# USE OF ASSISTIVE TECHNOLOGIES FOR PEOPLE WITH VISUAL IMPAIRMENT: SMART GLOVE DESIGN FOR CLOTHING FIELD

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Thesis for the Ph.D. Program in Design Studies

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# ETHICAL DECLARATION

I hereby declare that I am the sole author of this thesis and that I have conducted my work in accordance with academic rules and ethical behavior at every stage from the planning of the thesis to its defense. I confirm that I have cited all ideas, information and findings that are not specific to my study, as required by the code of ethical behavior, and that all statements not cited are my own.

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# ABSTRACT

## USE OF ASSISTIVE TECHNOLOGIES FOR PEOPLE WITH VISUAL IMPAIRMENT: SMART GLOVE DESIGN FOR CLOTHING FIELD

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Ph.D. Program in Design Studies

Advisor: Assoc. Prof. Dr. Arzu Vuruşkan

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According to World Health Organization, there are 2.2 billion people with vision impairment and blindness worldwide in 2019 (WHO, 2022). Assistive technology is a current area that has the potential to enhance the quality of life for individuals with visual impairment through innovative initiatives. In this dissertation, clothing, one of the areas where visually impaired people have the most difficulty in their daily lives, is evaluated. It has been determined that the most problematic point is to define the garment and then to create a harmonious combination with these garments. In order to suggest solutions for visually impaired people, firstly, assistive and wearable technologies were examined in this dissertation under the titles of mobility, communication, and daily living activities. The existing literature was overviewed in detail in order to identify the gap, and up-to-date innovative material research was conducted to show possibilities in improvement of such assistive and wearable technologies for visually impaired people. Thus, in this dissertation a smart glove design is suggested as a solution to clothing related problems for those people. In order to guide the design process of Smart Glove, user scenarios were created considering the user-centred design approach. Finally, a prototype glove was developed that can take a photo of the garment and inform the user via audio feedback based on image processing and machine learning. Also, the system was tested in terms of both system operability using a dataset and combination suggestions specifically created for this study, as well as user experience with trials.

Keywords: Smart glove, visually impaired, assistive technologies, wearable technologies, image processing, user-centred design.

# ÖZET

## GÖRME ENGELLILER IÇIN YARDIMCI TEKNOLOJILERIN KULLANIMI: GIYIM ALANINA YÖNELIK AKILLI ELDIVEN TASARIMI

Süller Zor, Başak

Tasarım Çalışmaları Doktora Programı

Tez Danışmanı: Doç. Dr. Arzu Vuruşkan

Ocak, 2024

Dünya Sağlık Örgütü’ne göre 2019 yılında dünya çapında 2,2 milyar görme bozukluğu ve körlüğü olan birey bulunmaktadır (WHO, 2022). Yardımcı teknolojiler, yenilikçi girişimler yoluyla görme engelli bireylerin yaşam kalitesini arttırma potansiyeline sahip güncel bir alandır. Bu tezde görme engelli bireylerin günlük yaşamlarında en çok zorlandıkları alanlardan biri olan giyim konusu değerlendirilmiştir. Bu konuda en sorunlu noktanın giysiyi tanımlamak ve ardından bu giysiyle uyumlu bir kombin oluşturmak olduğu tespit edilmiştir. Görme engelli bireylere yönelik çözüm önerileri sunmak amacıyla bu tezde öncelikle yardımcı ve giyilebilir teknolojiler mobilite, iletişim ve günlük yaşam aktiviteleri başlıkları altında incelenmiştir. Eksikliğin belirlenmesi amacıyla mevcut literatür detaylı bir şekilde gözden geçirilmiştir. Görme engelli kişiler için bu tür yardımcı ve giyilebilir teknolojilerin geliştirilmesine yönelik olanakları göstermek üzere güncel yenilikçi malzeme araştırmaları yapılmıştır. Buna bağlı olarak, tezde bu kişilerin giyimle ilgili sorunlarına çözüm olarak akıllı bir eldiven tasarımı önerilmektedir. Akıllı Eldiven'in tasarım sürecine yön vermek amacıyla, kullanıcı odaklı tasarım yaklaşımı ilkeleri dikkate alınarak kullanıcı senaryoları oluşturulmuştur. Son olarak, giysinin fotoğrafını çekebilen, görüntü işleme ve makine öğrenimi ile kullanıcıyı sesli geri bildirim yoluyla bilgilendirebilen bir prototip eldiven geliştirilmiştir. Ayrıca sistem, hem bu çalışmaya özel oluşturulan veri seti ve kombinasyon önerileri kullanılarak sistemin çalışabilirliği hem de denemelerle kullanıcı deneyimi açısından test edilmiştir.

Anahtar Kelimeler: Akıllı eldiven, görme engelliler, yardımcı teknolojiler, giyilebilir teknolojiler, görüntü işleme, kullanıcı odaklı tasarım.

Dedicated to my dear son Deniz Sarp…

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I would like to express my sincere appreciation to my advisor Assoc. Prof. Dr. Arzu Vuruşkan for her guidance and insight throughout the dissertation.

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I also appreciate all the moral support I received from my family, my department head Elvan Özkavruk Adanır, my professor Ebru Corsini and my colleagues…

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# CHAPTER 1: INTRODUCTION

“Visual impairment” refers to all cases of moderate or severe vision impairment (i.e. low vision) and blindness (WHO, 2022). According to estimates from World Health Organization data, there are 2.2 billion people with near or distance vision impairment and blindness worldwide in 2019 (WHO, 2022). Almost half of these cases that could have been prevented, includes unaddressed refractive error (88.4 million), cataract (94 million), age-related macular degeneration (8 million), glaucoma (7.7 million), diabetic retinopathy (3.9 million), as well as near vision impairment caused by unaddressed presbyopia (826 million) (WHO, 2022). There are four levels of visual function, according to the International Classification of Diseases -10 (ICD – 10, Update and Revision 2006): (1) normal vision, (2) moderate visual impairment, (3) severe vision impairment, and (4) blindness. Looking at the figures in Turkey, according to the disabled and elderly statistical bulletin published by the Ministry of Family and Social Services of the Republic of Turkey (2021), 1,039,000 people are visually impaired in Turkey. In terms of the distribution of this population by gender, it is stated that 478,000 of the men and 561,000 of the women are visually impaired.

On the other hand, over the past 20 years, the social model of disability, in which disability is seen more as a social construction than a medical reality has come to the fore. An individual may have physical disability in a way that requires adaptation in daily life, but most obstacles stem from the attitude of the society and physical/environmental barriers (Kaduwanema, 2016). For these people, mobility, communication, education and other daily activities, such as clothing related issues or shopping can be very compelling. At this point, the medical model and the social model both agree that physical environment and opportunities should be made as accessible as possible for individuals with special requirements (Kaduwanema, 2016). Bringing such people to the collective communication environment, and facilitating their social, educational and the other daily life activities are significant social responsibilities. In response to this, there has been a significant surge in the development and application of assistive technology and wearable devices to enhance accessibility and independence for individuals with visual impairments.

Assistive technology encompasses a broad spectrum of tools and devices designed to solve the challenges posed by visual impairment.  Besides, wearable technology has emerged as a game-changer in the realm of assistive solutions for visual impairment. For instance, one of the critical areas where assistive and wearable technologies focuses is in mobility and navigation support. Navigation apps specifically designed for individuals with visual impairments utilize GPS and sensor technologies to offer step-by-step directions, location descriptions, and information about nearby points of interest. These applications contribute to increased independence in navigating both indoor and outdoor environments, promoting a sense of self-reliance. Devices such as smart glasses equipped with cameras and sensors offer real-time environmental information, allowing users to navigate physical spaces more confidently. Furthermore, wearable navigation systems provide auditory cues and haptic feedback, enhancing spatial awareness and reducing reliance on traditional mobility aids.

Assistive and wearable technologies have also revolutionized educational and professional landscapes for individuals with visual impairments. Screen readers, speech-to-text software, and magnification applications are some examples that have revolutionized the way individuals interact with digital content. These technologies enable access to information, digital publications, and communication platforms, empowering users to navigate a predominantly visual world. Braille displays and electronic braille notetakers facilitate reading and writing, while optical character recognition (OCR) technology embedded in wearables converts printed text into audible or tactile formats. These advancements break down barriers to information access, enabling participation in academic and professional pursuits.

Even important developments have been made for visually impaired people, these developments have mostly focused on navigation, education, or health issues, so developments in assistive and wearable technologies that assist in social and daily activities have remained limited, in fact, a niche area. In addition, challenges persist in ensuring the widespread adoption and affordability of these technologies. Further research and development are needed to address specific user needs, improve user interfaces, and enhance the overall user experience. Collaboration between technology developers, researchers, and individuals with visual impairments is crucial to creating solutions that are not only technologically sophisticated but also genuinely responsive to the diverse needs of the user community. As these technologies continue to evolve, the potential for encourage greater independence, participation, and inclusion in various facets of life becomes increasingly apparent. Through ongoing research, development and collaboration, the future promises a more inclusive and empowered experience for individuals with visual impairments, facilitated by ongoing advances in assistive and wearable technologies.

### *1.1. Purpose of the Dissertation*

This issue particularly interests designers, engineers and urban planners, due to their role in developing a proper design and planning approach to provide wider accessibility considering the needs of all.

- The purpose of this study is to address the challenges faced by the visually impaired people in clothing field and suggest solutions. Regarding this, section of the survey was allocated specifically for clothing related issues in order to identify the relationship between individuals with visual impairment and concept of design, clothing and AT/ WT.
- Besides, based upon the daily obstacles faced by people with visual impairment, this study also aims to introduce a review of existing examples of uses of assistive technology (AT) and wearable technology (WT) as AT in daily life that focuses on major purposes, strengths and weaknesses of current examples. In addition, it aims to introduce up-to-date innovative material research. Therefore, both research projects and commercial products are covered in the literature review to an analysis of the potential contribution of design in this context.
- Accordingly, although 1,039,000 visually impaired individuals are reported in Turkey, there are very few studies in the literature about assistive and wearable technology for the visually impaired. In particular, no studies have been found on wearable technologies that will solve the problems of visually impaired people in the field of clothing. Therefore, one of the aims of this dissertation is to contribute to the literature on this subject.
- In relation to the obstacles in clothing field, the main goal is to create a wearable as an assistive technology product for visually impaired people that identifies various garments and combines them to selecting appropriate clothing for diverse

social occasions, thereby enhancing the independence and confidence of those people in their daily lives. Towards this objective, a wearable garment identifier - a smart glove- system, has been designed to help their clothing selection process. By integrating a textile product with hardware components, machine learning algorithms, and audio feedback mechanisms, the smart glove seeks to empower users with the ability to discern and combine different clothing items effortlessly.

- In addition, it is aimed to create the dataset required for the operation and testing of the smart glove system from the current products of fashion brands, instead of choosing from ready-made datasets, to provide a detailed clothing categorization and to prepare combination suggestions by taking these products into consideration in line with trends.

Through these approaches, the dissertation tries to contribute to inclusivity by increasing autonomy in the realm of fashion choices for individuals with visual impairments.

## *1.2. Methodology*

Considering social perspective on disability, in order to improve physical environment and make daily life activities easier, designers are in need of information and tools that could enable the evaluation of design and production processes, from design concept to final product or service (Persad et al., 2007). In this dissertation, aiming to develop a wearable product (i.e. smart glove) to assist visually impaired people in garment selection and combination processes, mixed methods combining survey, interview, secondary data analysis and product development were implemented. The dissertation was discussed under five main chapters after introduction part, as “literature review”, “survey analysis”, “construction of smart glove”, “testing the Smart Glove and results”, and “further conceptual design” (Figure 1). The ideas of “accessibility and equal opportunities for all” have become increasingly prominent in recent years. However, when these ideas are discussed under the “design” notion, different approaches such as universal design, design for all, usable design, user-centred design etc. come to exist (Persson et al., 2015). All these approaches can serve for the design of products and services which are easier for everyone to use, including people with disabilities (Washington Edu., 2017). In order to refer in the design process, the user-centred design (UCD) approach was selected as the most appropriate concept. The selection of the UCD approach for developing a wearable assistive technology product for visually impaired people in this dissertation can be justified by several academic considerations. For instance, UCD is a methodology that prioritizes the end-users throughout the design process, ensuring that the final product meets their needs, preferences, and usability requirements. It also considers usability and accessibility factors, so developing a wearable device for visually impaired users requires a well understanding of their interactions with technology, tactile preferences, and sensory capabilities. This is particularly important when designing assistive technology where user needs may be diverse, and a one-size-fits-all solution is unlikely to be effective.

On the other hand, UCD encourages the collection of pragmatic data through usability testing and user studies. This data-driven approach ensures that design decisions are supported by evidence rather than assumptions, so in the context of assistive technology, it is crucial to ensure that the designed solution effectively addresses the identified needs of visually impaired users. Also, the needs of users, especially in the context of assistive technology, may evolve over time. UCD's iterative and flexible nature allows for adaptability to changing user needs and technological advancements. Therefore, in the literature review, firstly, the UCD approach was introduced in terms of its principles and its relationship with assistive and wearable technologies. Afterwards, in order to identify gaps and opportunities for innovation within the realm of assistive devices for visually impaired individuals, assistive technology (AT) concept was discussed by categorizing them based on their applications, including mobility, communication, and daily activities. Under the AT umbrella, early examples of smart wearables and items in this field are classified and examined in terms of their utility, technical and design details, and missing points. Following, the scope and importance of wearable technology, providing insights into the classification and processes involved. A focused examination of wearables as assistive technology set the stage for the development of the Smart Glove. In the last part of literature review, since to build a seamlessly integrated wearable, understanding the properties and capabilities of electronic and textile components is crucial, the section outlines the exploration of latest innovative electronic components, textile materials, and the methodologies for effectively integrating these components into a unified wearable system.

