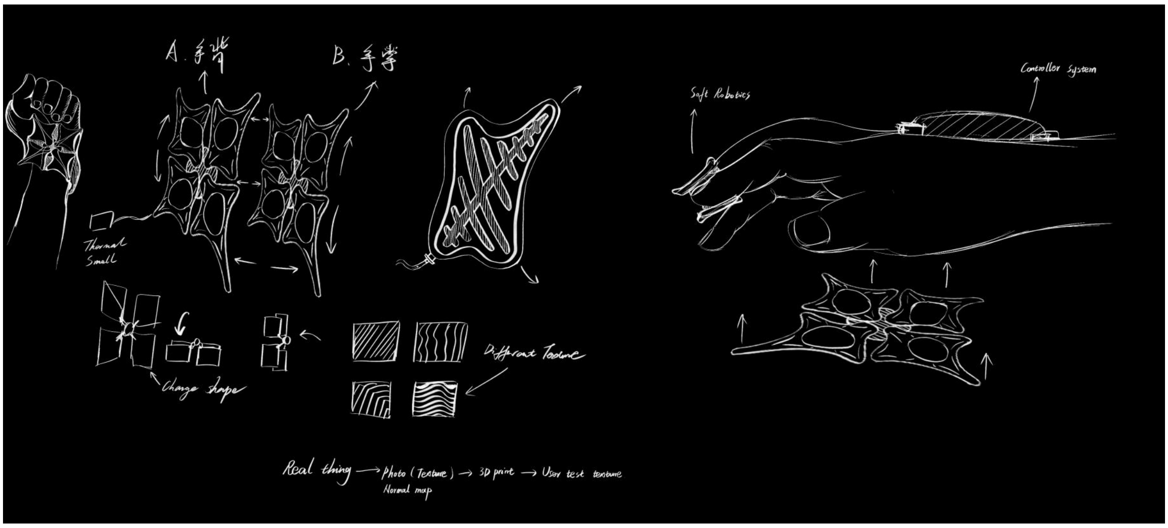


Fig. 4.3 Concept Sketch.

4.1.2 Visual and material experimentation

I tested different soft materials, exploring their textures, softness, toughness and structure in the inflated state. Food-grade silicone is superior to several other materials in terms of toughness, softness, weight and tactility across the board. This is why food-grade silicone was chosen to create the wearable device. A mould to make a soft robot was rapidly constructed using 3d printing technology and a series of prototypes of different shapes and sizes were made for testing.

Fig. 4.4 The silicone airbag making process: **(a)**: 3D print the mould **(b)**: introduce the silicone into the mould **(c)**: remove the silicone **(d-e)**: make the front and back silicone **(f)**: combine the silicone and put in the hose

Fig. 4.5 Testing the toughness.

Fig. 4.6 Testing the toughness.

4.1.3 Prototyping and testing

Based on the initial ideas, I designed the basic functional architecture. Figure 4.7 shows the main parts used.

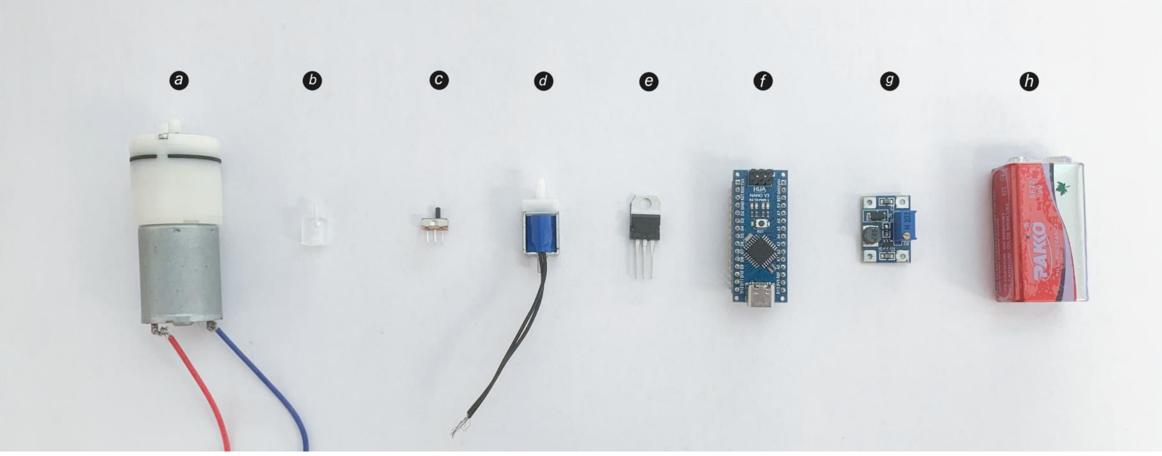


Fig. 4.7 Main parts: **(a)**: Pump **(b)**: Adapters **(c)**: Switch **(d)**: Solenoid valves **(e)**: TIP120 Triode **(f)**: Arduino Naono **(g)**: Step-down voltage regulator modules **(h)**: Battery

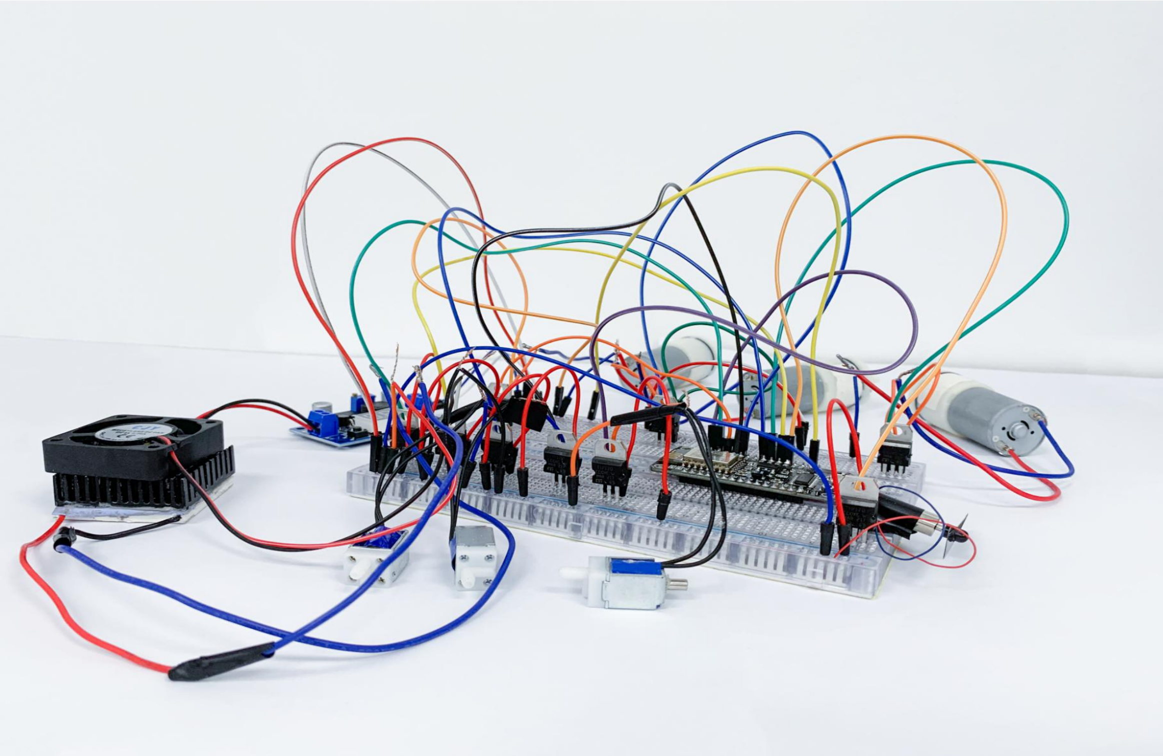


Fig. 4.8 Functional prototypes.

Fig. 4.9 Testing of cardboard models.

4.1.4 User Evaluation

User testing was carried out on the initial prototype of the design. In particular, user interviews conducted after our internal tests found that most users mentioned the material and size of the control system. They said: The control system is heavy and complex, which detracts from the experience during use. They said: "I can obviously feel the control system on my arm, it’s heavy." The material is too hard. The contrast with the soft robot in hand is too strong. Used close to the skin, the user would prefer the material to be soft.

4.1.5 Concept Refinement

These interactions occur in both directions between the physical and virtual worlds. Some participants desire the ability to not only feel the haptic effects of a virtual environment, but also to change the virtual environment through haptic feedback. They believe that two-way interaction would enhance their experience.

The interaction between the virtual and the real requires occurrence in both directions: from the physical world to the virtual world and vice versa. A more immersive interaction requires consideration of two aspects: (a) haptic wearable devices as triggers for AR/VR content, and (b) AR/VR content as triggers for wearable haptic devices.

Tactile wearables need to be wireless.

Participants in the user test reported how they felt about the experience of the prototype. One participant said, "I think the wireless wearable is better because the cables are getting in the way of an enjoyable virtual experience." They mentioned most often that the cable limited their range of motion and affected their experience.

4.2 Design Phase II: Two-way interaction

4.2.1 System Architecture

A new microcontroller (Nodemcu V3.0 ESP8266) was chosen for the first version of the system architecture in order to get rid of wiring and to allow fast and stable communication between wearable haptic devices and immersive technology. It communicates via 2.4G wifi and is small, low power and stable. To further enrich the experience, more electronic valves have also been added to provide pneumatic control.