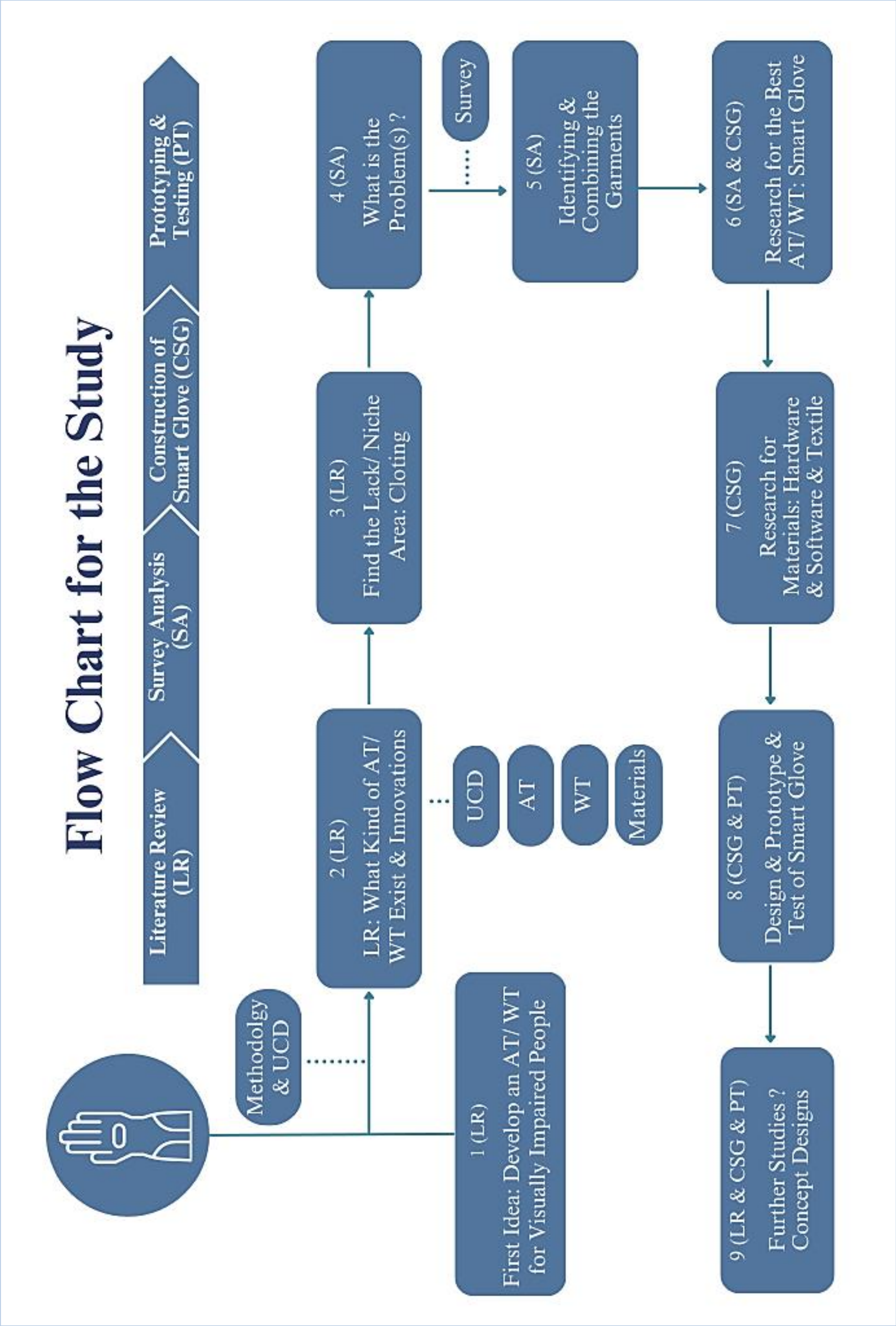


Figure 1. Flow Chart for the Study

The study is based on user-centred design approach that can help in design process in terms of usable product and system design. Hence, it starts with the analysis of users' needs. It also requires evaluating physical devices, as well as communication and action modalities in order to examine usability, effectiveness, efficiency of a device as well as user's satisfaction. It appears to be especially important when aiming to design for people with special needs. For this reason, in the third chapter, as qualitative data collection method, first hand research was conducted in the associations of people with visual impairments, in the form of interview, and a survey was applied through online platform. Thus, it provided insights into those people's obstacles in their daily life, especially in clothing. Also, it helped to understand their opinions about assistive devices and to develop design ideas.

Considering the information obtained from the literature review and survey results, the "Construction of the Smart Glove" chapter divided into three subheadings that first, "Purpose of the Smart Glove," explains the rationale for choosing the glove and outlines the main concept behind the Smart Glove. The second section, "Creation of User Scenarios," explores how user scenarios were developed and their role in guiding the design and prototyping processes. The final part, "Design Development," delves into the glove's design and development, covering material selection and design specifics.

In the following Chapter 5, the process of testing the developed smart glove prototypes is included. Accordingly, first of all, information is given about the data set and combination recommendation table created specifically for this study to test the algorithm. Then, data processing and system operation methods of the Smart Glove are explained. Finally, information and results of tests on the system operability and user experiences are given. In Chapter 6, in regards to results of study, the gaps identified both in the literature and in the developed prototype, user comments and possible adaptation of current innovative approaches conceptual design suggestions for future studies are presented.

### *1.3. Research Contributions*

This research on the design and implementation of a Smart Glove for visually impaired individuals to aid in garment identification and combination selection makes several significant contributions to both academia and the assistive and wearable technology field. The primary contribution lies in the development of a wearable assistive technology that goes beyond conventional solutions. The Smart Glove addresses the specific needs of visually impaired individuals in the realm of garment identification and selection, providing a solution to enhance their independence and confidence in daily life activities. In regards to user-centred design approach, by thoroughly understanding the preferences, challenges, and requirements of visually impaired users through user scenarios and survey analysis, the Smart Glove is designed with consideration of user needs, ensuring its practical relevance and acceptance in real-world scenarios. In addition, the conceptual framework in this study represents an interdisciplinary collaboration between the realms of fashion and product design and engineering. In particular, the creation of such functional products is seen as a meaningful contribution to the visually impaired community and constitutes a social outreach initiative that provides tangible benefits for social welfare. Furthermore, it is expected that the dissertation will make a significant contribution to the literature, as there are very few studies on assistive and wearable technologies for the visually impaired in the literature in Turkey, and especially since there are no studies on wearable technologies that will solve their problems in the field of clothing.

On the other hand, another contribution of this study is the created dataset that includes more than 5000 garments, which were collected from several fashion brands, and classified according to their main categories, silhouettes, colors and patterns. It was also created the combination offers more than 16000 by considering color and style theories, and global trend forecasting & analysis authorities. Although there are some datasets for clothes, the dataset prepared in this study is distinguished with its more fashion-oriented character. The dataset is specializes with up-to-date examples from fashion brands, and has a detailed categorization which can be adapted to other fields.

In conclusion, the Smart Glove design presented in this study contributes to the evolution of assistive technologies, emphasizing user-centred design, wearable technology integration, and empowerment through garment identification. The study aspires to inspire further innovations that prioritize the independence, confidence, and social inclusion of visually impaired individuals.

# CHAPTER 2: LITERATURE REVIEW

The "Literature Review" chapter covers key themes and research areas crucial to the understanding and advancement of design considerations in the field of assistive and wearable technologies. This chapter goes through the subsections as "user-centred design", which prioritizes the needs and experiences of users throughout the design process, the dynamic landscape of "assistive technology" and "wearable technology", and "material research". Within this framework, wearable technology emerges as a pivotal component, offering innovative solutions that seamlessly integrate into users' lives. Additionally, material research plays a significant role in enhancing the functionality, durability, and comfort of assistive and wearable devices, contributing to the overall effectiveness of these technologies. Thus, this chapter aims to explain the evolving relationships between user-centred design, assistive technology, wearable technology, and material research, providing a foundational understanding for the subsequent part including the development of smart glove in this research.

## *2.1. User Centred Design (UCD)*

User-centred design (UCD) is a human-centric approach to designing products and systems that prioritizes the needs, preferences, and abilities of the end-users throughout the design process. This part explores the principles of user-centred design and its application in the theoretical framework of developing assistive technology and wearables. Originating in Donald Norman's research laboratory at the University of California San Diego in the 1980s, UCD has evolved into a multifaceted approach that encompasses a spectrum of user involvement, ranging from periodic consultations to deep collaboration throughout the design lifecycle. Norman's principles, explained in his works, notably "The Psychology Of Everyday Things" (1988), articulate essential guidelines for creating user-centred designs. These principles include making actions easily distinct, ensuring visibility of conceptual models and alternative actions, facilitating evaluation of the system's current state, and establishing natural mappings between intentions, actions, and outcomes (Norman, 1988). Norman's insights underline the necessity of integrating user considerations into the design process to enhance usability and minimize the learning curve for users. By examining the key components of UCD, its relevance in creating inclusive and accessible technology is highlighted. Its principles emphasize understanding user needs, involving users in the design process, and iteratively testing and refining designs to meet user requirements (Figure 2). The theoretical underpinnings of UCD align with human-computer interaction theories, emphasizing the continual engagement of users, feedback loops, and adaptability in design. This paradigm addresses the fundamentals of modern product development, aiming to enhance user satisfaction, engagement, and overall product success. In the context of assistive technology and wearables, where the end-users often have diverse needs and abilities, applying UCD becomes crucial to ensure the creation of inclusive and effective solutions (Mallin and Carvalho, 2015).

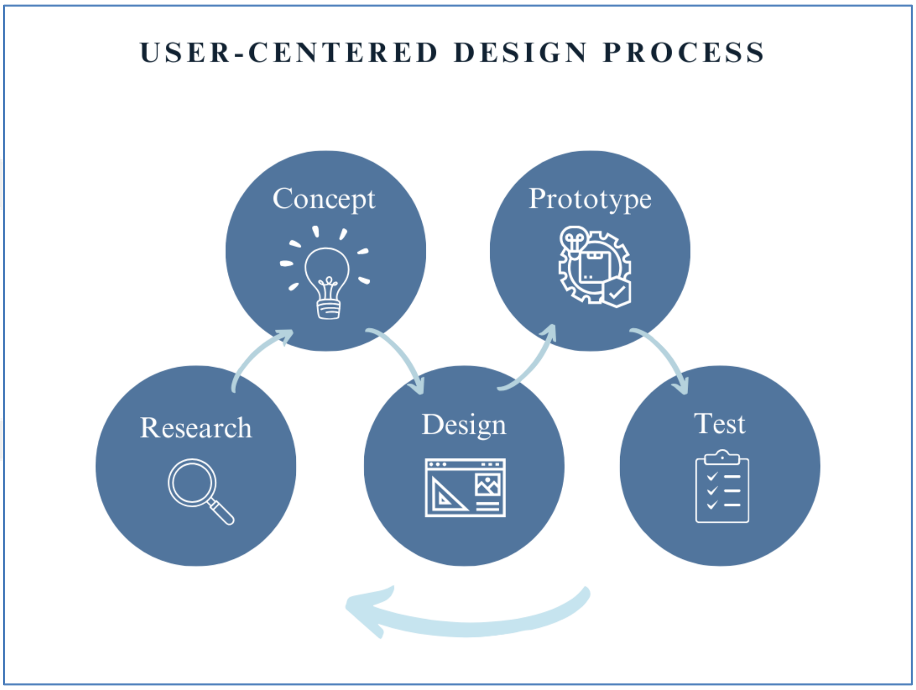


Figure 2. User-centred Design Process

The principles of user-centred design guide the development process, ensuring a focus on the end-user from conception to implementation. Key principles include user involvement, iterative design, holistic design and accessibility. While actively involve users throughout the design process provides understand their perspectives, needs, and expectations, continuously test and refine designs based on user feedback allows for the evolution of the product to better match user requirements. Also, it’s important to consider the entire user experience, addressing not only functional aspects but also emotional and aesthetic components. On the other hand, prioritize accessibility to accommodate users with diverse abilities ensures that the technology is usable by individuals with various disabilities.

Disability is a unique and individual experience, and incorporating pleasure and emotion into the design process is crucial for establishing a positive connection between users and assistive products (Preece et.al., 2002). This approach aims to provide not only style and functionality but also emotional quality, inspiring innovative processes that align with users' real needs. This is particularly important for individuals who continually face challenges with temporary solutions due to a lack of considerate design. Research in the field of Assistive Technology and Wearable Technology underline the importance of adopting a User-Centred Design (UCD) approach, emphasizing the need to consider users throughout the entire design process. Assistive and Wearable Technologies encompass a wide range of elements, including products, resources, methodologies, and services, all aimed at enhancing the functionality, activity, and participation of individuals with disabilities. Recognizing disability as an individual experience, the adaptation of assistive products should be a conceptual change that addresses effectiveness, efficiency, and satisfaction. Focusing on the user's capacities and the innovation of technology to improve quality of life is essential. This involves detailed studies for each disability type, active listening to user feedback, and collaboration within interdisciplinary teams to achieve objectives. Additionally, there is a crucial aspect of transforming everyday objects like Assistive Technologies into desirable items that positively impact users' quality of life. Thus, the holistic approach to design and innovation in Assistive Technology and relatively the Wearable Technology involves recognizing the individuality of disability experiences, implementing a User-Centred Design philosophy, and prioritizing the enhancement of users' functional capacities through collaborative efforts and thoughtful adaptations.

### *2.2. Assistive Technology*

Constant technological improvement in terms of devices, applications or production systems has changed the nature of interaction amongst people and with environment. These improvements have had positive outcomes for ATs, especially for people with sensory, cognitive, and physical impairments. AT gives those people independence in their daily activities and enhances their overall quality of life. By definition: “Assistive technology (often abbreviated as AT) is any item, piece of equipment, software or product system that is used to increase, maintain, or improve the functional capabilities of individuals with disabilities” (ATIA, 2015).

The Global Cooperation on Assistive Technology initiative at WHO focuses on five interlinked areas (5Ps): (1) People: user involvement; (2) Policy: development of tools to support countries in developing national policy; (3) Products: encouraging countries to develop a list of national priority products; (4) Provision: integration of assistive product service into the health system; and (5) Personnel: building the capacity of their community-level workforce (Chavarria et.al., 2021; WHO, 2019). On the other hand, in a similar approach, 5Ps are defined as person, purpose, product, policy and place. The person, as the first point, underlines the importance of design assistive technology considering individual needs, preferences, capabilities, and daily routines. This involves a comprehensive evaluation of the specific disability, lifestyle, and integration of technology into the person's existing environment. Purpose, the second element, centres on defining the specific function or goal that the assistive technology is meant to fulfil, ensuring a direct alignment with the user's needs, whether it be enhancing mobility or facilitating communication. The product, refers to the actual assistive technology device or tool itself, requires careful consideration of features, usability, compatibility, cost, and support, ensuring a suitable match for both the person and the intended purpose. Policy covers legal, ethical, and institutional frameworks affecting assistive technology availability and utilization, necessitating an understanding of aspects like insurance coverage, legal rights, governmental programs, and institutional support. Finally, the element of place emphasizes evaluating and adapting the physical environment where the assistive technology will be used, requiring potential modifications to homes, workplaces, schools, or community spaces for effective and safe utilization (AbleDocs, 2023). Together, these elements form a comprehensive approach to implementing assistive technology, addressing the interplay between technology and the individual's context.

Assistive technology tools cover a spectrum ranging from low-tech to mid-tech and high-tech solutions, each offering distinct advantages based on the complexity of user needs. Low-tech assistive technologies are characterized by their simplicity and minimal reliance on electronics. Examples include pencil grips, magnifying glasses, white cane and non-digital communication boards. These tools are cost-effective and easy to use, making them accessible to a wide range of users. Mid-tech assistive technologies introduce a moderate level of electronic components. Devices such as portable communication devices or electronic magnifiers fall into this category. They make a balance between functionality and simplicity. High-tech assistive technologies, on the other hand, involve advanced electronic systems and sophisticated software. Devices like voice-controlled wheelchairs, screen readers, or brain-computer interfaces exemplify high-tech solutions (ATIA, 2015). While offering advanced functionalities, high-tech solutions may require specialized training and are often more expensive. Besides, at this point, there is a close relationship between assistive technology and wearable technology, so some of the wearable technologies can be discussed under the mid/ high-tech solutions as shown in the Figure 3. The diverse array of assistive technology tools ensures that individuals with varying needs can find appropriate solutions that enhance their independence and quality of life.

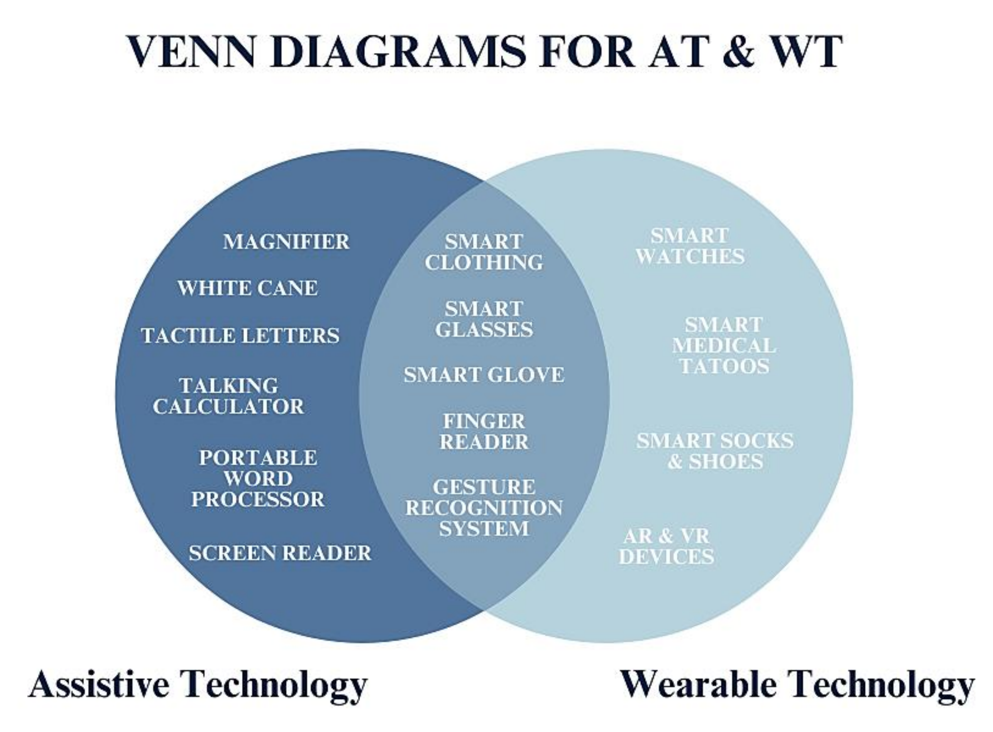


Figure 3. Venn Diagrams for AT & WT

The review of assistive technologies was classified in terms of their usage area in this study, as *mobility* (e.g., mobility AT/ the batcane, navigation AT/ context aware computing, orientation AT/ blind person’s navigator etc.), *communication* and *access* *to information* (e.g., screen readers, self-voicing applications and speech, text, Braille conversation technology etc.), and for *daily living* activities such as interaction with objects, clothing, shopping etc. In addition, in the main classification of AT examples, a sub-category was added for the initial discussion of research projects, and consequently the inclusion of commercial examples/ applications. Table 1 illustrates the three categories of AT use with the name of examples. Blue indicates research projects, while orange refers to commercial examples/ applications. In addition to guiding the overview in this research paper, this table visually gives a clue about the allocation of wearable technologies and applications, and research projects and commercial examples in this field.

Table 1. AT Classification According to the Usage Area (WT refers to “wearable technology; App refers to “applications”)

| **ATs for MOBILITY** | **ATs for COMMUNICATION** | **ATs for DAILY ACTIVITIES** |
|---|---|---|
| 1-Wearable Obstacle Detection System (WT) | 1-Braille Glove (WT) | 1- Shop Talk (WT) |
| 2-NAVIG Project (WT) | 2-Finger Reader (WT) | 2- Trinetra (WT) |
| 3-Design of a Wearable Technology for the Visually Impaired People (WT) | 3- Gesture-based Smart Hand Gloves for Disabled Persons (WT) | 3- Assistive Clothing Pattern Recognition System (WT) |
| 4- BuzzClip (WT) | 4-Smart Glove: a Wearable Device for Disabled Person (WT) | 4- BlindShopping (App) |
| 5- Microsoft 3D Soundscape Technology (App) | 5-TalkBack (App) | 5- OrCam MyEye 2.0 (WT) |
| 6-BlindSquare (App) | 6-BrailleBack (App) | 6-Give Vision (App) |
| 7-Lazarillo (App) | 7-VoiceOver (App) | 7- LCW Sense (App) |
| 8-Lazzus (App) | 8-KNFB Reader5 (App) | 8-Tap Tap See (App) |

As a result, assistive technology serves as a catalyst for empowerment, aiming to bridge the gap between ability and disability. From mobility aids to sensory augmentation, assistive technology covers a vast array of tools that empower users to overcome physical, cognitive, or sensory limitations, and enhance the quality of life for individuals with diverse needs. In terms of evolving technology, the intersection between assistive technology and design, fashion, and textile via innovation has become increasingly pivotal. This dynamic relationship not only represents the impact of technology on human life but also underlines the potential to enhance accessibility, inclusivity, and aesthetics. Through thoughtful design, assistive technology can transition from being a mere necessity to a seamlessly integrated aspect of everyday life.

### *2.2.1. Assistive Technologies for Mobility*

The significant challenge encountered by individuals with visual impairment (BVI) lies in their limited ability to perceive the world around them, hindering their independent navigation. Wayfinding, a crucial aspect for those individuals, comprises two essential tasks: (1) perceiving the immediate environment to evade obstacles and (2) navigating towards a destination that extends beyond the immediate surroundings (Fernando et al., 2023). Various Orientation & Mobility techniques, such as shore-lining, wall-tracing, strategies for directions through open spaces, utilization of white cane methods for detecting obstacles at different heights, and actively sensing and acquainting themselves with the surroundings to facilitate the development of mental maps, are employed to address this limitation (Deverell, 2009). The oldest and the best-known example of AT is white cane that people with visually impairment still commonly use. However, since this tool can only detect nearby objects, and is intended to detect obstacles in the ground, it gives user limited time to change direction and may not be able to detect objects above ground level. Thus, in this part, we review research projects, technological applications and devices designed to enhance the white cane’s function.

#### *Wearable Obstacle Detection System*

As an example of one the first research projects in this field, Bahadır (2011), developed a wearable obstacle detection system that warns users about obstacles and hazards, and enables them to navigate safely in indoor environment (Figure 4). The system comprises a wearable garment with sensors, actuators, power supplies and a data processing unit. The challenge in this system is to integrate technical elements in a wearable garment without affecting features such as garment flexibility and weight.

The system, firstly, senses the surrounding environment and detects obstacles via sensors, and consequently, it guides the user by actuators through a feedback process interpreted in signal processing unit (Bahadır et al., 2011).

Figure 4. Wearable Obstacle Detection System

***NAVIG Project***

The second research project example on navigation is the NAVIG system (2012), which has been designed and prototyped in order to provide visual information from the environment surrounding people with visual impairment. The system includes head-mounted stereoscopic cameras (Figure 5), SpikeNet Vision object localization algorithm, that identifies the images and even the objects sharing similar shape and processes them in real-time based on pattern matching. The detection signals are transmitted to the user via 3D audio rendering engine (Kammoun et al., 2012).

Figure 5. NAVIG Project

### *Design of a Wearable Technology for the Visually Impaired People*

The wearable device serves the purpose of providing guidance and essential environmental information to the user. Positioned above the hand and partially covering the wrist, the user can scan their surroundings by moving their hand, enabling them to perceive vibrations and interpret the environment (Figure 6). In addition to distance information, the device includes a button for the user to access time-related data. The design of the wearable glove prioritizes ergonomics, encompassing all electronic components while ensuring user comfort and resistance. Extensive material options were explored, ultimately determining that plastic parts, specifically those manufactured using 3D printing with ABS plastic, provide the desired strength and lightness.

Figure 6. Design of a Wearable Technology for the Visually Impaired People

The primary microcontroller responsible for system operations is not situated within the glove itself; instead, it is housed in a custom case intended for the user's belt or pants, prioritizing comfort. This case also accommodates the battery and necessary electronic circuitry for power management. The selected microcontroller is the Raspberry Pi Zero (RPIZero), chosen for its processing capability, compact size, low energy consumption, and sufficient input/output pins. The RPIZero processes information from the ultrasonic sensors, watch module, and GPS module, which is then presented to the user through understandable means such as vibration intensity, voice, and sound (Alvarado et.al, 2016).

### *Microsoft 3D Soundscape Technology*

In addition to research projects, software and technology companies are developing a variety of ATs for people with visual impairment. For instance, Microsoft has developed 3D Soundscape Technology from a research project, which at the first stage, consists of a bone-conduction headset with a smartphone and indoor/ outdoor wireless beacons (Microsoft 2015). The system later evolved into the commercial application which runs on iPhone 5S or later versions or with most wired or Bluetooth stereo headsets. It allows real-time environment tracking with the smartphone’s GPS and accelerometer sensors. By creating a 3D sound map, the device listens to the surroundings through sensors, and can determine the direction of the user. The headset, which transmits to the bone next to the ear, can also give information about the places and shops or any points of interest around and additional journey details (Microsoft, 2019).

### *BuzzClip*

BuzzClip is a commercial wearable device by iMerciv, attachable to clothes (Figure 7), which is able to detect nearby obstacles. The working principle of the system is based on sending and receiving sound waves, and then transmitting them to user as intuitive vibrations (Mali, 2015). It has three selectable modes, 1, 2 and 3 meters, and the company suggests selecting 1 meter mode for indoor usage, and 2- or 3-meter modes for outdoors. It works by sending warning vibrations about obstacles in its conical shaped detection area (Figure 7) (Imerciv, 2019). Creators of BuzzClip report that one of the main advantages of the system is that lighting condition or transparency of the object affects neither detection nor distance measurement (Mali, 2015).

Figure 7. BuzzClip

### *BlindSquare*

BlindSquare is a GPS-based application which allows people with visual impairment to travel independently by describing the environment, highlighting points of interest, street intersections and venues through a dedicated speech synthesizer. The app enables users to access the most important functions through an audio menu via any headset or speaker which supports Apple’s music controller. Thus, there is no need for the users to touch the phone screen. The app searches a 200-meter radius and uses iOS-device’s GPS capabilities to inform users about their surroundings on Foursquare and Open Street Map. The app is available in many languages (BlindSquare, 2019).

### *Lazarillo*

Lazarillo is another commercial guidance application, which use voice messages to inform users about the current location and nearby services regarding bus stations, cafes, banks, restaurants, street intersections, etc. It can give directions on how to reach your destination by different types of transportation. The application requires a mobile phone with an Android 4.3 operating system or iOS 9.0 (or newer versions), mobile internet and the activated GPS of the Smartphone. Because the application uses the main international databases for its maps, it can be used worldwide. The application is also able to work with the screen readers such as "Talkback" or "VoiceOver" (Lazarillo, 2019).

### *Lazzus*

Another commercial navigation application is Lazzus which gives information on items near the users such as pedestrian crossings, street intersections, stairs and stores, at any given time, by creating an auditory field of vision within 100-meter radius. To provide greater accuracy, it uses two complementary data sources: Google Places and Open Street Map. The app has three modes serving to different types of demands. The first, “Beam Mode”, informs the users of items in the current direction. The second, “360º Mode”, highlights everything in users’ immediate surroundings in every direction. The third, “Transport Mode”, is automatically activated when the users travel by bus or car and informs them about the streets through which they pass (Lazzus, 2019).

Mobile phone navigation applications, such as BlindSquare, Lazarillo and Lazzus are popular and practical tools for navigation, and it is expected that the number of similar apps will rapidly increase. Even though their purpose is more advanced than the use of white cane, these apps still can be evaluated under the category of navigation.

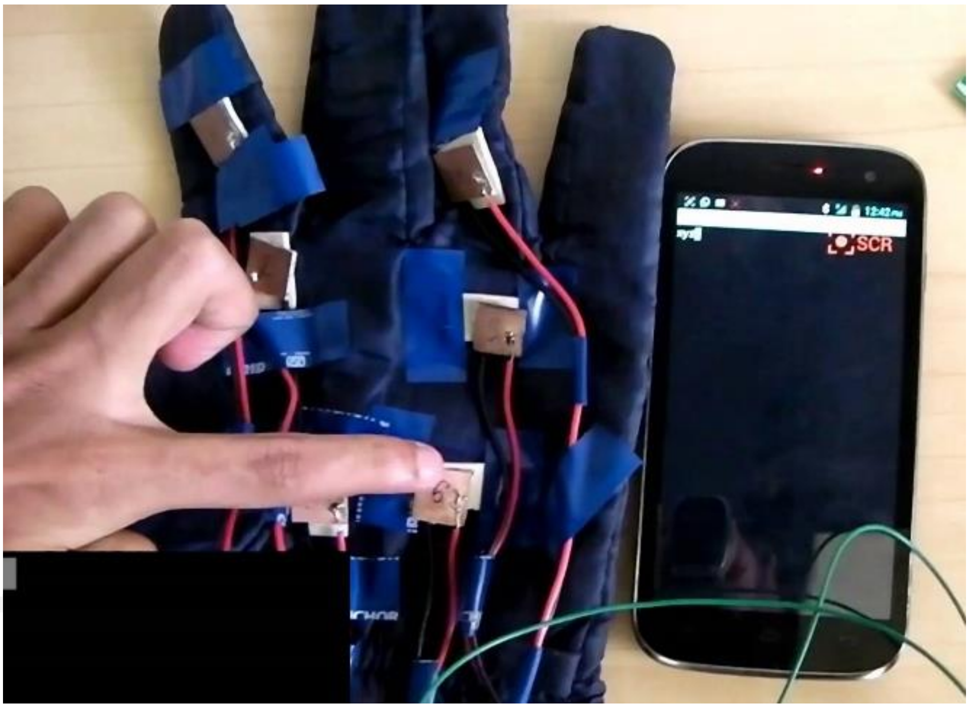
### *2.2.2. Assistive Technologies for Communication*

Communication is a complex process that uses different forms as speech, vocalizations, gestures, and facial expressions, to exchange information with a communication partner about one’s wants/need, experiences, ideas, thoughts and feelings. Communication can also be in the form of reading or sending text messages as online communication. For people with visual impairment, written communication ways, such a reading mobile phone or computer screen can be challenging, even impossible in some cases. At this point, assistive applications and devices have huge potential for people with vision loss. In the following section, descriptions of some examples of those research projects and commercial applications that make this process easier, and support communication of people with visual impairment (Table 1).