4.2.2 Visual and material experimentation

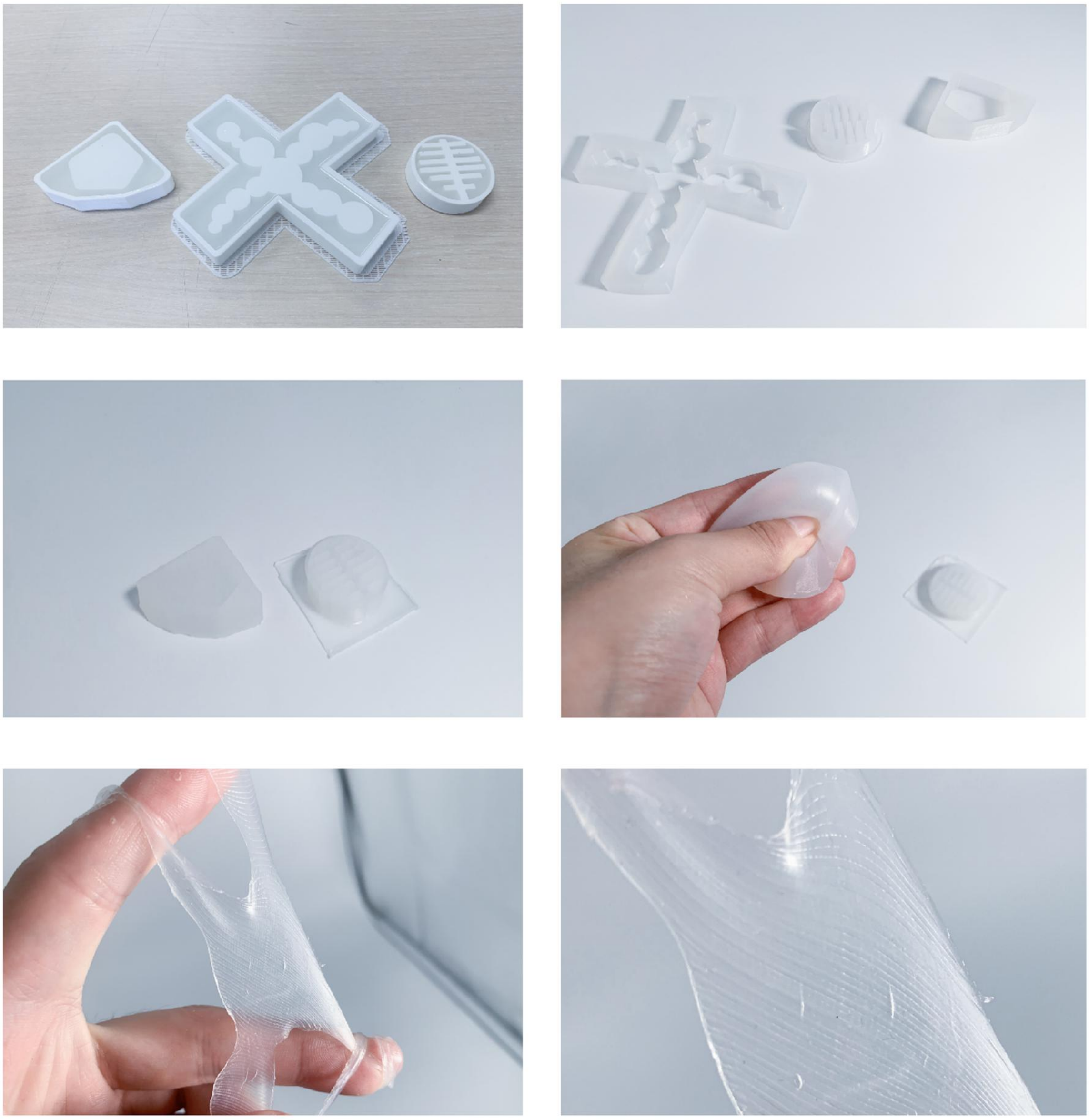


Fig. 4.10 Testing of silicone materials.

The design of the control system section was iterated, especially the materials section. By testing prototypes for 3D printing using different materials, a very soft (30 degrees of softness) soft rubber was chosen for 3D printing and moulding. For the structural part, a lattice structure was designed based on the user's need to "want the skin to breathe", which reduces weight while increasing airflow. We compared the skin's reaction to the different materials after a period of contact (1H) with the skin surface and found that the lattice structure and the soft rubber printed material worked best.

4.2.3 Prototyping and testing

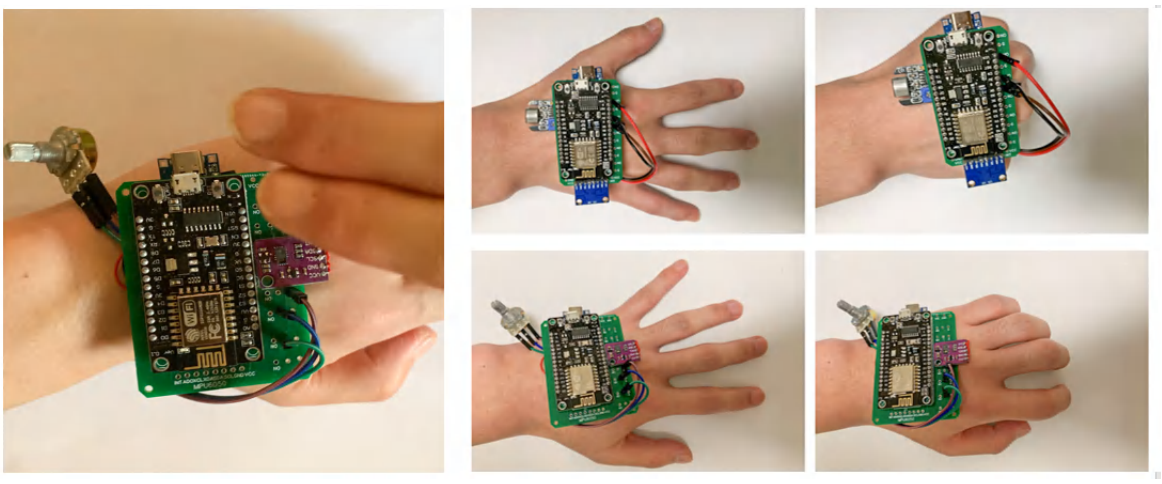


Fig. 4.11 Prototype test.

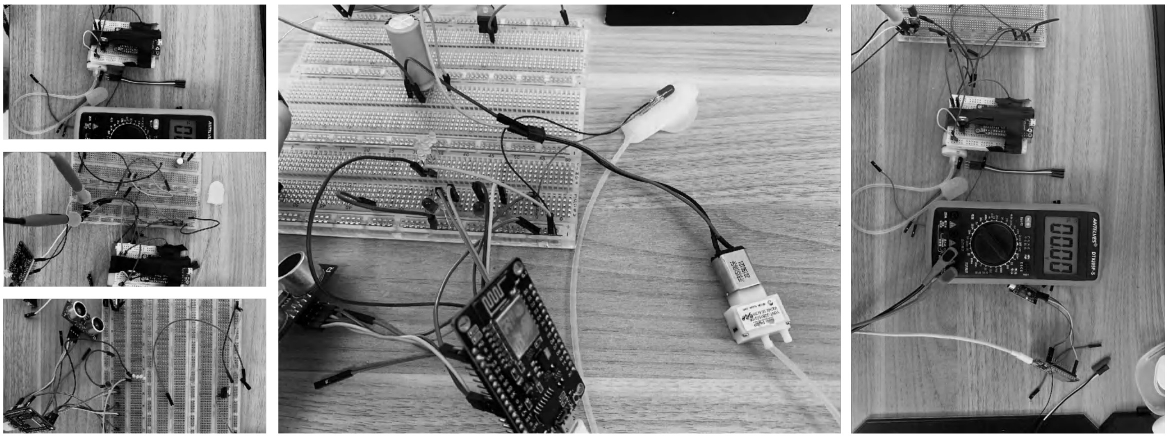


Fig. 4.12 Prototype test.

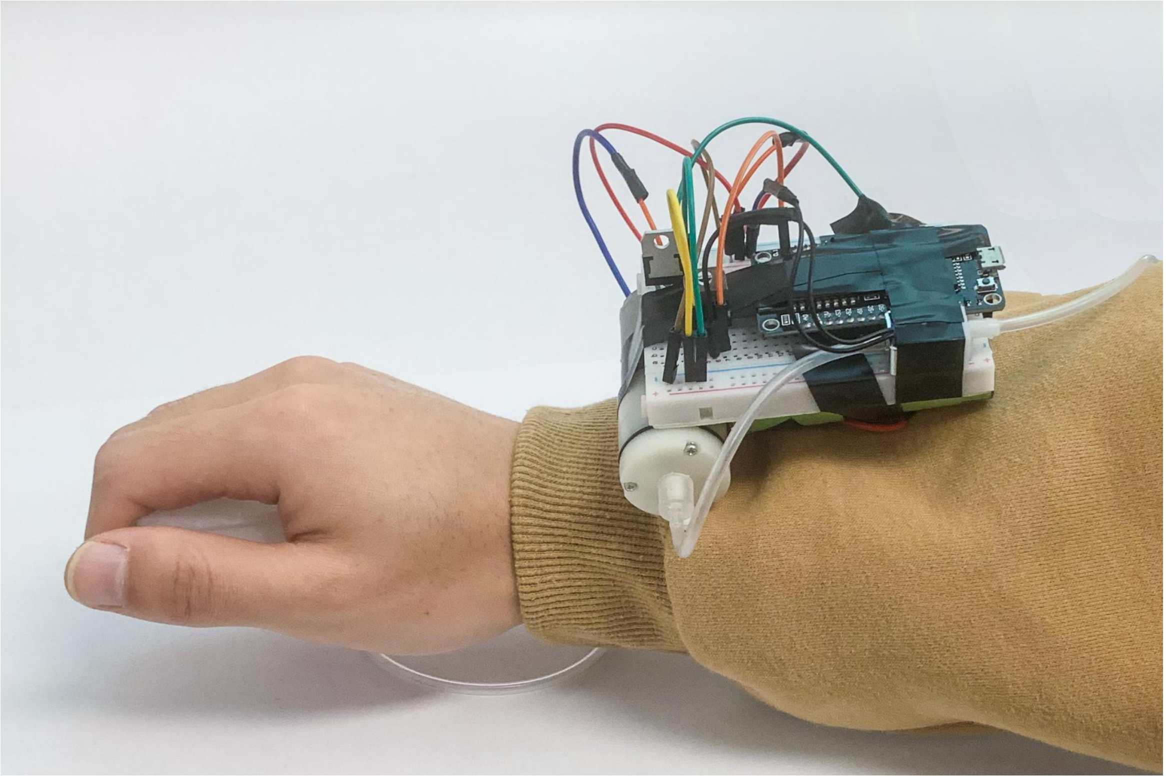


Fig. 4.13 Prototype test.

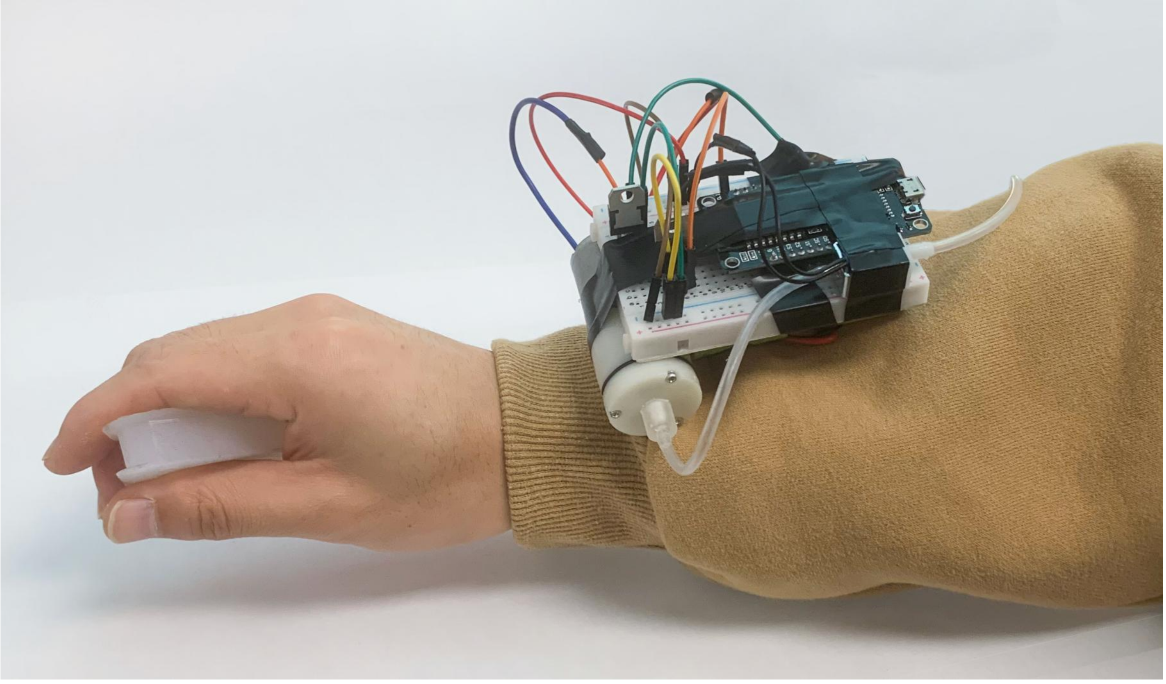


Fig. 4.14 Prototype test.