#### *Braille Glove*

Braille Glove (2014) is an example of a research project prototype helping to convert the Braille alphabet into text, and vice-versa. The touch sensors, made of copper and arranged like six Braille cells on the palm of the glove, wirelessly transmit texts to the receiving PC/mobile phone (Figure 8). When touching the sensors, the capacitance of the circuit changes, triggering the microcontroller and recording the touch. Tactile feedback patterns provided by small vibrating motors on the back of the glove enable the user to receive regular incoming text messages (English) in Braille. Then, the received data is compared with the entries in a look-up table (Coudhary et al., 2015).

This prototype is an example of wearable technologies with the use of a glove; however, the focus is overwhelmingly on the function, and therefore, aesthetic features and practicality are not the strongest characteristics of this specific product.



[redacted]

Figure 8. Braille Glove 2014

***Finger Reader***

Finger Reader is another research project prototype, under development at the MIT Media Lab. It is worn on the index finger and used for assisting in reading printed text, as well as an aid for language translation. The device consists of vibration motors embedded in the ring for tactile feedback, a dual-material case, and a high-resolution mini video camera (Figure 9). Wearers scan a text line with their finger and receive audio feedback of the words and a haptic feed. In addition, Finger Reader’s software stack includes a sequential text-reading algorithm, hardware control driver, integration layer with Tesseract OCR and Flite Text-to-Speech feed (Shilkrot, 2015).

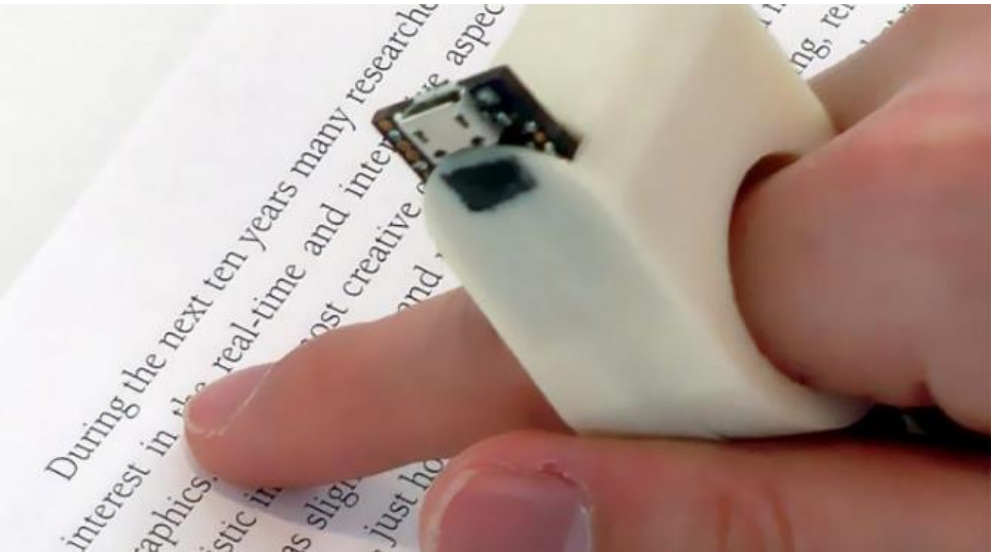


Figure 9. Finger Reader

***Gesture-based Smart Hand Gloves for Disabled Persons***

The objective of the project is to develop Smart Hand Gloves that facilitate communication and independence for individuals with disabilities. These gloves enable deaf or paralyzed individuals to translate their hand gestures into text and pre-recorded audio, enabling them to communicate effectively with others. Additionally, these gloves allow normal individuals to comprehend the intended message and respond accordingly. Furthermore, the Smart Gloves can control home appliances, empowering physically disabled individuals to live independently. The project utilizes Arduino Leonardo and flex sensors to detect hand movements. The sensor data is analyzed by the Arduino, generating corresponding speech output through a speaker and displaying the message on an LCD screen connected to the Arduino. The gloves operate by detecting changes in resistance values as the flex sensors bend in response to hand movements (Figure 10). The focus is on creating reliable, user-friendly, and lightweight gloves that eliminate communication barriers and promote ease of interaction with others (Chand et.al, 2022).

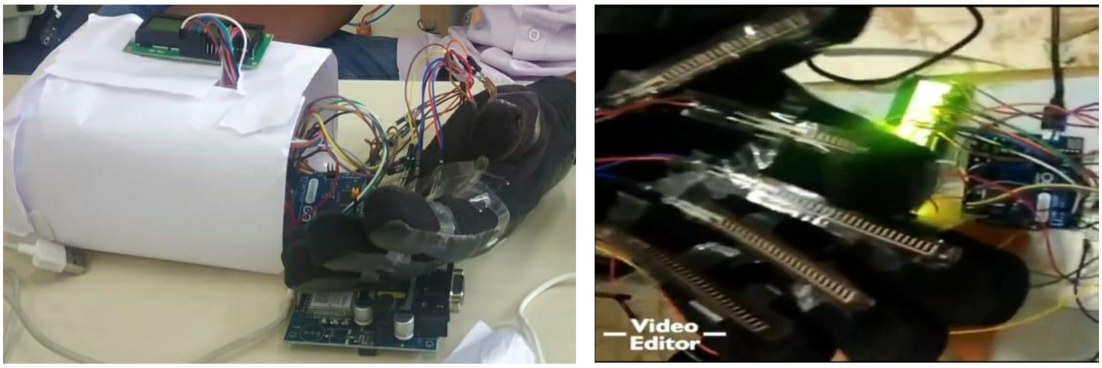


Figure 10. Gesture-based Smart Hand Gloves for Disabled Persons

### ***Smart Glove: a Wearable Device for Disabled Person***

The study presents a proposed assistive system designed for individuals who are blind, deaf, or mute. It utilizes a wearable device in the form of a hand glove, incorporating embedded system technology and natural language processing (NLP) for data input functionalities. The glove prototype integrates buttons with alphabets, numbers, and special characters, allowing communication for deaf and mute individuals. Typed text is converted to speech using Google API. Additionally, the glove enables blind individuals to send messages, make calls, and control home appliances through dedicated buttons. In case of a fire, a fire sensor detects the danger, triggering a buzzer alarm. The safety button can be used to send the location to family members. The researchers present GlovePi, an open-source assistive system, composed of a glove, Raspberry Pi, and an MPR121 capacitive touch sensor module with an expansion board. An Android app facilitates communication with the Raspberry Pi, displaying and listening to the phases created by the deaf-blind user during typing (Figure 11). The system offers cost-efficiency, simplicity, and ease of use as advantages. However, it lacks two-way communication of data, with data flowing only from the glove to the mobile app (Deekshitha and Mamatha, 2019).

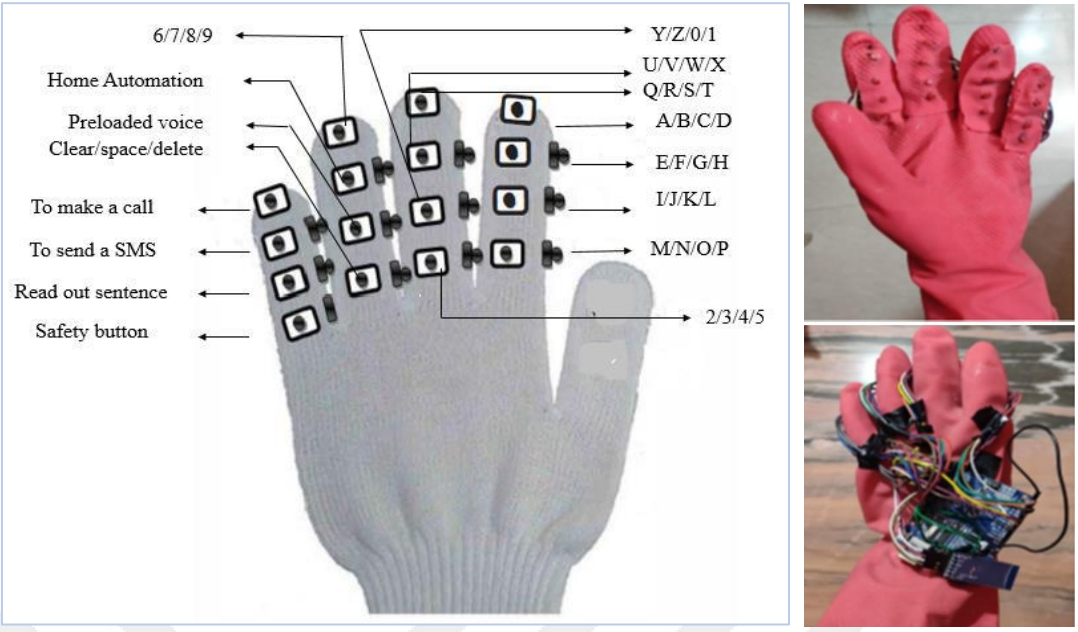


Figure 11. Smart Glove: a Wearable Device for Disabled Person

### *TalkBack*

Besides research project prototypes, some services and applications providing easier communication are already on the market. TalkBack is one of those communication applications, developed by Google, installed into Android devices. The application enables users to interact with their devices, informing users about what they touch on the screen. Besides, through a screen reader service, users can access texts including menu names, time and notifications. It can read incoming messages aloud and send voice and send text messages. In addition, via settings, users can adjust speech volume, start/ stop screen reading by shaking the device, or use a specific voice pitch as a signal to start typing. (Hildenbrand, 2015).

### *BrailleBack*

BrailleBack is another accessibility service specially developed for the visually impaired, allowing the use of computers and other mobile devices with the Braille alphabet. The application works with the TalkBack screen reader to provide a unified conversation and braille experience, and allows user to pair devices via Bluetooth, and display the text on the screen in Braille alphabet. The users can navigate or interact with their devices using the keys on the display. It also allows text entry using the device’s Braille keyboard (Google BrailleBack, 2015).

#### *VoiceOver*

VoiceOver is an application for Apple products, while TalkBack and BrailleBack applications are suitable for Android devices. It uses gestures to signal the user's iPhone to speak what is written on the screen, including the description of all screen items, such as battery level, status, cell network, time, date etc. VoiceOver also provides contextual information, such as the adjoining objects or the location of objects on the screen (VoiceOver, 2017).

#### *KNFB Reader*

KNFB Reader is another application, which, in real-time, converts the picture of printed text into high-quality audio output. Different from the other mobile readers, the KNFB Reader has built-in image processing technology that allows the users to take photos for accurate results of the things that they want to read or listen to. The system bases on image processing technology (or optical character recognition technology), which identifies the words in the image and allows them to access Braille. KNFB Reader can also provide access to single or multi-page documents, recognize and read printed materials in various languages, and link to Dropbox or OneDrive (KNFB Reader, 2017).

### *2.2.3. Assistive Technologies for Daily Activities*

All assistive technologies, from the simplest to most sophisticated and specialized high technology devices and applications, provide accessibility in daily life. This part focuses on the technologies required for daily living activities in or outside the home environment. AT examples are explained in terms of these activities, with research projects mentioned first, and the commercial examples, subsequently (Table 1).

The grocery shopping, shopping for clothes, and interacting with objects are some of the main challenges for people with visual impairment in daily life. Sighted shoppers can easily find their way around the store, find the products and find out related information, such as the ingredients/ composition and price, and then purchase the items. However, for people with visual impairment, it is very difficult to carry out these processes independently.  For this purpose, projects and applications have been developed that will enable independent shopping, recognition of objects and identification of colors, some of which are investigated as following:

### *BlindShopping*

BlindShopping is a smartphone application using entirely off-the-shelf technology, developed as a research project to assist shopping. The application processes the RFID data received via Bluetooth, products are recognized by pointing a QR code reader, and results are transmitted as the verbal navigation commands. The working principle of the system is mainly based on classification of products and environmental elements in the supermarket organization. Thus, with minimal environmental adjustments to navigate the store, search and select products, all products are grouped into different product categories, subdivided into product types, and again into concrete brand products. The supermarket is divided into cells of shelves and passageway cells. Thus, BlindShopping provides product category navigation, product search, product identification, and product selection (Lopez-de-Ipiña, 2011).

### *Trinetra*

Trinetra system as another research project was developed at Carnegie Mellon University (2006), and consists of a Nokia mobile phone, a Bluetooth headset, a Baracoda IDBlue Pen, a Baracoda Pencil, and a Windows-based server. While the system is similar to BlindShopping, Trinetra differs in that it has a headset as a wearable technology item. The system enables people with visual impairments to shop independently. It uses both barcodes and RFID tags; for scanning barcodes, The Baracoda Pencil is used, and for RFID tags, the Baracoda IDBlue Pen. The user scans the product’s barcode with a Baracoda Pencil, providing description of the product. Following this, the data are transferred wirelessly to the mobile phone *via* Bluetooth. The system on the phone first checks its mobile application’s memory for previous scans of the barcode. If the barcode is already in the memory, the information is returned to the phone, if not, a request is sent to the remote server. The server communicates with a generic UPC database to get the necessary information (Lanigan et al., 2006).

***Shop Talk***

Shop Talk developed by researchers at Utah State University (2009), is a wearable system for people with visual impairments to independently shop in the supermarket environment, which is comprised of a portable computational unit, a numeric keypad, a wireless barcode scanner, base station, headphones, a USB hub, and a backpack to carry them (Figure 12) (Nicholson et al., 2009). The system assists those shoppers in supermarket navigation, product search, and selection.

Shop Talk represents the supermarket environment using data structures as a topological map of movement area, the supermarket inventory management system, and Barcode Connectivity Matrix (BCM). While topological map providing to achieve to the directional labels of "left", "right" and "forward" according to the supermarket floor plan, the supermarket inventory management system creates verbal descriptions of product information. Besides these data structures, the Barcode Connectivity Matrix (BCM) and Universal Product Code (UPC) barcode serve to provide information regarding aisle, aisle side, section, shelf, position, and product description (Jethani, 2012).

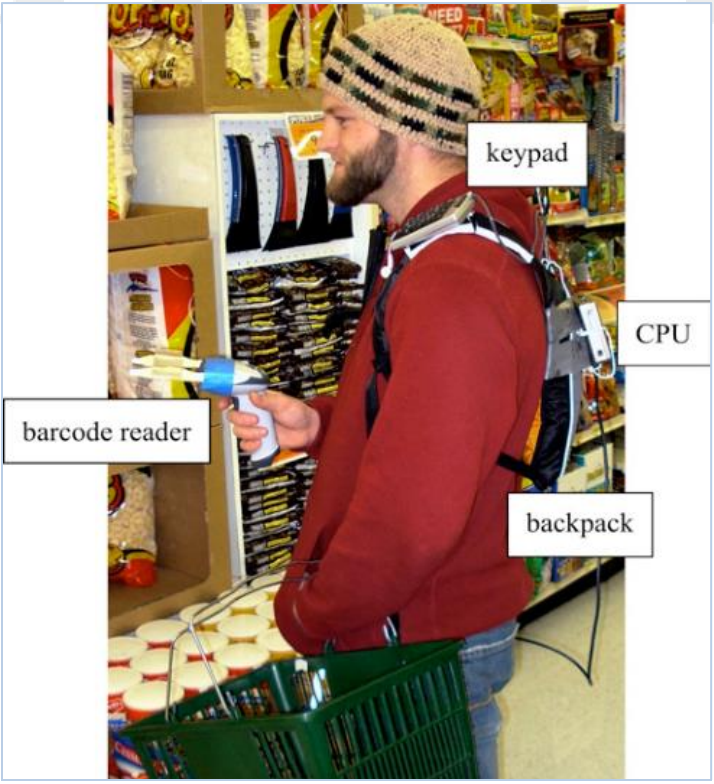


Figure 12. Shop Talk

### *Assistive Clothing Pattern Recognition System*

Assistive Clothing Pattern Recognition System is a research project output composed of a camera, microphone, computer, and Bluetooth earpiece. This camera-based prototype system can recognize clothing patterns in four categories (plaid, striped, out of patternless, and irregular) and identify 11 colors (Figure 13).

Figure 13. Assistive Clothing Pattern Recognition System

In order to capture clothing images, camera mounted upon a sunglass is used, and to recognize patterns researchers proposed Radon Signature descriptor, which creates 2 or 3 dimensional images by projecting an object from every angle. The system can be controlled by speech input through microphone, and audio description of clothing patterns and colors arrive via Bluetooth earpiece (Yang et al., 2014).

### *LCW Sense*

LCW Sense is one of the commercial examples, as an application for specifically designed for people with visual impairment by LCW clothing company's RD department and can be free downloaded from Appstore or Google PlayStore to mobile phones. The application promises users the freedom to shop alone and provides product information such as color, pattern, fabric type, washing instructions, price, and information about the care label. It distinguishes clothes by scanning the product barcode. If the user likes the product, it can add it to 'my favorites list, and if purchased, to "my wardrobe" list (LCW, 2017). The application was tested by the author and worked partially; product was identified from the barcode, but after this step the exact product information was not found. LCW is a clothing popular brand in Turkey, targeting a wide range of customers.

### *Give Vision*

The Give Vision is a commercial application with a blind-friendly user interface, which was designed by two developers with visually impairment to provide feedback on the environment around the user, via hands-free control of a smartphone. The application aims to assist users during traveling, shopping, reading text, and recognizing places and objects by using image recognition features and algorithms (Munche, 2015).

It can also be integrated with other smartphone applications for messaging and calls. The other innovative solution of the Give Vision Company is SightPlus hands-free and portable wearable headset (Figure 14), that enables users to magnify nearby or farther objects, and change the contrast or apply custom filters. Although the device has a wide area of usage, it is only suitable for stationary activities such as reading, watching TV, recognizing people's faces, sports events, playing music etc., and not for mobility or driving (SightPlus, 2018).

Figure 14. Give Vision, SightPlus Headset

### *OrCam MyEye 2.0*

OrCam MyEye 2.0 is a commercial device consists of smart camera and earpiece attached to the user's eyeglass frame (Figure 15). Working principle of device is through capturing the text or any visual information, and then reading or identifying as directed by the user (OrCam, 2017). The device provides real-time identification of previously stored faces in its memory (up to 100 faces) and announces the information in the user’s own voice. In addition, OrCam enables the user to shop independently as the device has a database of product barcodes and stores, and it also has color detection features that allows the user to identify product colors (OrCam, 2017).

Figure 15. OrCam MyEye

***The TapTapSee***

The TapTapSee is a mobile camera application designed specifically to allow iOS users with visual impairment to take a picture of any object by double-taping the screen and to get a description of it in real-time. The application uses VoiceOver to audibly identify the visual information about object. In addition, the application can repeat the previous image’s identification, upload images from the camera roll, and share identification via social media, text or e-mail (The TapTapSee, 2017).

### *2.3. Wearable Technology*

Wearable technologies, as defined by Veilette (2014), are devices equipped with sensors, screens, processors, memory, and software featuring algorithms for processing, interpreting, organizing, and storing raw data. These products connect to the internet, providing real-time or retrospective data presentation to users. In essence, wearables collect and process user physiological data, delivering processed information through notifications or network connections to other devices or actuators like sound, light, or vibration (Başkan and Berk, 2022). The umbrella term "wearables" encompasses small electronic and mobile devices, as well as computers with wireless capabilities integrated into accessories, clothing, or gadgets meant to be worn on the body. This category also extends to more invasive options, such as micro-chips or smart tattoos (Luczak et.al., 2020).

Wearable technology refers to electronic devices that are worn as accessories, embedded in clothing, or even implanted in the body, with the primary purpose of collecting, monitoring, and transmitting data. These devices are designed to be worn on the body and often connect to smartphones or other external devices to enhance user experience and provide valuable insights into various aspects of daily life.

### *2.3.1. Scope and Importance of Wearable Technology*

The increase in popularity of personal activity trackers in 2014 marked a significant trend in wearable technology. For instance, one of the innovative designs was the Tommy Hilfiger's solar jacket which could charge mobile devices. This jacket had integrated solar cells sewn into the fabric that connected to a battery located in the front patch pocket, capable of powering two devices such as cell phones or tablets. Solar panels are designed to be easily removed (Ometov et.al., 2021).

In that same year, a big change happened with the launch of Android Wear, later called the Wear Operating System (OS). This was the first time a major company got into making wearable tech. Wear OS became the first operating system made specifically for wearables, like smartwatches. This move showed that Google wanted to be part of the growing market for wearables. Seeing the competition, Apple also joined in by releasing its first wearable, the Apple Watch, in 2015 (Ometov et.al., 2021).

Unlike current smartphones and tablets, wearables offer additional value by providing various monitoring and scanning features, including biofeedback and sensory physiological functions like biometrics (Khan et.al., 2020). Despite their battery limitations, wearables offer convenience, portability, seamlessness, and hands-free access to electronics. Beyond conventional sports trackers, smartwatches, on-body cameras, heart rate meters, and eyewear, the next generation of wearables will incorporate augmented reality, virtual reality, mixed reality devices, various smart clothes, and industrial wearable equipment. Sub-fields of wearable technology include (Niknejad et.al., 2020):

- **Fitness and Health Monitoring**: Wearables in this category track physical activity, monitor vital signs, and provide feedback on health metrics. Examples include fitness trackers, smartwatches with health sensors, and even smart clothing with embedded health monitoring capabilities.
- **Smartwatches**: These devices are often an extension of smartphones, providing notifications, fitness tracking, and various apps directly on the user's wrist. They may include features such as heart rate monitoring, GPS, and integration with other smart devices.
- **Smart Glasses**: These are eyeglasses with built-in computing capabilities. They can display information like notifications, navigation, and augmented reality (AR) overlays. Google Glass is an example of smart glasses.
- **Smart Clothing and Footwear**: Garments with integrated sensors and electronics to monitor various aspects such as movement, biometrics, or even environmental conditions. Smart clothing is used in sports, healthcare, and other industries. On the other hand, Shoes with embedded sensors for tracking steps, analyzing walking style and path, or providing navigation feedback. They can be used for fitness tracking or to enhance the user's overall experience.
- **Smart Jewelry**: Accessories like rings, bracelets, or necklaces embedded with technology, often focused on notifications or activity tracking. They blend fashion with functionality.
- **Wearable Cameras**: Devices like body cameras or lifelogging cameras that capture images and videos from the user's perspective. These can be used for personal documentation, object definition or professional purposes.
- **Augmented Reality (AR) and Virtual Reality (VR) Devices**: While not exclusively worn on the body, AR and VR headsets can be considered a form of wearable technology. They provide immersive experiences, with AR overlaying digital information on the real world, and VR creating entirely virtual environments.
- **Head-Mounted Displays (HMDs)**: Similar to AR and VR devices, these include devices like smart helmets or headsets used for specific applications, such as industrial training or navigation.

- **Implantable Devices**: These are devices implanted under the skin for various purposes, such as health monitoring or even as a form of identification. Examples include RFID implants and implantable health sensors.

Most of the Internet of Wearable Things (IoWT) available today in the market delivers a smartphone-like experience through voice and gesture control, coupled with well-designed input and output interfaces. The combination of miniaturization, portability, wireless communication, energy-efficient computing, and advanced display technologies have led to the development of the latest smart devices. Therefore, these sub-fields mentioned above continue to evolve, with on-going advancements in technology leading to innovative applications and new types of wearable devices. They are expected to enhance technological and socio-cultural aspects of lives and impact well-established sectors, including the smartphone industry and other handheld devices.

In terms of a financial statement, the wearable market has a potential of significant growth in the coming years, with an expected annual growth rate exceeding 20%. Predictions and reports suggest that the market will surpass 40 billion EUR per year within the next 5 years and exceed 150 billion EUR by 2028 (Hayward, 2018). This proliferation of wearables is expected to continue over the next decades, with a shift from basic bracelets and sport trackers to more sophisticated and wearable devices with more features (Ometov et.al, 2021).

On the other hand, the expansion of the mobile devices market has introduced new and practical devices, offering various advantages and presenting innovative applications from the user's standpoint. Wearable technology, a significant driver in this growth, provides proactive solutions across diverse domains, including healthcare, fitness, aging, disabilities, education, transportation, enterprise, finance, entrance systems, gaming, music, and more. Wearable technology is important for several reasons, and its significance has grown with technological advancements. For instance, it offers real-time data on various aspects of daily life, from health metrics to location tracking. This real-time information enables users to make immediate decisions and adjustments based on the data they receive. Some wearable devices can track various health metrics, such as heart rate, steps taken, sleep patterns, and more. This information helps individuals gain insights into their health and fitness levels, encouraging healthier lifestyles. They often offer personalized experiences by collecting and analyzing user data that allows for customized feedback, recommendations, and services tailored to individual preferences and needs. They also provide quick and easy access to information without the need to pull out a smartphone. Smartwatches, for example, allow users to receive notifications, answer calls, and check information on their wrists, enhancing convenience and accessibility. Besides, wearable technology opens up new possibilities for innovative applications in various fields, including healthcare, sports, education, and entertainment. For example, AR and VR devices offer immersive experiences, and smart clothing can be used for advanced biometric monitoring.

The current state of wearable technology is characterized by ongoing innovation and expanding market presence. Major technology companies continue to release new and improved wearables with enhanced features, longer battery life, and increased functionality. The market includes a diverse range of devices, from smartwatches and fitness trackers to AR glasses and smart clothing. Additionally, there is a growing focus on improving the accuracy of health-related measurements, expanding the use of wearables in medical and clinical settings. Advancements in materials, miniaturization, and sensor technologies contribute to the development of more compact and capable wearables.

### *2.3.2. Classification of Wearable Technology*

In essence, the categorization of wearable devices can be discussed in different ways considering various factors. It’s important to note that devices worn or carried may exhibit comparable functionality while possessing entirely distinct form factors, varying technology levels, and different on-body locations. Accordingly, the following classification table (Table 2) was created based on the study of Ometov et.al. (2021).

Table 2. Wearable Classification Criteria (Adapted from the study of Ometov et. al., 2021)

| CLASSIFICATION TYPES OF WEARABLES | |
|---|---|
| **Functionality** | Communication,<br>Control/ input,<br>Education,<br>Professional Sports,<br>Entertainment & Gaming,<br>Hands-free Info,<br>Healthcare,<br>Location Tracking,<br>Notification,<br>Output, Safety & Security,<br>Monitoring |
| **Device Type** | Activity Trackers<br>AR Devices<br>E-skin<br>E-textiles<br>Location Trackers<br>Smart Bands<br>Smart Clothes<br>Smart Footwear<br>Smart Gloves<br>Smart Patches<br>Smart Jewellery |
| **Placement** | Head-mounted Wearables<br>Body-worn Devices<br>Lower Body Devices<br>Wrist-worn and Handled Wearables |
| **Energy-consumption** | Low-power Wearables<br>Medium-power Wearables<br>High-power Wearables |
| **Battery Type** | Lithium-coin<br>Lithium-ion<br>Lithium Polymer |

One of the most extensive classifications covers various application or functionality types. As seen in Table 2, the first functionality is communication, wherein wearables serving this function have the potential to exchange data with surrounding nodes and/or remote cloud systems. Secondly, input devices ranging from smart buttons to sophisticated gesture recognition devices aim to extend conventional Human-Computer Interaction (HCI) input by focusing on the usability of the devices. Besides, wearables for education and professional sports try to improve these functions via monitoring assistants. In terms of healthcare function, wearables can sense, obtain and monitor the data. On the other hand, as an output function, wearables with various visual, audio or haptic feedback mechanism can provide the user around with prompt information from the personal ecosystem.

The second main criterion for classification is device type including activity trackers, AR devices, e-skin, e-textiles, location trackers, smart bands, smart clothes, smart footwear, smart gloves, smart patches, and smart jewellery. The other category is based on the placement of the wearable on the human body. Therefore, this category covers head-mounted, body-worn, lower-body, and wrist-worn/ handheld wearables (Figure 16).