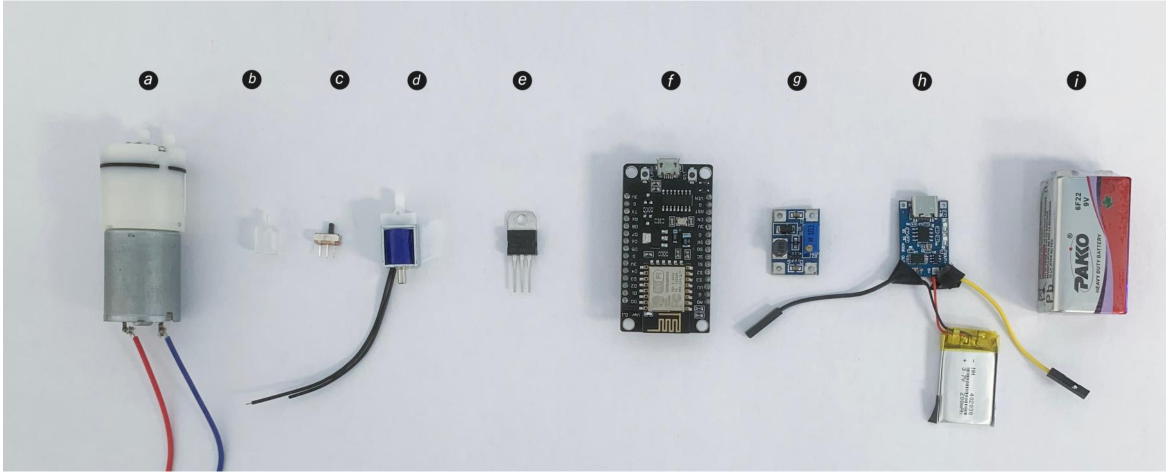


Fig. 4.15 Main parts: (**a**): Pump (**b**): Adapters (**c**): Switch (**d**): Solenoid valves (**e**): TIP120 Triode (**f**): NodeMCU V3.0 (**g**): Step-down voltage regulator modules (**h**): Charge protection module and Battery (**i**): Battery

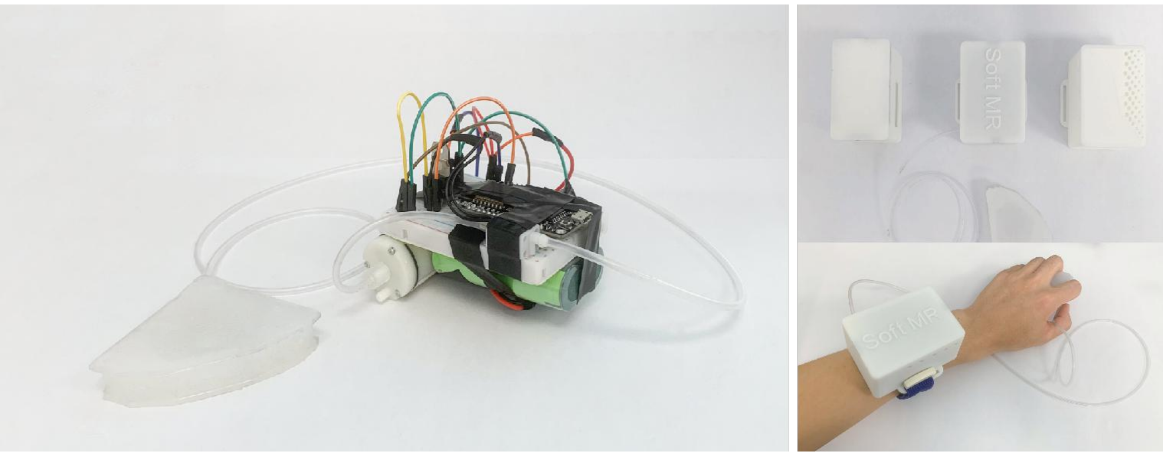


Fig. 4.16 Prototype test.

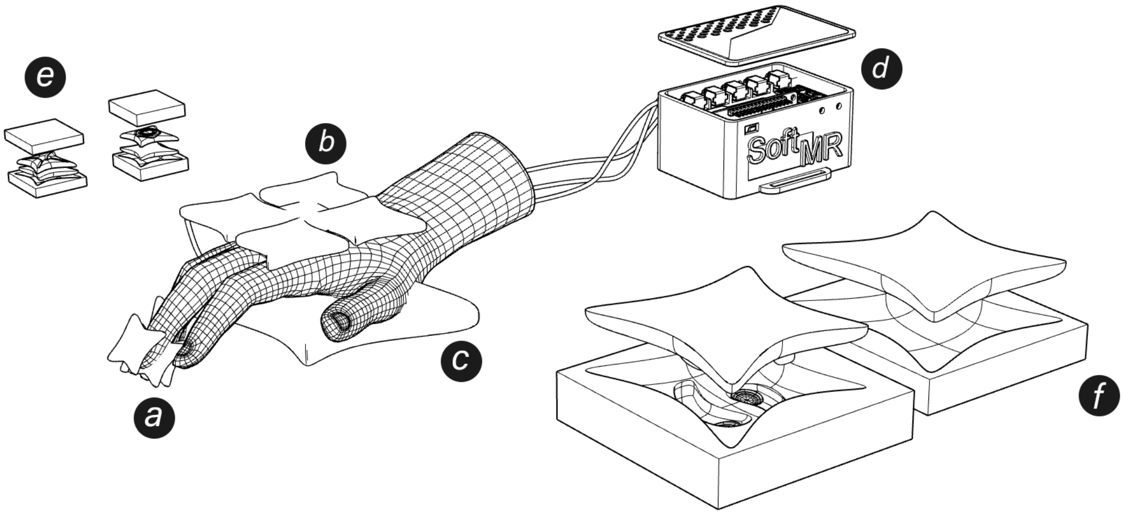


Fig. 4.17 (**a**): Soft body attached to the fingertips. (**b**): Deformable soft body attached to the back of the hand. (**c**): Soft body attached to the palm of the hand. (**d**): Control system. (**e-f**): Mould for the production of a soft robot.

Fig. 4.18 User test.

4.2.4 User Evaluation

A beta user test was carried out and user interviews were conducted after the test was completed. This was done to support the iteration of this design project.

User Test Interview: Interview Question:

1. What changes would you make to the device ?
2. How has wearing the devices affected your experience ?
3. What do you like about this device ?
4. What do you dislike most about using this device ?

Participants reported that the soft robot gave a relatively good haptic experience. In particular, his haptic feedback was prompt and rapid, and changes were evident. In terms of areas for improvement, they would like the soft finger robot to be able to provide haptic feedback on multiple fingers simultaneously or non-simultaneously. In addition some users said they would like this haptic wearable to be more personalised. "I wish I had a little different colour for this soft robot, I like that one." They felt that the same soft robot worn on their hands made them feel ordinary." I need something personalised, and I would prefer it to be colour."

4.2.5 Concept refinement

Many in the HCI community have been exploring ways to create alternative, more caring relationships and attitudes in the hope that by changing such relationships, users can connect their devices more responsibly and thus extend the lifetime of their devices [33] [34]. Many researchers have advocated the introduction of interdependent wearables to improve the user-device relationship, arguing for a different relationship between the user and the device. [35] [36].

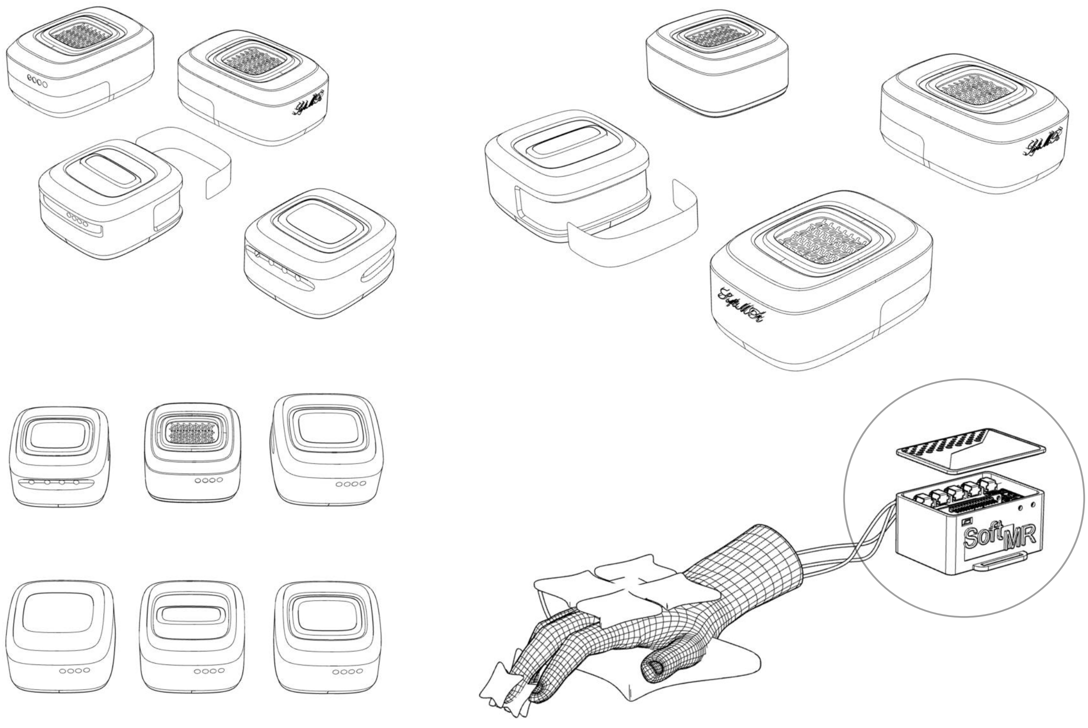


Fig. 4.19 Design concept development of system part.

Fig. 4.20 Breathable mesh design for the strap of a wearable device.

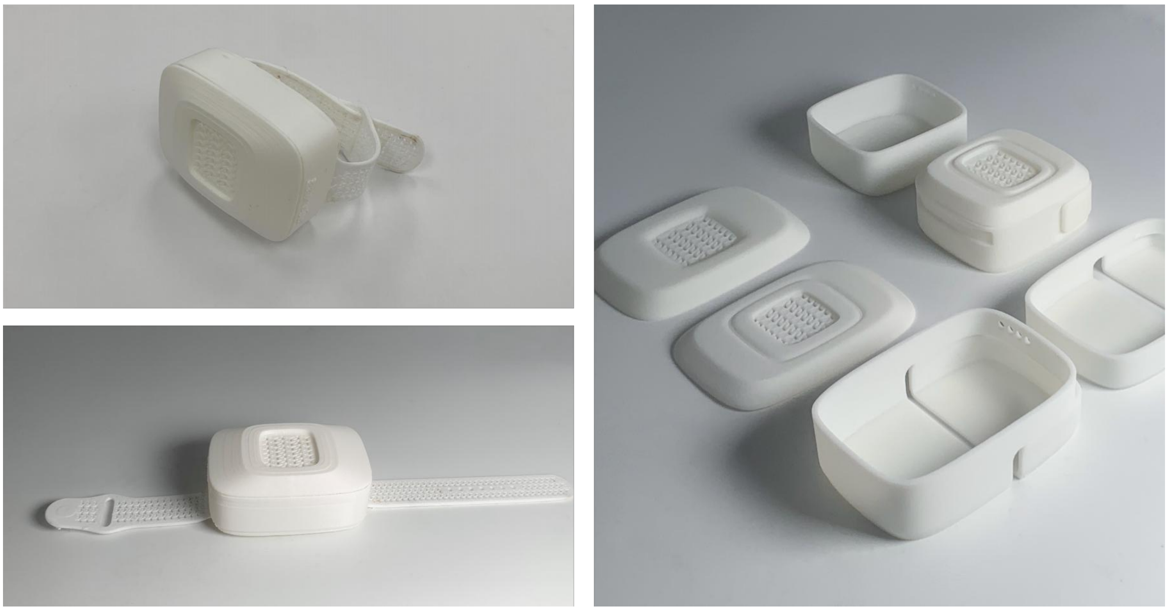


Fig. 4.21 Breathable holes have been designed for the part of the wearable that is close to the skin, making it more skin-friendly and sweat-proof. A lattice structure is used for the parts that have a large contact area. Ventilating and skin-friendly, it also serves to support the weight of the wearable device, reducing the pressure of its weight on the skin.