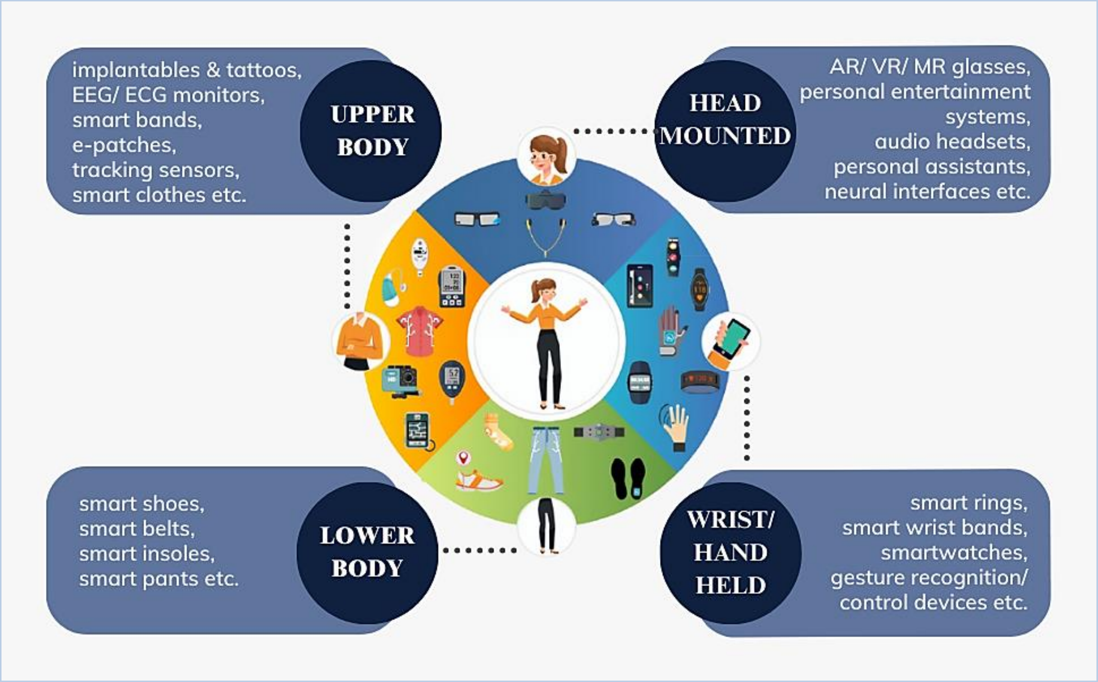


Figure 16. Placement of the Wearables (Adapted from the study of Ometov et.al., 2021)

Head-mounted wearables primarily emphasize perception and control aspects, this category includes AR/VR/XR/MR glasses, relaxation masks, HMDs, personal entertainment systems, headsets, personal assistants, bass systems, and a standalone group dedicated to neural interfaces. Body-worn devices exhibit diverse functionality, this category can be subdivided into three that the first one is near-body and sport wearables comprising devices which complement the existing wearable ecosystem, such as e-patches, smart bands, and supplementary activity tracking sensors. The second one is on-body wearables encompassing EEG and ECG monitors, posture-correcting devices, safety devices, various smart clothes, and related items. And the last, the third one is related to in-body wearables including implantable, smart tattoos, and similar devices for medical aspects (Figure 16). On the other hand, lower-body devices include wearables like smart shoes, belts, insoles, etc., designed primarily for specific monitoring purposes in professional sports or medical contexts (Figure 16). The last one, wrist-worn and handheld wearables representing the most widely adopted, this category includes smart rings, wristbands, smartwatches, gesture control devices, and others (Ometov et.al., 2021). The classification based on wearable placement is a natural and significant one. Designers, researchers, and early integrators must carefully consider the appropriateness of their device's placement to meet the application requirements.

Apart from the mentioned types, wearables can also be sorted by how much energy they use. Low-power wearables mostly include devices with efficient parts and basic functions meant to last a long time, especially for collecting data and sensing things. This category includes health-related wearables that need slow data communication. For example, a small smart ring that senses human body info is a low-power wearable because it has a small battery, radio, and only a few sensors (Mahmud et.al., 2018). Moderate-power wearables consist of devices with slightly more advanced features, possibly incorporating a compact screen. These wearables might come with several built-in sensors, providing either direct or indirect internet connectivity options that need moderate data rates. Instances of moderate-power wearables encompass smartwatches, fitness trackers, and other gadgets created for recognizing activities and gestures in personal, business, and industrial settings (Xu et.al., 2019). High-power wearables include devices with significant energy requirements, usually equipped with powerful processing units that require high data rates and large displays capable of handling computationally intensive tasks like real-time image/video processing and Machine Learning (ML). This category encompasses a range of devices such as headsets, glasses, and head-mounted cameras used for video crowd sensing, among others (Ometov et.al., 2021).

Wearables can be sorted based on the type of battery they use. There are three main types of Lithium batteries used in wearables. Lithium Coin, like button cell batteries, was one of the first types used in devices like watches. Lithium-ion batteries are widely used in wearables like smartphones and smartwatches because they're rechargeable and lightweight, but there are safety concerns due to instances of overheating or exploding. Special circuitry is needed to make them safe, and their performance can decline over time. Lithium Polymer, another rechargeable option, is safer than traditional Lithium-ion batteries, although it's slightly less powerful and more expensive (Ometov et.al., 2021).

### *2.3.3. Working Process of Wearable Technology*

Wearables collect and process a large amount of data, following key stages in their data lifecycle. The process begins with data collection through user-generated activities like exercise tracking and passive sensing. Pre-processing involves filtering out incomplete or erroneous data. Data transfer optimizes power during transmission. The evolution of wearables includes computing layers like Cloud, Fog, and Edge computing, utilizing various paradigms. The data processing phase employs Machine Learning (ML) techniques such as clustering and regression, addressing challenges like limited data and computation capacity. Finally, the altered data is stored for analysis, contributing to recommendation systems and collective intelligence for decision-making. This summarizes the critical stages in the data lifecycle of wearables, highlighting data collection, pre-processing, transfer, computing paradigms, ML techniques, and data storage (Figure 17).

Figure 17. Wearable Data Processing Lifecyle (Adapted from the study of Ometov et.al., 2021)

### *2.3.4. Wearables as an Assistive Technology*

Wearable technology is changing lives, especially for individuals with disabilities. These devices provide customized solutions, promoting independence and improving the quality of life. For those with mobility issues, smart prosthetics and exoskeletons with sensors enable natural movements, enhancing mobility. Wearables also assist those with communication disorders or limited motor skills, using smart glasses or headsets with gesture recognition or eye-tracking technology. Health-focused wearables, such as smartwatches, monitor vital signs, medication adherence, and activity levels, benefiting individuals and healthcare providers. Devices with GPS enhance independence for those with visual impairments, aiding in navigation (Tapu et.al. 2018). Wearables also support individuals with cognitive impairments through reminders and stress detection. They have the potential to aid learning for people with cognitive or learning disabilities, with augmented reality (AR) glasses providing interactive and immersive learning experiences. The integration of wearables into the lives of people with disabilities promotes inclusivity and well-being. Ongoing advancements in wearable technology offer endless possibilities to enhance the quality of life for individuals with disabilities. Collaborative efforts among researchers, engineers, and healthcare professionals hold the promise of creating a more accessible and supportive world. By leveraging the power of wearables, we can empower individuals with disabilities to overcome challenges, achieve greater independence, and lead more fulfilling lives.

### *2.4. Material Research: Review for AT/ WT*

Innovative materials play a pivotal role in the advancement of wearables as the assistive technologies, opening up new possibilities for improving the lives of individuals with disabilities. By exploring and harnessing the potential of cutting-edge materials, researchers and engineers are revolutionizing the field, creating assistive technologies that are more comfortable, functional, and tailored to individual needs. Relatedly, the demand for materials that are flexible, durable, and capable of delivering advanced functionalities is ever-growing. Researchers are exploring novel materials with unique properties, such as washable capabilities, stretchability, and breathability, to create wearables that not only perform their intended functions but also adapt to the user's body and movements. Thus, they are offering wearables as assistive technology aesthetically pleasing and comfortable to wear.

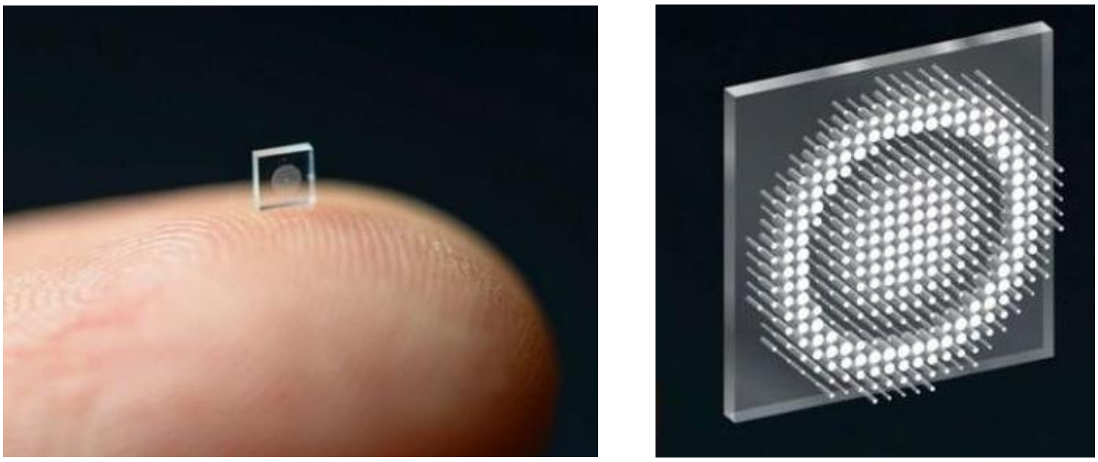
In this section, an overview of materials for textiles and electronics that could be related to the design of smart glove has been provided. Innovative electronic components, yarns and fabrics are discussed, for the glove development. Finally, the integration methods of electronic materials with gloves are mentioned.

### *2.4.1. Electronic Components*

The electronic components of wearables form the backbone of these increasingly ubiquitous devices, enabling them to deliver a wide range of functionalities and transforming the way we interact with technology on a personal level. Innovation in these components such as sensors, cameras, microprocessors, batteries, displays, connectivity modules and more, is crucial to drive the continuous improvement of wearables. Advancements in miniaturization, power efficiency, and performance have made it possible to create smaller, flexible, lighter, and more powerful wearable devices that seamlessly blend into everyday lives. Additionally, innovative components enable wearables to offer new features, enhanced accuracy, longer battery life, and improved connectivity. Here, electronic components are examined according to the working process sequence of the glove, as camera, processor, microphone/ speaker and battery.

#### *Camera*

In terms of electronic components, the camera plays a pivotal role as the primary tool for capturing images and initiating subsequent image processing steps. With the advancement of technology, the camera scales have been reduced and the development of nano cameras has emerged as a significant breakthrough in the field. Researchers have successfully engineered these cameras with advanced features and functionalities. By developing nanoscale technology, these devices offer improved clarity and reduced image distortion compared to their conventional counterparts.



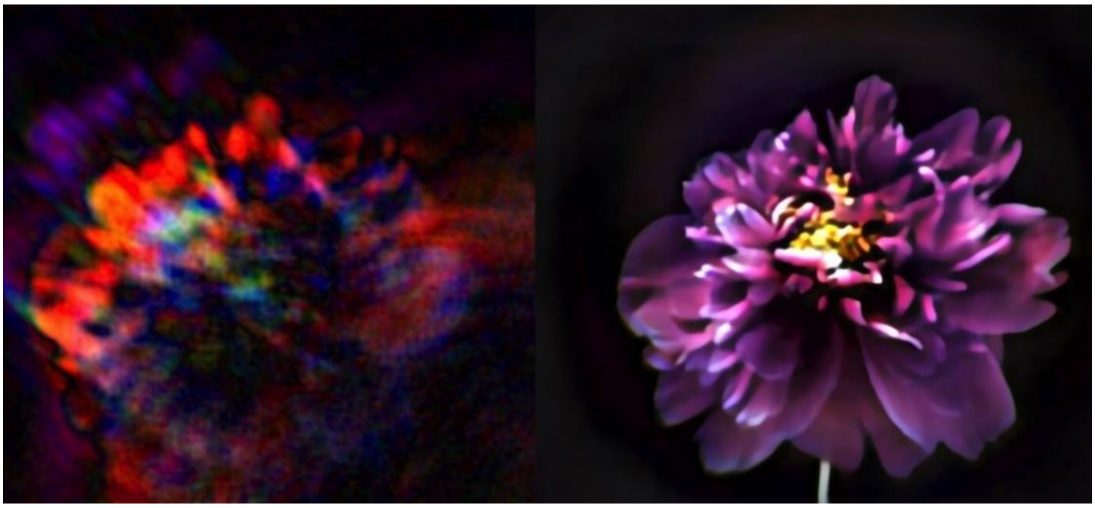


Figure 18. Nano Camera by Princeton University and the University of Washington

A team of researchers from Princeton University and the University of Washington has developed a grain of salt scaled camera that incorporates 1.6 million cylindrical posts to facilitate light processing (Figure 18). Each of these posts which are placed inside silicon nitride, a glass like material, acts as an optical antenna; receives light and shapes the optical wavefront (Team TC, 2021; Halfacree, 2021). The camera chip achieves image clarity through the utilization of machine learning-based algorithms. The novel technology employed in these nano cameras is referred to as “metasurface”. This technology involves the replacement of curved lenses found in traditional cameras with nano geometric shape. This advancement enables the transformation of entire surfaces into cameras. Consequently, the camera protrusions on the back of the devices can be eliminated (Sharlach 2021).

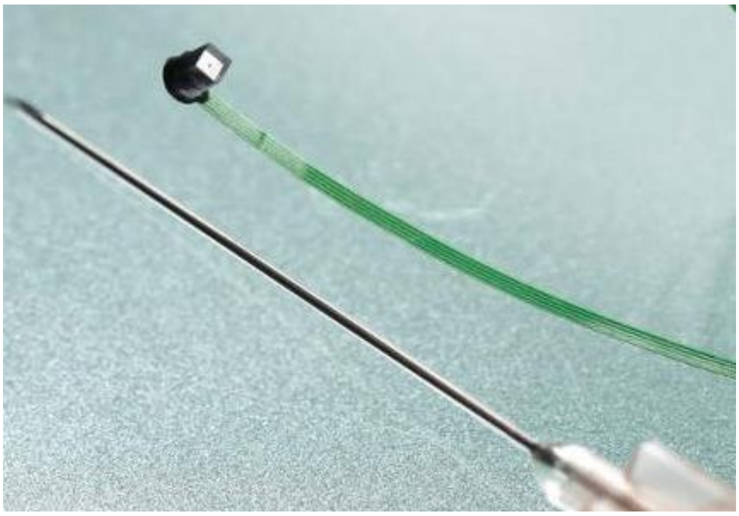


Figure 19. Mini Camera by The Fraunhofer Institute

The second innovative compact camera that has a potential of using in wearables, resembling the size of a pinhead, has been developed by The Fraunhofer Institute in the form of a one-milimeter cube. Its composition consists of a minute square substrate equipped with a thin layer of sensors and a lens, transmitting its signal through an electrical wire due to the impractical thickness of a fiber optic cable (Figure 19). Originally designed for medical purposes, this camera holds potential for diverse applications, including integration into computers, phones and wearables. Despite its size, this microdevice possess the capability to produce images with a resolution of 0.025 megapixels. While this resolution may not be good enough for conventional photography, it represents a groundbreaking advancement within the realm of medical imaging and looks promising in terms of wearables (Danigelis, 2011).