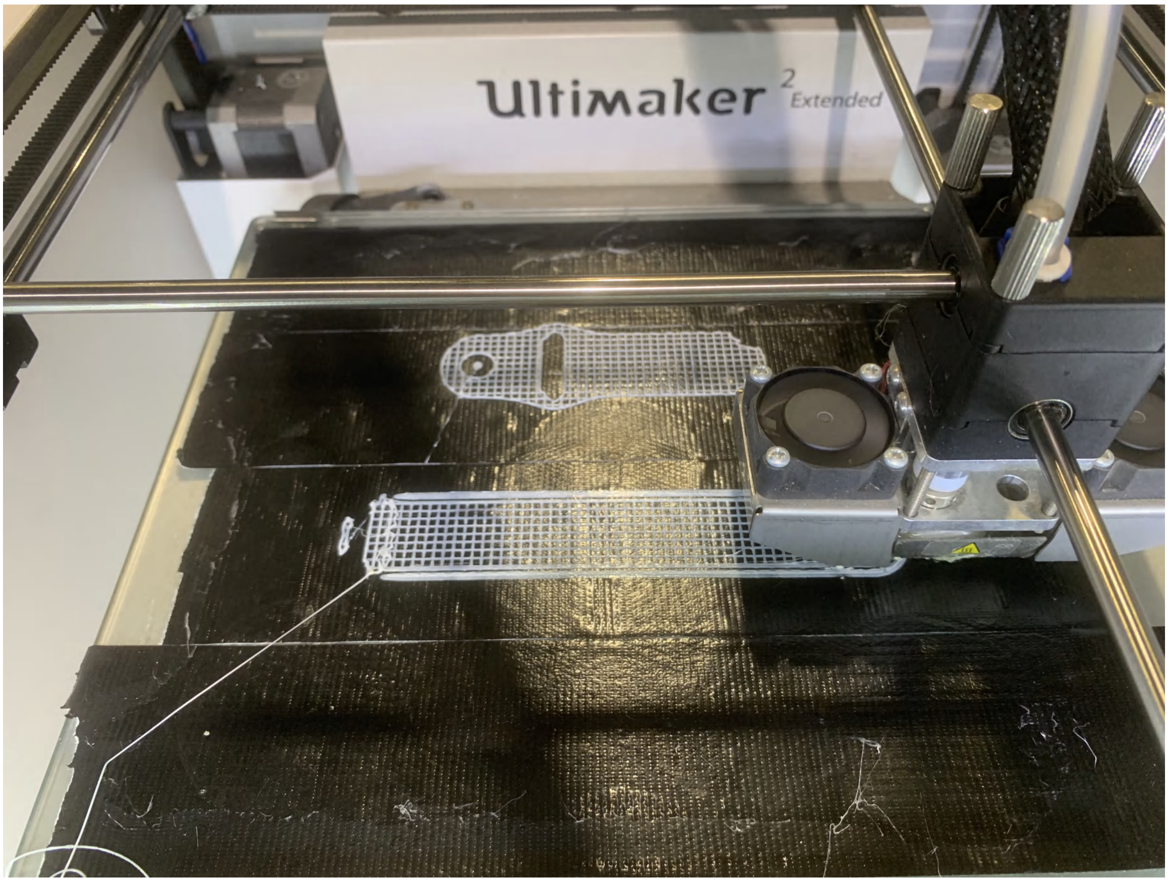


Fig. 4.22 Additive manufacturing of watch straps using soft materials.

Fig. 4.23 Prototype by additive manufacturing.

4.3 Design Phase III: Interdependent wearable devices interactive feedback

Currently, most commercial wearable designs still focus on personal data tracking and management for self-improvement, healthcare support in helping to diagnose, monitor or provide treatment recommendations, or on network communication, neglecting support for interaction between people.

Previous expert interviews and user research have also validated this need. As mentioned by the [37] [38] the isolation brought about by immersive technology requires new interaction techniques and experience design to improve it. Therefore, the design of the haptic wearable soft robot was further iterated, building on its two-way interaction with immersive technology and introducing a new design concept: interdependent wearability.

4.3.1 System Architecture

In order to create opportunities for interaction between wearable haptic devices, the ESP32 microcontroller was added to the previous version of the system architecture and a peer-to-peer network communication was constructed using the ESP-NOW communication protocol.

To further reduce the size of the system, the ESP32 microcontroller is used, using the ESP32 main controller chip, but in a relatively smaller size. The communication part of the system is then divided into two parts: interaction with immersive technology and interaction between haptic devices.

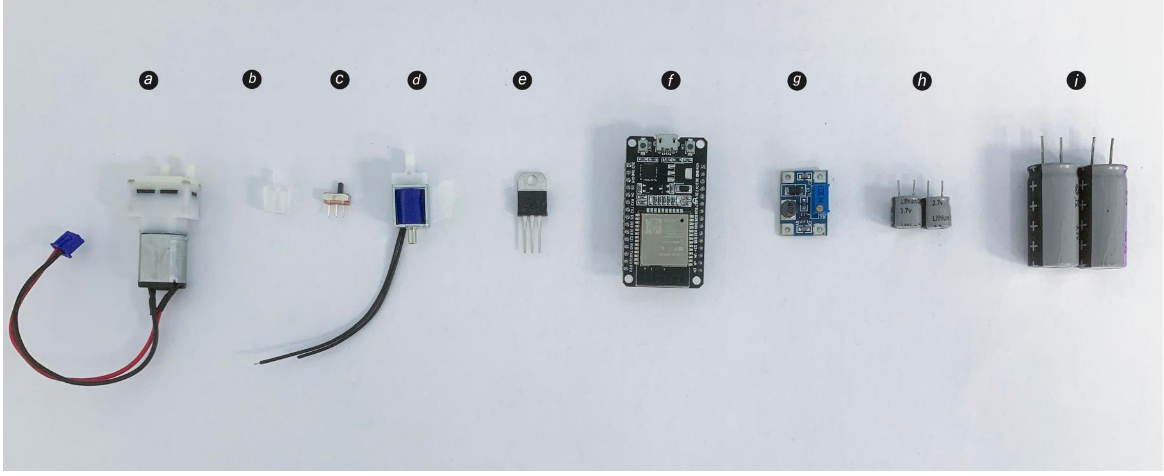


Fig. 4.24 **(a)**: Pump **(b)**: Adapters **(c)**: Switch **(d)**: Solenoid valves **(e)**: TIP120 Triode **(f)**: ESP32 **(g)**: Step-down voltage regulator modules **(h)**: 3.7V Battery **(i)**: Battery

Fig. 4.25 Uninflated state

Fig. 4.26 Inflated state

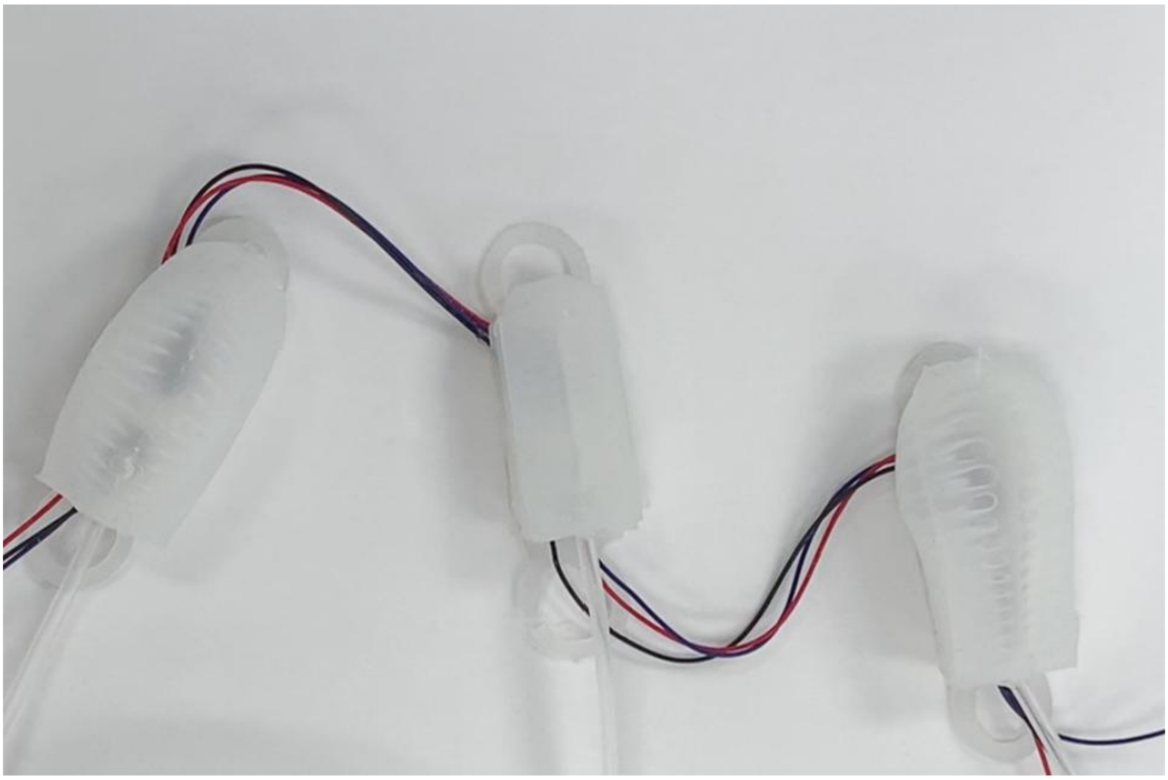


Fig. 4.27 Soft robot in different states of inflation.

4.3.2 Implementation

In this section, the implementation of hardware and software of Haptic Soft Robotics is described, including 1) conductive soft silicone material, 2) ESP-NOW communication, WIFI communication and actuator unit, 3) pneumatic control circuit, and 4) implementation of feedback control and mutual communication of soft robots.

Mechanism

Bi-directional data transfer between the ESP32 microcontroller and the game engine via WIFI transmission signals. The pins of the ESP32 microcontroller are set to output or read the state of the input to control the pneumatics, which in turn controls the soft robot's movement and provides haptic feedback via the soft robot's air chamber.

Bi-directional communication between the soft robot and the immersive technology: The user wears a head-mounted display while wearing a soft robot. When a command is given in the virtual environment of the head-mounted display, the microprocessor in the control system worn on the user's wrist receives the command via the WIFI network. The microprocessor control pin outputs a high level, which is set to a connected state via the TIP120, thus controlling the pneumatic system consisting of a micro air pump and electric valve. The electric valve gate is energised and deflated; the electric valve gate is de-energised and inflated. The pneumatic system delivers gas through a hose to the soft robot's air chamber to control the soft robot's ability to provide tactile feedback to the user.