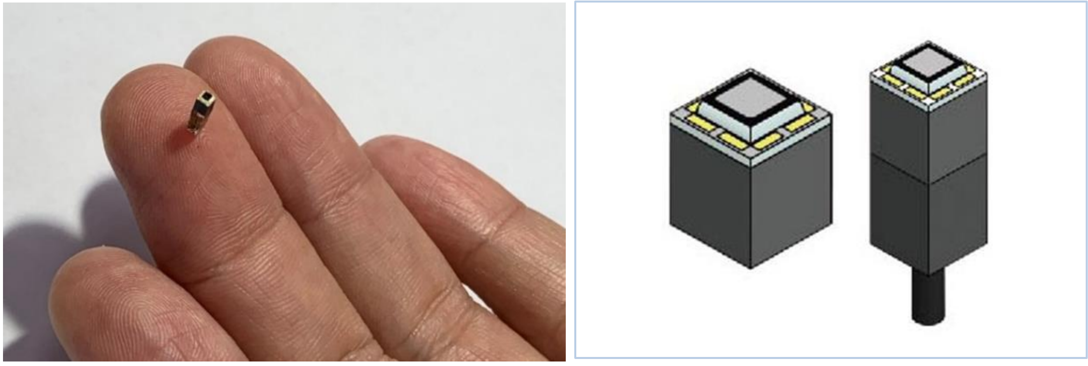


Figure 20. MiiS Camera

The last camera example is a state-of-the-art LED-on-Tip camera technology by MiiS Technology Company, characterized by its compact form factor and its advancements in medical imaging processing. The camera's dimensions measure 1.8mm x 1.8mm x 5mm, while offering a resolution of 720x720 pixels (Figure 20). The proprietary encapsulation technology ensures the LED light source is tailored to encompass the sensor, effectively reducing the size of the microelectronic module (MCM) and outer diameter. Additionally, this innovation enables the expansion of the working channel while maintaining exceptional color uniformity and brightness performance (Miis Medimaging Integrated Solution Inc.).

### ***Microcontroller & Flexible Circuits***

Since the wearables have become an integral part of daily lives, there emerges a pressing need for more flexible and miniaturized microcontrollers and processors.

These advanced components hold the key to enhancing the functionality, comfort and overall user experience of wearables. Thus, this part includes some innovative examples that have potential of applying to smart glove as a wearable assistive technology.

Figure 21. IBM Microchip

The technology company IBM has achieved a significant innovation in the processor industry by developing a groundbreaking microchip measuring only 2 nanometers (Figure 21). This nanometric chip created in IBM2s research lab in United States, is referred as the smallest chip ever produced and is anticipated to yield extensive benefits for the technology sector. This new processor boats the capability to accommodate an impressive 50billion transistors on a chip equivalent in size to a fingernail (Duffy, 2021). IBM asserts that their innovative microchip can enhance performance by %45 compared to the current high end 7nm chip, while consuming %75 less energy to maintain comparable levels of performance. This advancement holds the potential to quadruple the battery life of mobile phones, enabling them to be charged once every four days. In realm of microchip technology, advancements are measured in nanometers, with smaller numbers indicating reduced power consumption and improve performance. Moreover, this innovative approach has the potential to revolutionize AI applications, eliminating the need for a powerful graphics card to perform certain tasks (IBM, 2021).

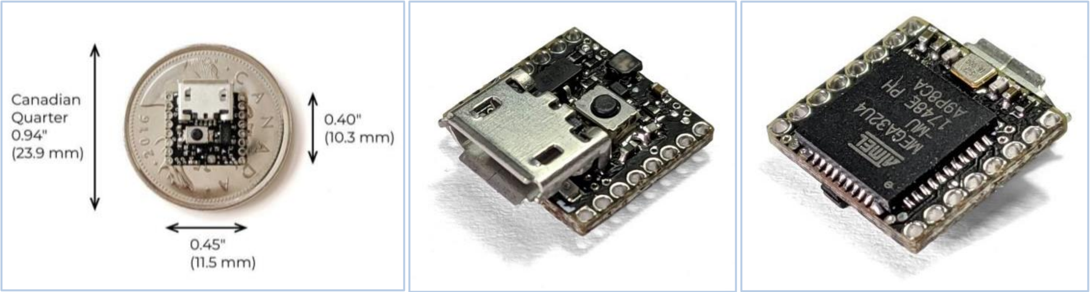


Figure 22. Arduino Atto

Arduino Atto is a compact and energy-efficient microcontroller board, recognized as the world’s smallest Arduino compatible board (Figure 22). Developed by Nionics, it utilizes the ATmega32U4 microcontroller and incorporates a reset push-button and an RGB (rainbow) LED that can be controlled through three PWM channels. With dimensions of 10.3mm x 11.5mm and weight as 0.68g, Arduino Atto is specifically designed for small-scale projects and prototypes. It encompasses 12 digital input/ output pins, 4 analog input pins, and a reset button. These boards are compatible with the Arduino programming environment, rendering them user-friendly. Due to their diminutive size and low power consumption, Arduino Atto boards are commonly employed in projects necessitating a compact form factor or remote sensors, including wearable technology such as smartwatches, AI gloves, and smart glasses. They serve as suiteble options for prototyping wearable devices (Cook, 2019).

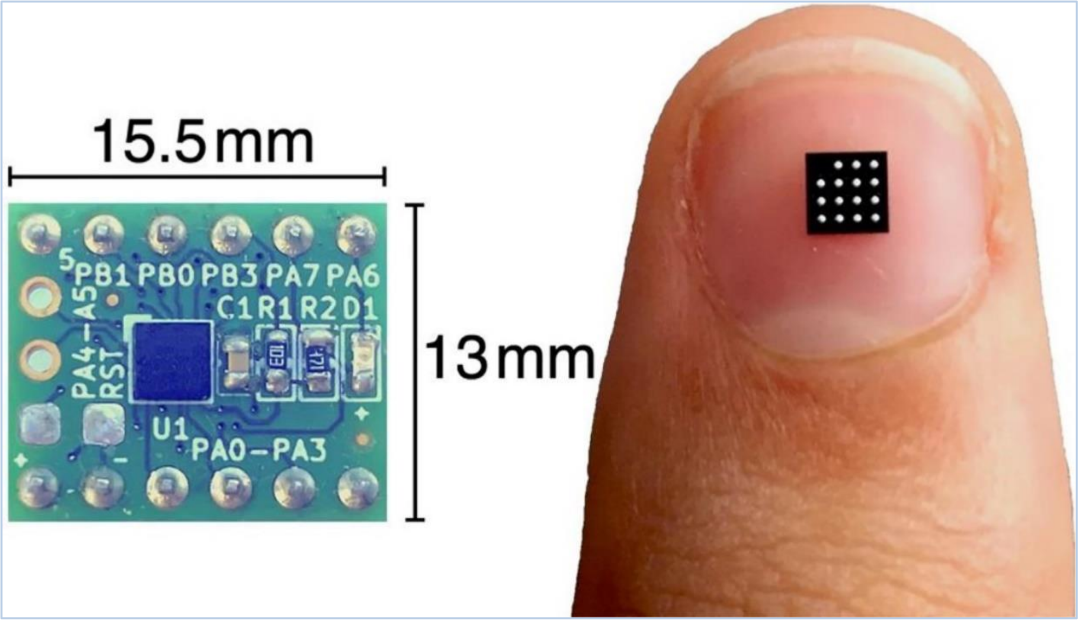


Figure 23. Breakout Board for a Ball Grid Array (BGA) Microcontroller

This academic text introduces an open-source, diminutive Breakout Board for a Ball Grid Array (BGA) microcontroller. The board is specifically designed for the development of wearable and cyber-physical prototypes. It is centered around the low-power 8-bit ATtiny20-CCU Microchip AVR microcontroller. The employment of Ultra Fine-pitch Ball Grid Array (UFBGA) packaging technology for the ATtiny20-CCU allows for the reduction of the Electroless Nickel-Immersion Gold (ENIG) Printed Circuit Board (PCB) to a compact size of only 15.5 x 13 mm (Figure 23). The cost-effectiveness of the board renders it a feasible option for various educational electronic projects, particularly those related to Instrumentation and Assistive Technology. Recent advancements in the electronics fabrication industry, facilitated by the introduction of high-density BGA chip packaging technology, have resulted in a nearly 1:1 ratio between chip area and package area. This characteristic is essential for the design of assistive devices that align with the principles of a resilient, human centered. Notable advantages of the UFBGA m-breakout developed board include a higher number of supported Inputs/Outputs, improved electrical and frequency behavior due to smaller soldering joints and reduced inductance. In summary, the UFBGA m-breakout board offers a low-cost, low-power solution for instrumentation applications, featuring a small size and lightweight profile suitable for wearable health tech devices (Antunes and Palma, 2022).

On the other hand, beside the nanometric chips and miniaturized microcontrollers, in recent years, technology has advanced to the point where flexible silicon chips and materials can be helpful in circuit applications. Flexible silicon fabric, printed thin films, and nanoscale structures are part of the process. Flexible silicon and printed circuits are suitable materials for flexible electronics. Because of the flexibility of this material, it minimizes the need for multiple materials and eliminates assembly errors.

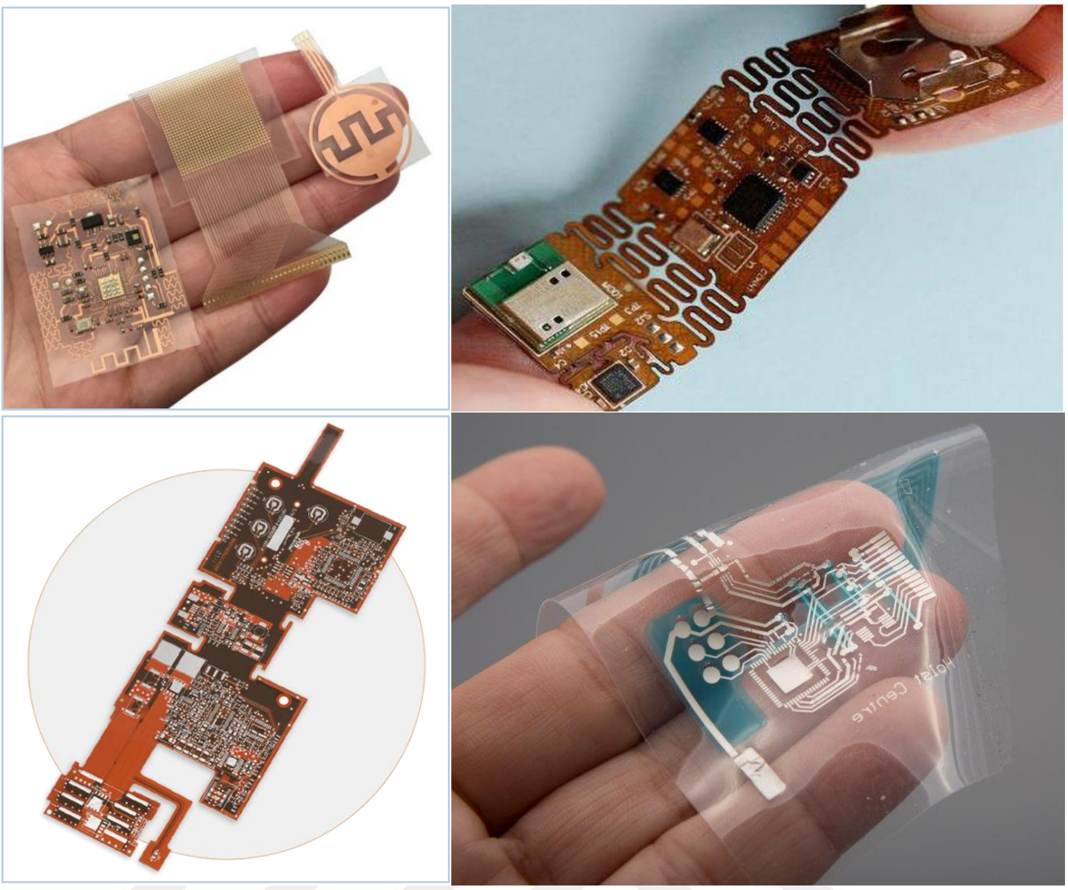


Figure 24. Flexible Microcontrollers

In the realm of electronic circuit boards, the concept of multi-layer flex circuits represents to involve the combination of single-sided or double-sided circuits with intricate interconnections, shielding, and surface-mounted technologies in a multi-layered design (Figure 24). The lamination process may or may not be continuous throughout production, depending on the desired flexibility of the design. Multi-layer circuits are particularly advantageous in addressing various design challenges such as crossover issues, impedance requirements, crosstalk elimination, enhanced shielding, and high component density. Flexible printed circuits have various benefits, including the reduction of assembly errors through accurate designs and automated production, thereby eliminating human errors associated with manual wire harnesses (Flexible Circuit Technologies, 2023). Flex circuits minimize assembly time and costs due to reduced manual labor, integration of form, fit, and function, and the avoidance of costly routing, wrapping, and soldering processes. Moreover, flex circuits offer design freedom by not being confined to two dimensions like rigid boards. Their flexibility allows for limitless design options, including highly complex configurations, resilience in harsh environments, various combinations of single and double layers, intricate interconnections, shielding, and rigid/flex capabilities.

Consequently, initially employed in military applications, multilayer flex circuits have gained widespread acceptance in commercial domains as a wide range of applications, spanning from jewelry and clothing to medical devices. Furthermore, their remarkable lightness makes them particularly well-suited for portable electronic devices. In the context of impedance requirements, the multilayer flex circuit serves as a flexible integrated circuit designed to address such demands (Saxena, 2021).