Intercommunication between soft robots: The new conductive soft silicone material can measure changes in contact between human fingertips. The basic sensing mechanism is similar to a capacitive sensor; the change in capacitance can be detected via the touch pins of the ESP32 development board. Point-to-point data communication is carried out through the ESP-NOW networking. When the ESP32 microcontroller at the transmitting end detects a change in capacitance, it transmits a value to the ESP32 microcontroller at the receiving end. The receiving end judges whether to trigger the pin command based on the received value, thus controlling the movement of the soft robot through the operation of the pneumatic system.

Electro-soft silicone material

In the field of human-computer interaction, a number of methods have been explored for the fabrication of new soft, conductive materials. One is the use of screen printing [39] [40] or inkjet printing [41] techniques that allow conductive traces and circuits to be printed directly with conductive inks on stretchable or non-stretchable substrates. Building on this valuable background, experiments were carried out on silicone, taking into account the need for wearable devices to be safe, low-cost and easy to manufacture. The experiments revealed that the addition of highly conductive activated carbon to silica gel could transform the silica gel material from an insulating material into a soft, conductive new material, and their conductive properties were evaluated. In this project, soft conductive materials were used as the basis for soft wearable haptic devices.

Fig. 4.28 **(a)**: From left to right, carbon nanotube dispersant, highly active carbon nanotube, highly active carbon nanotube and silica mixture. **(b)**: On the left, a highly reactive carbon nanotube and silica gel blend; on the right, a highly reactive carbon nanotube and silica gel blend with the addition of carbon nanotube dispersant. **(c)**: Softness test without the carbon nanotube dispersant. **(d)**: Softness test with the carbon nanotube dispersant.

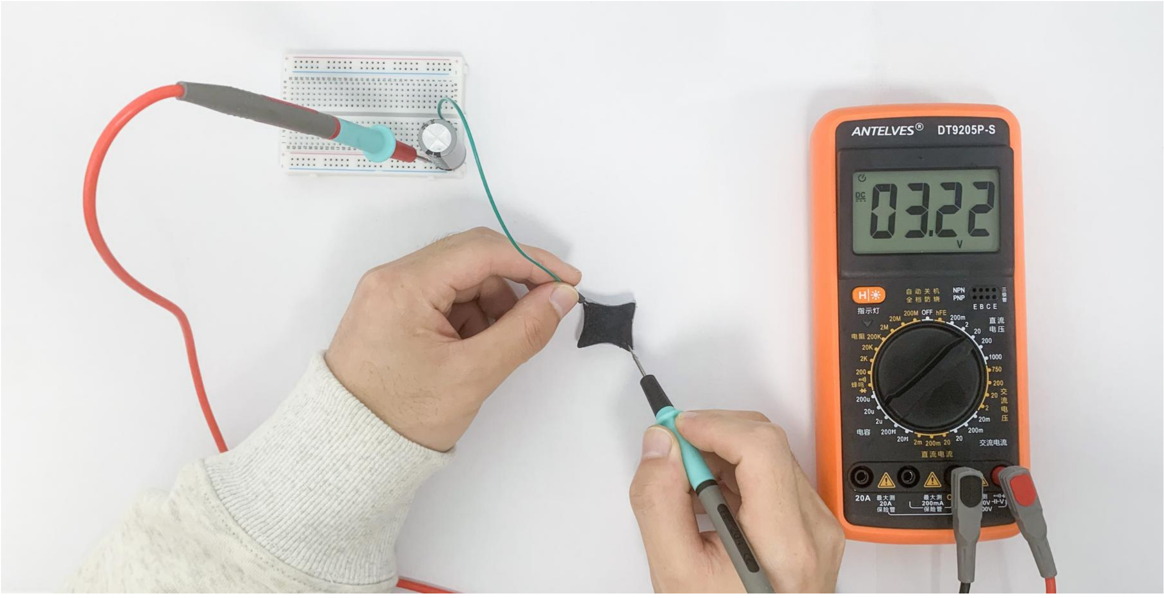


Fig. 4.29 Testing the electrical conductivity of silica materials incorporating highly reactive carbon nanotube.

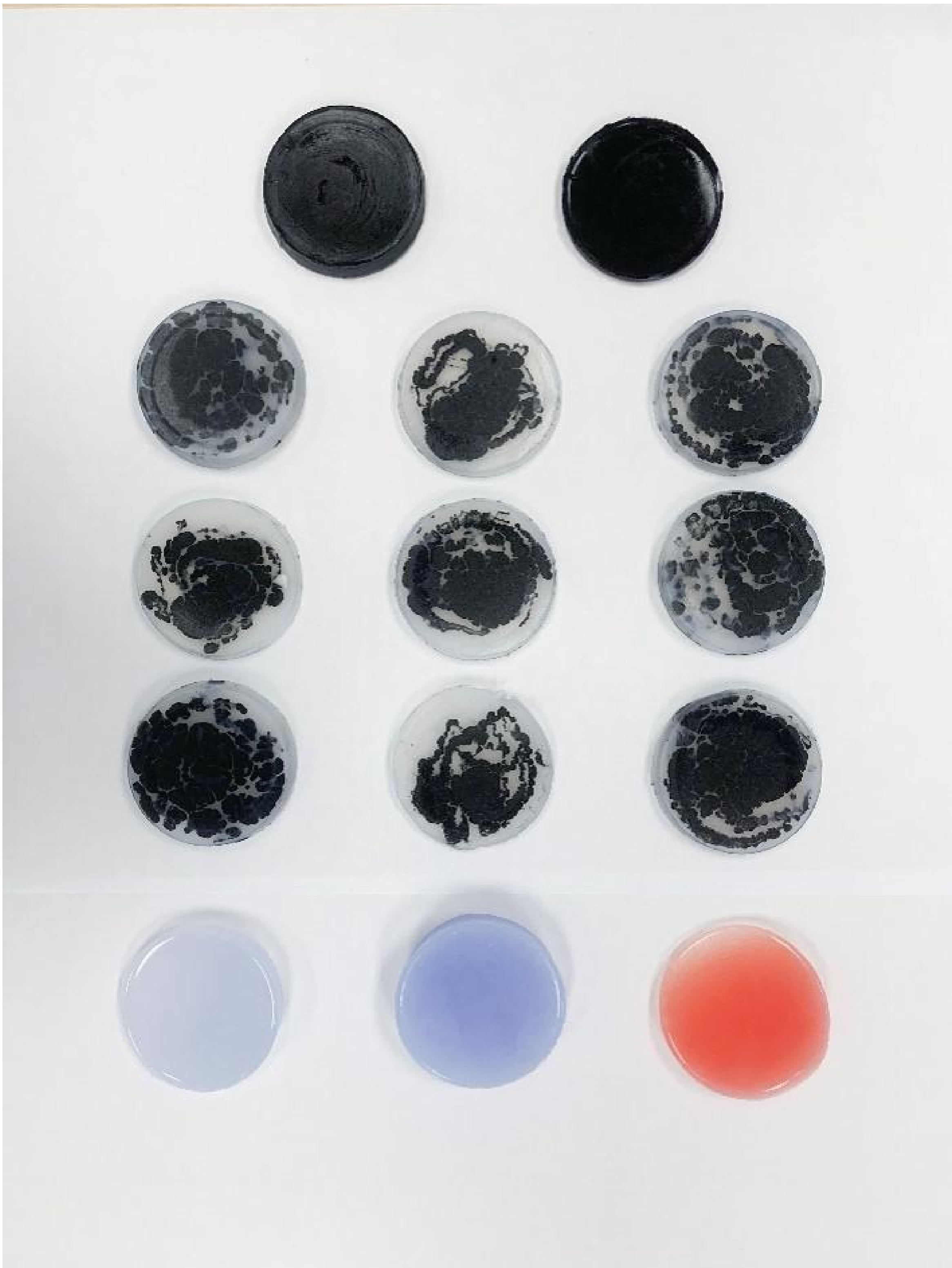


Fig. 4.30 Material Testing.

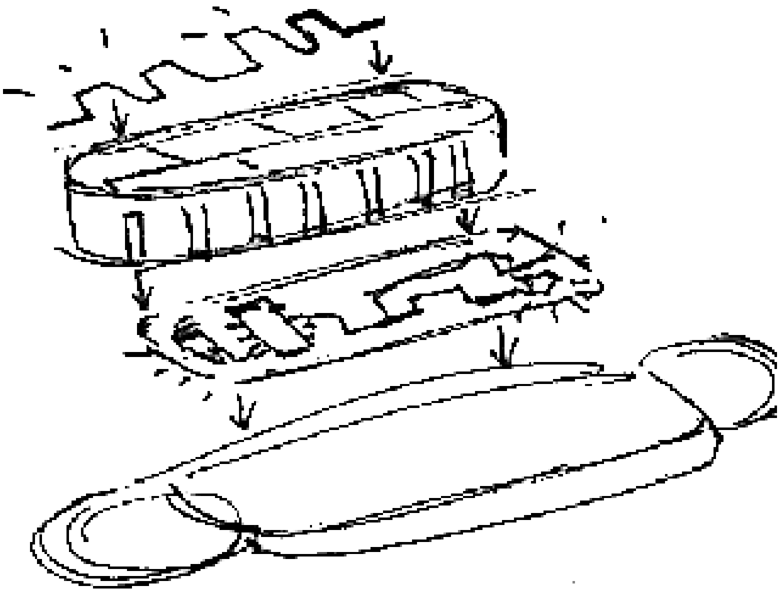


Fig. 4.31 Structure of soft robotics.

Here, the manufacturing process of conductive soft silicone material is described. It is shown in the Figure4.31. The conductive soft silicone follows three steps. 1) making a soft silicone base layer, 2) building a conductive material filler layer, and 3) installing conductive wires.

In order to make a conductive soft silicone material, we follow the basic procedure presented above. We first prepare the experimental equipment and gauges, proportion the AB silicone material in a container in a one-to-one ratio and mix it thoroughly. The mixture was then poured into the pre-prepared 3D printed finished mould and waited for the silicone to solidify. The solidified silicone is removed and a tool is used to create a groove for the conductive material.

The next step is to make the silicone conductive. Firstly, the AB silicone material is mixed evenly in a container in a one-to-one ratio. The conductive mix is then obtained by adding dispersion aid (composition PVP) to the highly reactive carbon nanotubes and then adding the conductive mix to the silica gel mix and stirring well until the solution is viscous.

Once the conductive mix has been prepared, the solution is poured into the previously made conductive material filler layer and left to set completely.

The next step is to attach the electrodes to the conductive material, using conductive wire, copper wire etc. to connect the soft conductive silicone material to the pins of the microcontroller.

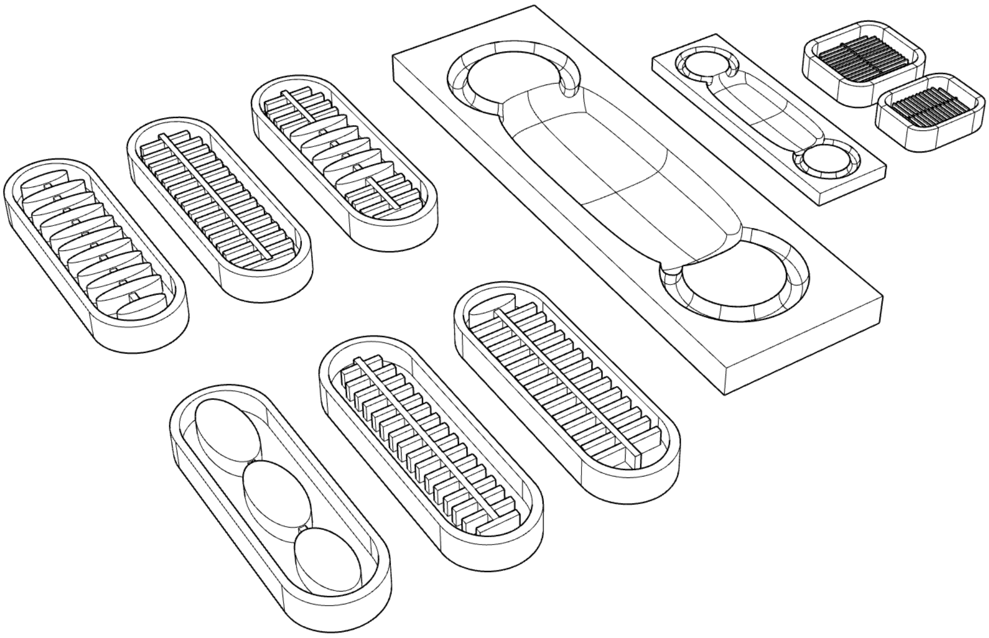


Fig. 4.32 Soft rubber additive manufacturing for soft robot construction moulds.

The moulds used to make the different parts of the soft robot were designed as shown in Figure 4.32, using additive manufacturing techniques to create the moulds.

Fig. 4.33 Soft rubber additive manufacturing for soft robot construction moulds.

Fig. 4.34 Soft rubber additive manufacturing for soft robot construction moulds.

4.3.3 Prototyping and testing

A further iteration of the product's appearance, based on previous user research. User testing has seen users mention more often the impact of the weight and appearance of the control system on the overall experience. The iteration of the design solution was focused on being smaller, lighter and more comfortable to wear.

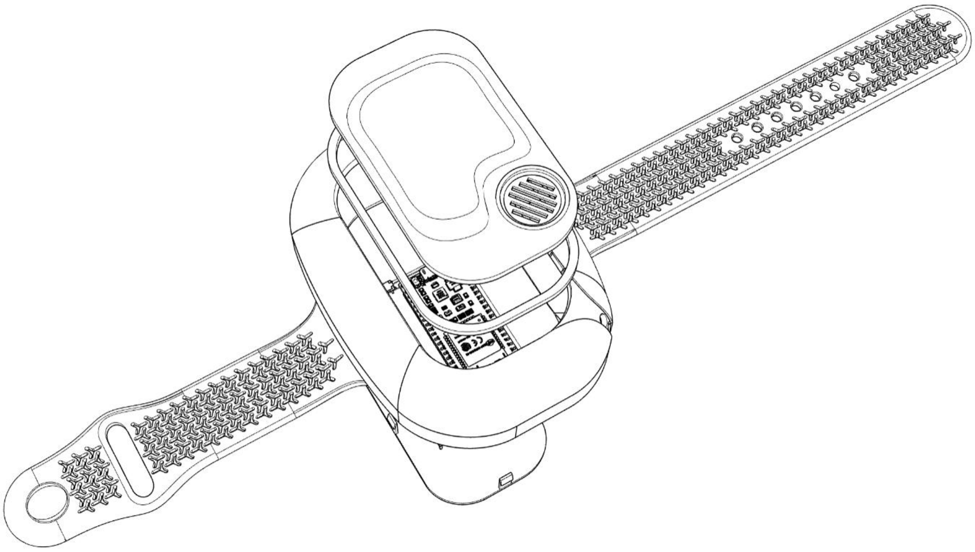


Fig. 4.35 Design Concept.

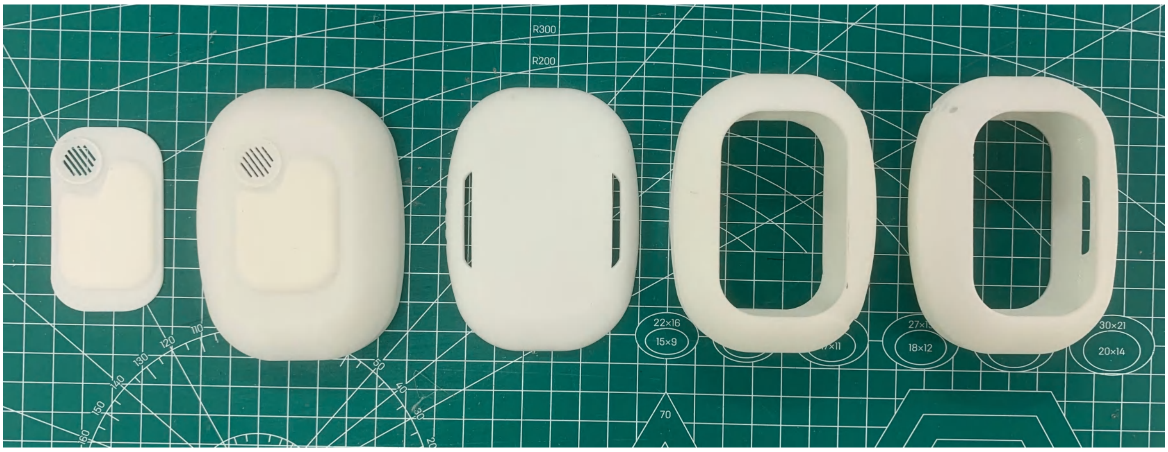


Fig. 4.36 Design prototypes for control systems.

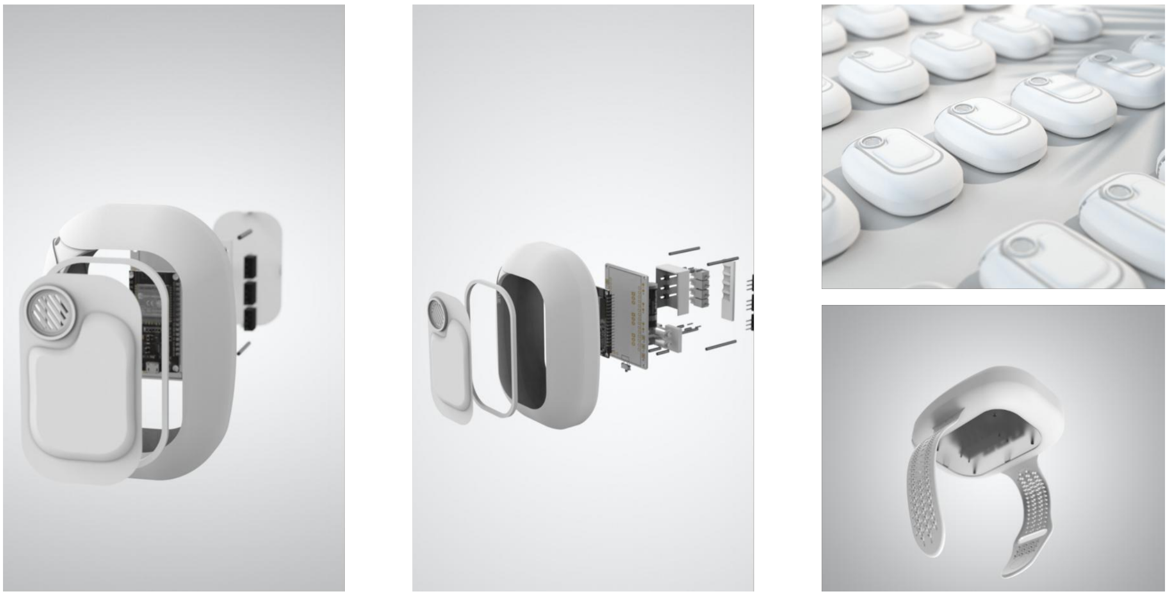


Fig. 4.37 Exploded views and renderings.

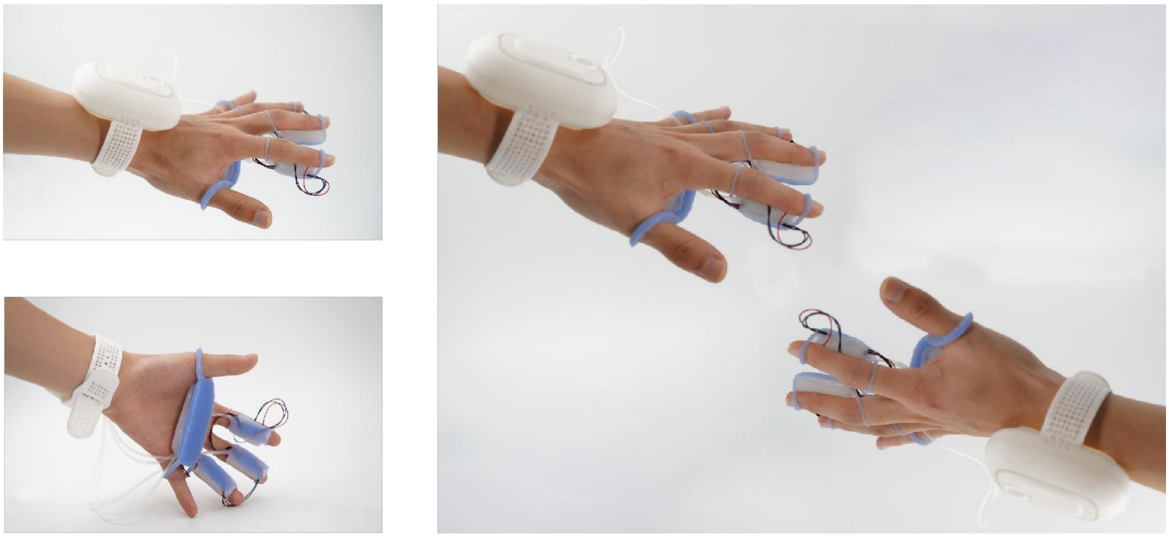


Fig. 4.38 SOFT-MR.

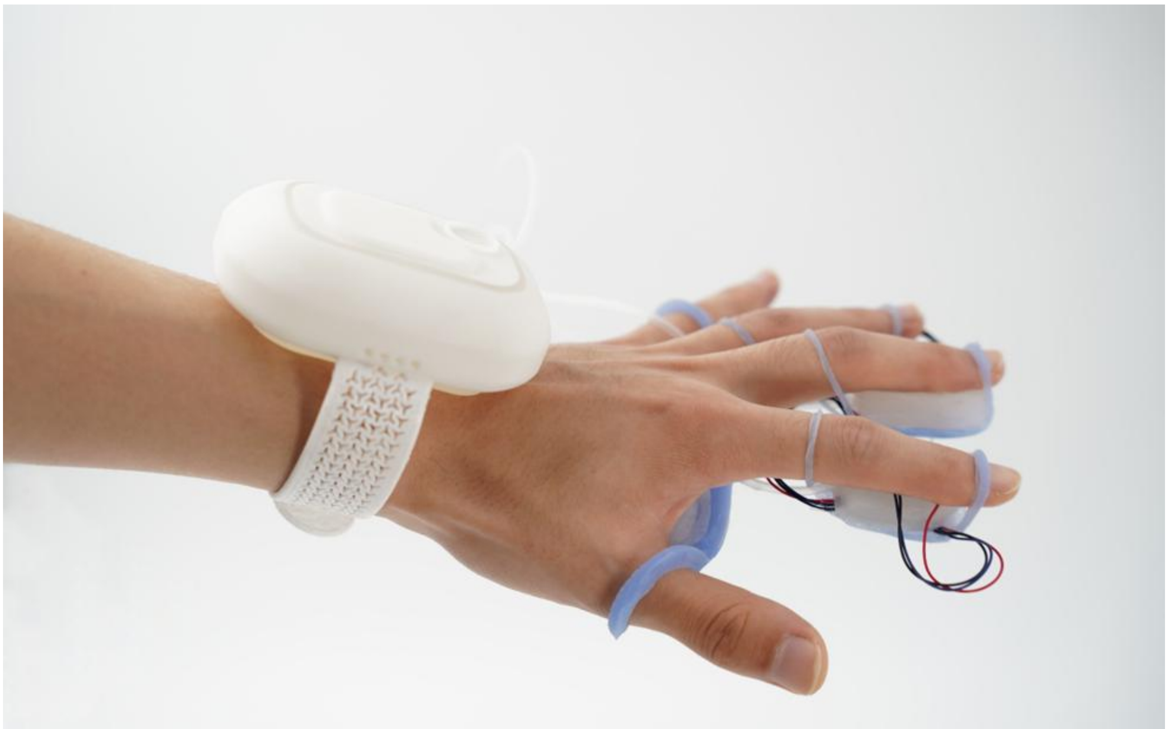


Fig. 4.39 SOFT-MR.

Fig. 4.40 SOFT-MR.

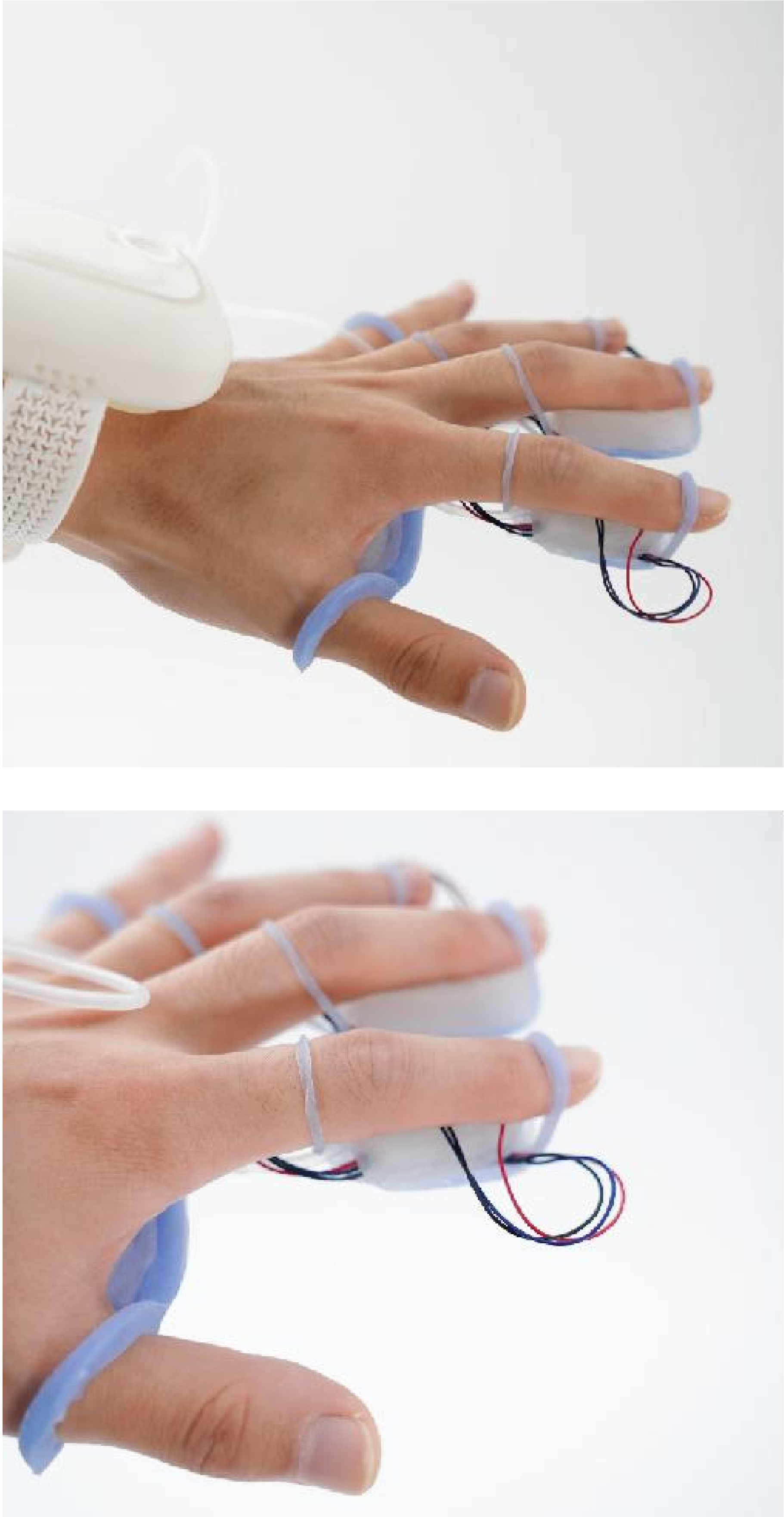


Fig. 4.41 SOFT-MR.

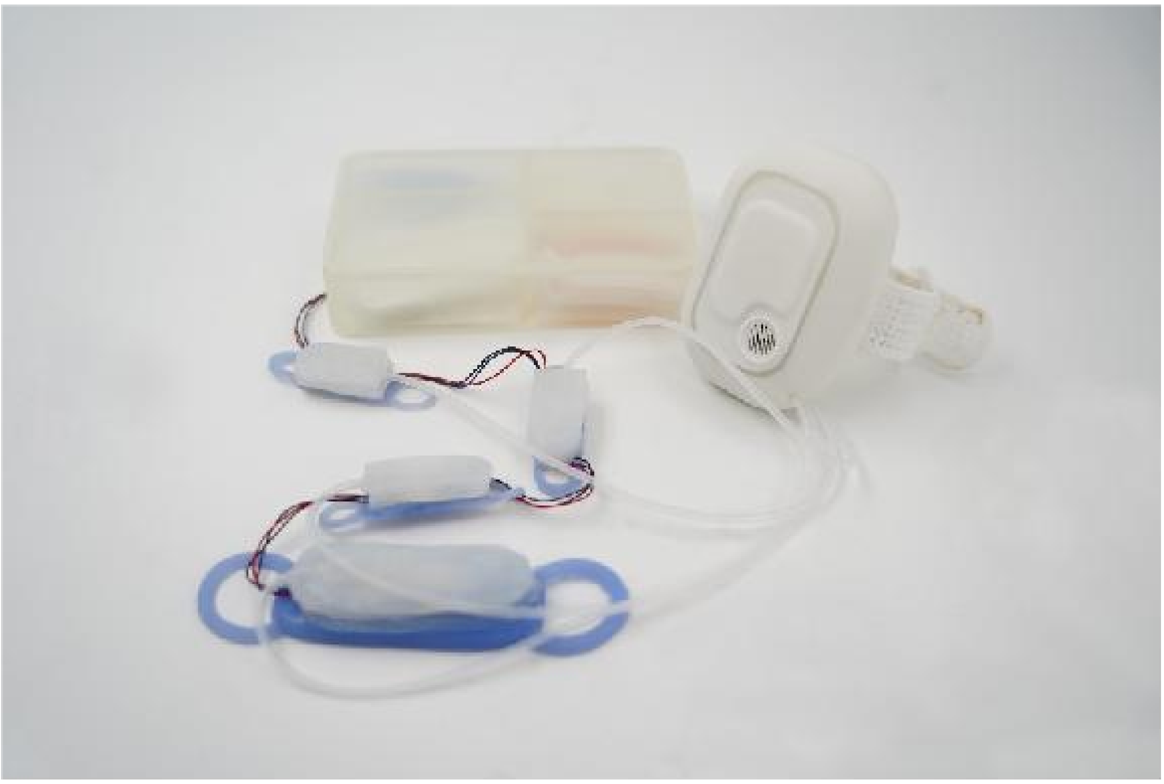


Fig. 4.42 SOFT-MR Toolkit.

Researchers, students, artists, designers, and manufacturers have demonstrated a growing interest in soft robotics in recent years. However, many practitioners in this field are faced with the challenge of building their own drive systems from scratch, which requires a significant amount of time and effort. Instead of focusing on developing innovative software actuators, applications, or user experiences, they often spend a considerable amount of time on the development of pneumatics, electronics, and software. So a complete toolkit has been developed based on design practices, including moulds for making soft robots and circuit boards for the main controls, to help interested parties quickly develop more interesting haptic experiences.

Fig. 4.43 SOFT-MR.

Fig. 4.44 SOFT-MR.

Chapter 5

Conclusion and Further work

5.1 Application Scenarios

5.1.1 Enhancing the user experience in VR and AR

SOFT-MR can change the shape and size of the soft robot in the finger area by changing the time of inflation. In addition, the speed of change of size and shape can also simulate different types of tactile sensations very well.

Haptic devices enhance the user's virtual experience because they help the user to better perceive the virtual world. The human ability to perceive virtual reality environments relies primarily on sight and hearing, but with haptic devices, users can also perceive haptic stimuli in virtual reality environments. This helps users to become more immersed in virtual reality and enhances the user experience.

In addition, haptic devices can also help users to better control the virtual reality environment, allowing them to interact more naturally with virtual reality. This also helps to enhance the user's virtual experience.

Fig. 5.1 User test.

Learning Skill In VR

SOFT-MR provides an immersive experience for the user, especially when learning skills that require practical work. For example, in the design of the bamboo bending scenario, SOFT-MR works well with virtual reality and augmented reality to simulate the real tactile sensation and synchronise the haptic experience. Students are able to experience what it is like to make something rather than just watch it, and haptic synchronisation is more effective and better for their skill acquisition.

As shown in Figure 5.2, a scenario of learning how to bend bamboo in an immersive environment using a haptic wearable is demonstrated.

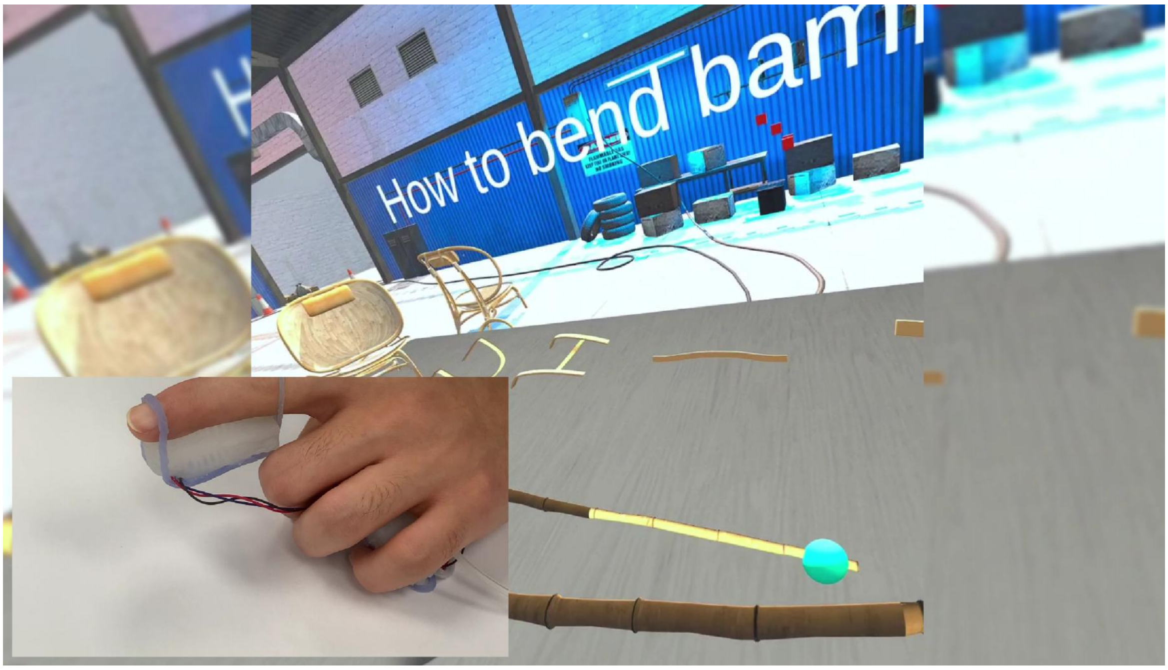


Fig. 5.2 Education in design practice in virtual reality.

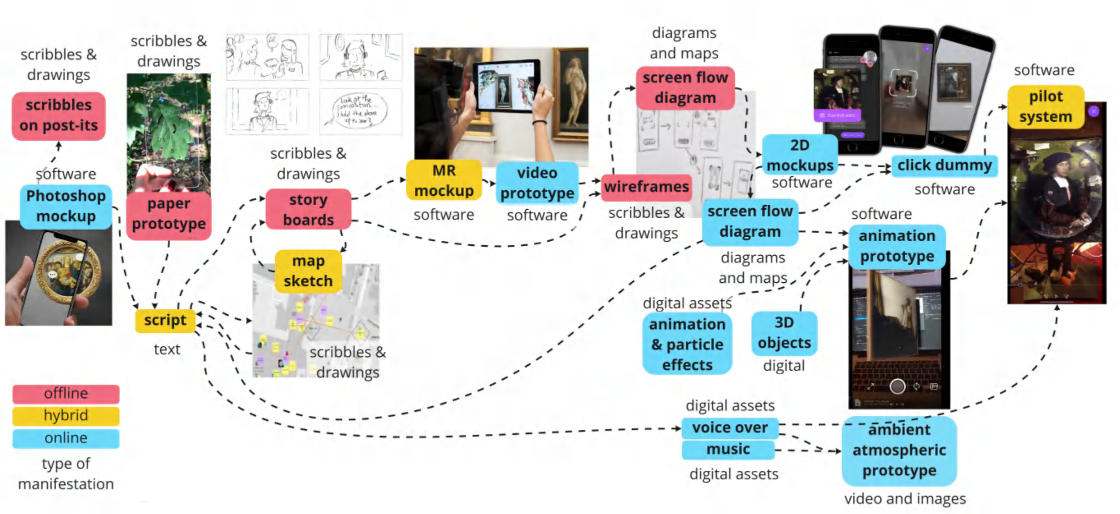


Fig. 5.3 Users using haptic wearables can experience immersive environments together with different types of users through collaboration and interaction [42].

5.1.2 Wide range of applications for haptic synchronisation

The enormous potential of haptic synchronisation has already received attention. Whether it is the [43] developed by Riecke et al. for remote mobile robots in space, or the robotic surgery [44] discussed by Wagner et al. in which haptic feedback reduces errors by a factor of three. Or the use of kinesthetic feedback for rehabilitation by Metzger et al. [45]

It is important to note that learning dexterous hand skills is crucial for many aspects of our daily lives, such as using highly dexterous interfaces (e.g., keyboards, touch screens) and playing musical instruments. These skills are also necessary for assisting others in movements, such as hand rehabilitation [46] and performing surgeries [47]. In order to effectively perform these tasks, precise and stable control over finger gestures, forces, speeds, and timing is required. As a result, research in interactive systems has focused on developing devices that support skill transfer. These devices include head-mounted displays (HMDs) [48] and projection mapping systems [49] that allow users to share visual perspectives. While these devices can be useful for skill transfer, they do not always provide all of the necessary information for learning complex movements. To address this issue, researchers have introduced wearable devices that provide haptic feedback to users in order to establish haptic synchrony.

Fig. 5.4 Training in surgery in a virtual environment.

5.1.3 Improving user-device care interactions

An interdependent wearable device is one in which there is an interdependent relationship between two or more devices that allows them to work together. Such devices often have network connectivity and are able to exchange data and communicate with other devices.

These devices facilitate social interaction because they can provide users with additional communication channels and tools. For example, with wearable devices, users can communicate with others at any time and from any place. In addition, such devices can offer many interesting interactive features, such as games and apps, that can engage users and facilitate social interactions.

Human-computer interaction (HCI) researchers have been exploring ways to cultivate a sense of care and responsibility among users for their devices to address the growing problem of electronic waste globally. One approach has been to focus on how to foster a sense of care and attachment between users and their devices. Researchers have also explored the care and maintenance of device materials through repair, maintenance, and creative reuse, as well as how to design interactive devices to facilitate caring interactions and encourage users to view their devices as something worth caring for. These design efforts often involve virtual care in the form of interactions that allow users to respond to the quality of life of digital entities. Overall, these efforts are important in helping to prevent devices from becoming outdated and discarded, and improving the relationship between the user and the device is important.

5.2 Future Work

5.2.1 More natural interaction

In recent years, EHD (Electro hydro dynamics) pumps have been gaining interest in the interactive sector. EHD pumps are proposed as a drive source for soft actuators [50] [51] because of their simplicity, compactness and light weight. Lighter weight, smaller and thinner haptic wearable devices are expected to further enhance the user experience.

Virtual Reality (VR) enables users to experience environments outside their physical surroundings. The advent of portable VR hardware (e.g. Oculus Quest 2, VIVE Focus 3) has further enabled users to experience virtual reality anywhere, anytime. However, while current VR systems present immersive visual and audio experiences, they largely ignore events in the user's physical environment. In contrast, users experiencing VR are constantly receiving two streams of sensory information, one from the VR and the other from the physical environment. [52]

Interaction that links the virtual and the real, and whether this distracts the user from the virtual experience, is not explored in depth in this project. This is worth exploring in depth in future work.

5.2.2 Integration of biomass and interactive devices

Interactive devices are designed to be easy to use, fast to run and virtually invisible. These are the key principles in Weiser's [53] for pervasive computing, which has driven decades of computing research and products. This vision enabled seamless interaction by designing for 'invisible' devices. But it also had a side effect in that the user-device relationship was not as close as it could be. Future work integrating living organisms (e.g. bacteria, plants) into wearable haptic devices is expected to improve the user-device relationship.

5.3 Result and Discussion

Using RTD research methods, I combine a range of user research methods related to human-computer interaction and design to design this complete product, link it to immersive technologies, and then describe the design process and its interaction and technical characteristics. Finally, test results from user research are described and design findings and design thinking are presented.

In this paper, I present SOFT-MR, a small, portable and highly adaptable soft robot-based haptic device that provides hand-based haptic simulation. The non-invasive and lightweight design allows for a wide range of uses outside the laboratory environment. In particular, the design concept of interdependent wearability is introduced, offering a new possible improvement to address the isolation caused by immersive technologies. In addition, based on design practice, a completely soft robot fabrication toolkit has been developed for a wider audience of HCI researchers, interaction designers, artists etc. interested in soft robotics and haptic design, including a complete fabrication tooling and process methodology. The results of this design and research provide insights for researchers and practitioners who are interested in designing haptic experiences, and tangible interfaces and improving the user experience in VR.

Finally, the importance of considering how virtual experiences are designed is discussed through the design process of RTD. It is worthwhile for people to explore in depth how researching information technology can improve their health by reducing the negative effects of social isolation and loneliness, while promoting social engagement.

5.4 Design virtual experiences

People have been thinking about how to introduce these immersive experiences into public settings. If the device is made to be invisible and inaudible to others, how will bystanders interact with the user? Similar questions impede immersive experiences in public settings today, as bystanders are unable to discern the user's intentions or see the behaviours (e.g., hand gestures, posture, or gaze) associated with them when the user is wearing headphones [54].

Mixed reality technology allows people to interact between the virtual world and the real world, making it possible to merge the virtual world with the real world [9]. This technology has great potential to help people make greater progress in their learning, work and play. Based on design practice, the following aspects need to be summarised that need to be considered when designing virtual experiences.

1. To make mixed reality more inclusive, consider the following.
2. Make mixed reality technology easier to use. This includes ensuring that the technology is simple to operate, easy to understand and use, and has a good user experience.
3. Provide a mixed reality experience that is appropriate for different user groups. This can be achieved by designing applications that are appropriate for different age groups, cultural backgrounds and physical abilities.
4. Consider accessibility. Ensure that mixed reality technology is accessible to all.
5. Work in tandem with other technologies. Mixed reality technology should work in synergy with other technologies, such as artificial intelligence, to provide a richer and more meaningful experience.
6. Consider social and cultural implications. When designing and using mixed reality technology, its social and cultural impact should be considered.

As the use of immersive technologies becomes more widespread, it is essential to investigate the long-term effects of virtual experiences. Previous studies have indicated that readjusting to reality after removing a head-mounted display can be uncomfortable and that the distinction between real and virtual experiences may be blurred. In order to guarantee that immersive technologies do not pose any risks or intrusions, it is necessary to consider the potential psychological and social consequences of prolonged immersion in such technologies, particularly as more advanced and potentially addictive technologies are developed.

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Appendix

Expert Interview Introduction: Hello, thank you for taking the time out of your busy schedule to participate in this expert interview. I am Kedong Chai from the School of Design, department of Industrial Design. I understand that you are a senior researcher (or designer) in the field of Human Computer interaction (or interaction design), and the purpose of this interview is to understand your insights and opinions on immersive technologies and wearable haptic devices. We hope you will feel free to share your insights and opinions, as they will be very helpful to our research. We have prepared some questions in advance and the interview will take about 20 minutes to complete. The content of the interview will be kept strictly confidential and will only be used for this study.

Part 0: General information

1. What are your main research interests in the field of human-computer interaction?
2. How long have you been involved in interaction design (years)?

Part 1: Immersive technologies

1. Do you know anything about immersive technologies (on a scale of 1-10)? Can you tell us briefly about your understanding of immersive technology?
2. What do you think are the main limitations that are currently preventing the widespread adoption of immersive technologies?
3. In our pre-survey, some people thought that immersive technology reduces interaction between people. What do you think are the reasons for this?
4. Do you think that current immersive technologies have to some extent contributed to social isolation (isolation and disconnection of people from each other)? What are your thoughts on this?
5. What solutions or measures do you think we can take to improve this phenomenon?

Part 2: Wearable haptic devices and immersive technologies My Master's project is intended to focus on promoting social connection and inclusion in mixed reality through the design work of wearable haptic devices.

1. Do you know anything about wearable haptic devices (on a scale of 1-10)? Can you talk briefly about your understanding of wearable haptic devices?
2. What impact do you think wearable haptic devices have on immersive experiences? Are they essential? Why?

3. Can you imagine a haptic device in an immersive technology context and what kind of design do you think would allow more people to be included in an interactive experience with immersive technology?
4. Currently, most haptic devices are used in laboratory environments. What solutions or measures do you think we can take to promote the popularity of haptic devices?

Part 3: Multi-person interaction control for wearable haptic devices

1. In your previous work or the work of other researchers, are there any examples that stand out to you that encourage people to socialise with others in the same place? Can you share any examples?
2. Currently, most haptic devices only support single-person interaction control, is there a need for multi-person interaction control for wearable haptic devices? How do you anticipate users will react?
3. Do you think it would be acceptable to create a backstory with multi-person interaction needs so users can connect (e.g. two "creatures" that have the potential to make a connection but need to be controlled by the user) in addition to controlling multi-person interaction based on the user's own needs? Do you think this fictional backstory would enhance the social experience?