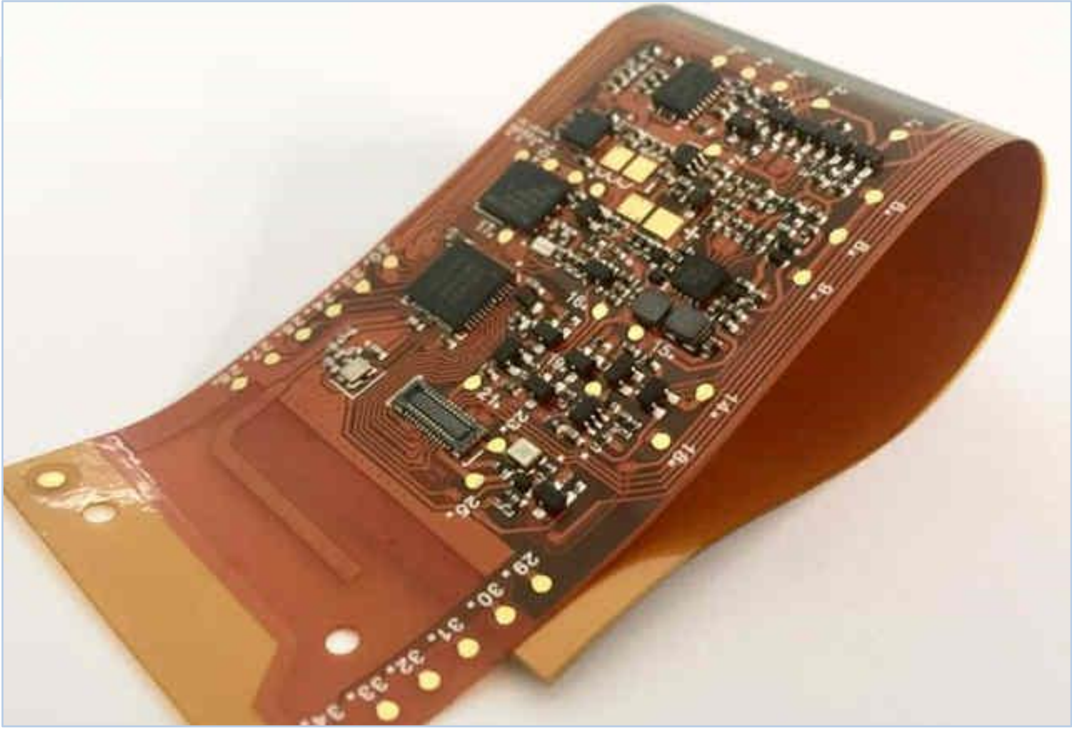


Figure 25. Flex Circuit

The flexible printed circuits that incorporate rolled copper foil demonstrate remarkable properties such as excellent flex fatigue, adequate half-softening temperature, and commendable tensile strength. Consequently, copper foil rolled specifically for flexible circuits proves suitable for a wide range of electrical and electronic applications (Figure 25). However, the annealing process is particularly advantageous for scenarios where the copper foil flex circuit is less susceptible to damage or deterioration. Among the various conductive elements present in flexible laminates, metal foil assumes a primary role. Copper foil, in particular, enjoys widespread popularity owing to its low surface oxygen content and exceptional electrical as well as thermal conductivity. Multiple options are available when selecting copper foil materials, with the most commonly employed types being rolled copper foil and the increasingly popular electroplated copper foil, which boasts a thinner profile (Rocktheshores PCB Manufacturer Company, 2022).

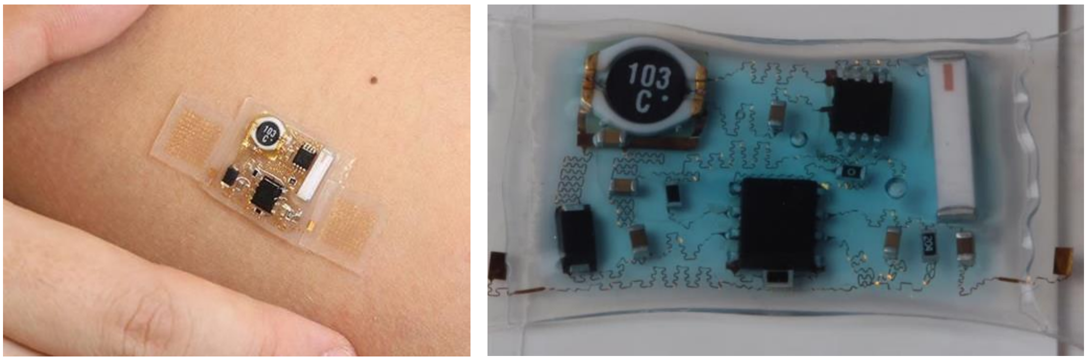


Figure 26. Stick-on-patch by University of Illinois at Urbana-Champaign and Northwestern University

A collaborative team of engineers from the University of Illinois at Urbana-Champaign and Northwestern University is actively engaged in the development of a stick-on patch (Figure 26) that aims to enhance the flexibility and practicality of health monitoring. This innovative solution combines custom-made components with readily available chip-based electronics to create a soft and tattoo-like epidermal electronic system (New Atlas, 2014). Notably, the patch incorporates a microfluidic device, integrating sensors and circuits interconnected by wires that exhibit unhindered flexibility in any direction. The device comprises two main components: one housing the mechanical aspects and interconnect network of the system, and the other being a thin, flexible polymer enclosure filled with fluid, providing a supportive substrate. Through the use of small cylinders, each component is securely attached to the bottom of the enclosure. This design enables the creation of a diverse array of bio-integrated devices that can be wirelessly powered, allowing for the measurement of various body functions such as acceleration, temperature, and more. The data obtained from these devices can be transmitted in real time to a computer through radio frequency (RF) data transmission. Thus, this flexible patch has the potential to be used in other applications of wearables if its content is adapted within the requirements (Hayword, 2018).

### *MEMS Microphone & Speaker*

In the realm of wearable technology, the demand for compact and efficient audio components has driven the development of miniaturized microelectromechanical systems (MEMS) microphones and speakers. Their reduced size enables seamless integration into wearables, such as smartwatches, fitness trackers, and headphones, without compromising the device's overall aesthetics or functionality (Fox, 2023). The utilization of miniaturized MEMS microphones and speakers in wearables opens up new possibilities for personalized audio experiences, including voice recognition, audio notifications, and hands-free communication.

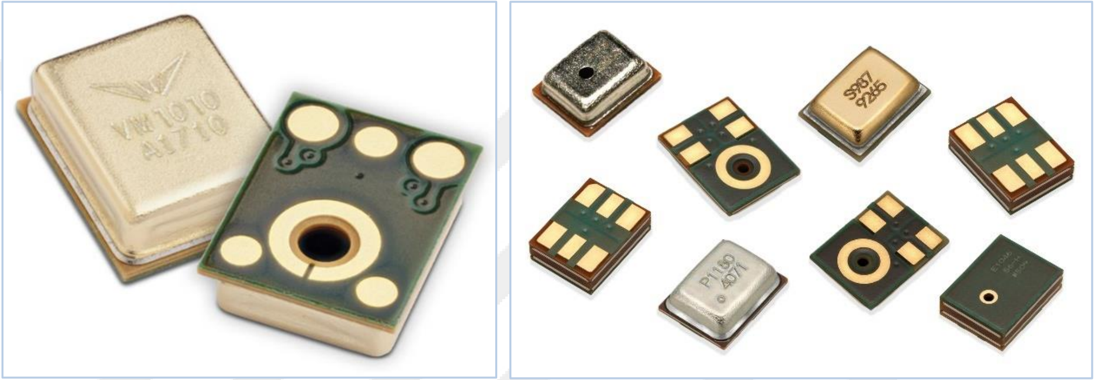


Figure 27. Vesper VM1010 MEMS Microphone

The Vesper VM1010 piezoelectric MEMS microphone (Figure 27) is a product known for its wake-on sound functionality, particularly suitable for battery-powered smart devices. What sets this device apart in the market is its energy harvesting feature, which allows it to scavenge sound energy and utilize it to wake a system from a complete power-down state. Additionally, the VM1010 offers a programmable loudness threshold, enabling customization of voice activation based on desired distance and ambient noise levels. When the surrounding environment is quiet, the system can enter the low-power "wake-on-sound" mode, significantly reducing battery drain. Key features of the Vesper Technologies VM1010 include its industry-leading power efficiency, configurable voice threshold, single-ended bottom port analog microphone design, programmable voice threshold, up to 7x extended battery life, and a dust-proof, water-resistant construction using piezoelectric MEMS technology. With its compact size of 3.76 mm x 2.95 mm x 1.3 mm, the VM1010 finds applications in various domains, including voice-activated TV remote controls, smart security cameras, smoke alarm detectors, smartwatches and wearables, and smart home applications (On Electron Tech, 2020).

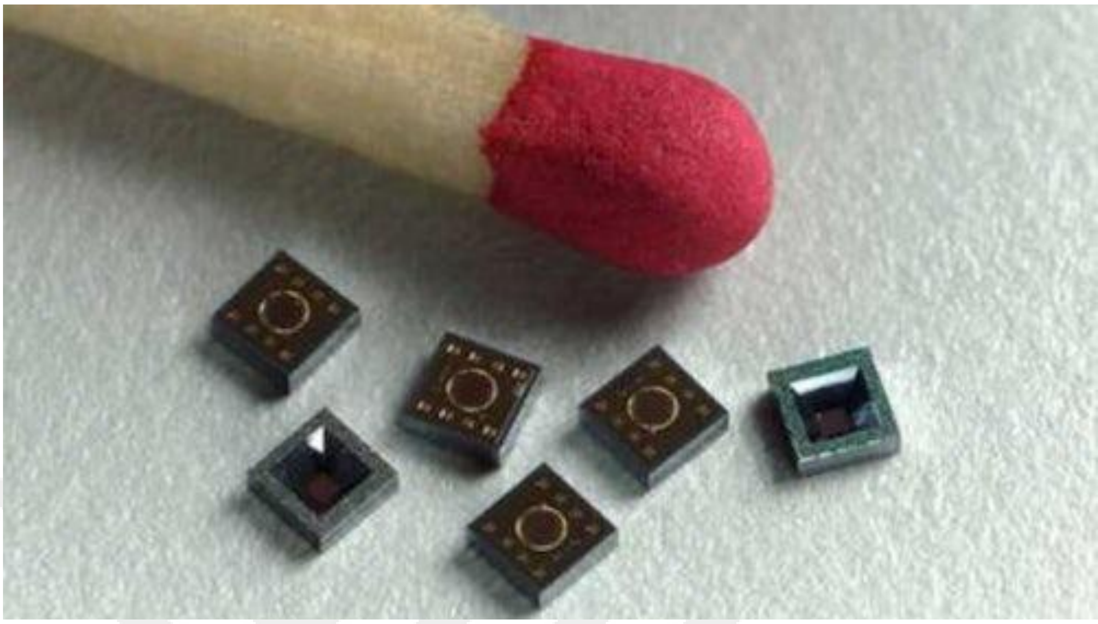


Figure 28. Tanner L-Edit used by Knowles Corporation for MEMS Microphones

Knowles Corporation explores the utilization of Tanner L-Edit, a design tool, for the efficient creation of MEMS microphones featuring intricate polygonal and curved structures. Pete Loeppert, the Vice President of research and development, presents his team's methodology for MEMS design (Figure 28). He highlights the challenge of using traditional electronic design automation (EDA) tools, which are more adept at handling Manhattan-style geometries and maintaining square shapes, while MEMS designs primarily involve circular elements (Siemens, 2023).

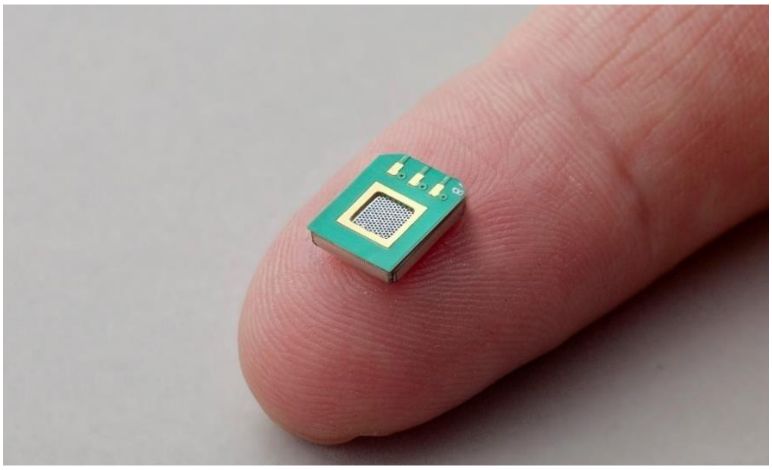


Figure 29. SonicEdge

SonicEdge (Figure 29) has successfully engineered an extremely compact MEMS speaker solution using an innovative design and modulated ultrasound technology, protected by a patent. This advancement holds the potential for substantial reductions in size, enhanced energy efficiency, and improved durability, all while maintaining superior sound quality. Unlike conventional microspeakers that exhibit a consistent sound level at lower frequencies, which diminishes at higher frequencies, the ultrasound speaker generates a volume velocity source irrespective of the frequency. This distinctive characteristic ensures a consistent and reliable sound output throughout the entire frequency range (Sonic Edge; SoundHub Denmark, 2023).

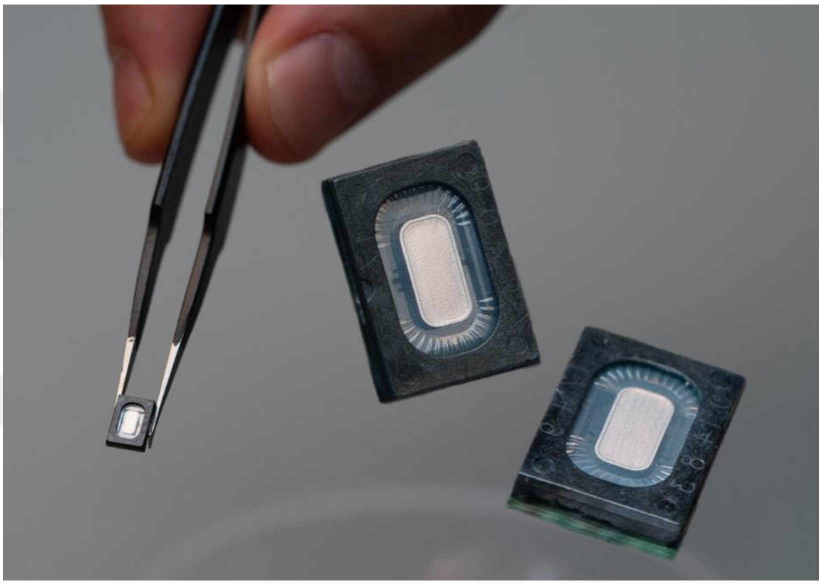


Figure 30. USound

USound is an audio semiconductor company specializing in the production of piezo silicon speakers utilizing MEMS technology (Figure 30). By leveraging their innovative MEMS concept, USound has effectively addressed the limitations typically associated with conventional piezo transducers. Through their approach, they have demonstrated the ability to generate significant displacements, surpassing previous constraints. Notably, the MEMS loudspeakers developed by USound offer remarkable flexibility, with distinct variations catering to both in-ear and speaker applications. Presently, USound microspeakers are available for integration into various devices such as smartphones, earbuds, augmented reality and virtual reality glasses' audio modules, a wide range of consumer wearables, and immersive 3D surround sound headphones (USound, 2023).

### *Battery*

The power supply for wearables remains a crucial challenge. Traditional rigid batteries often hinder the design and comfort of wearables, restricting their flexibility and limiting their utility. To address this issue, the concept of stretchable batteries has been actively researched. These innovative power sources offer a unique solution by combining flexibility and durability, allowing wearables to conform to the contours of the human body while maintaining reliable and long-lasting energy storage.

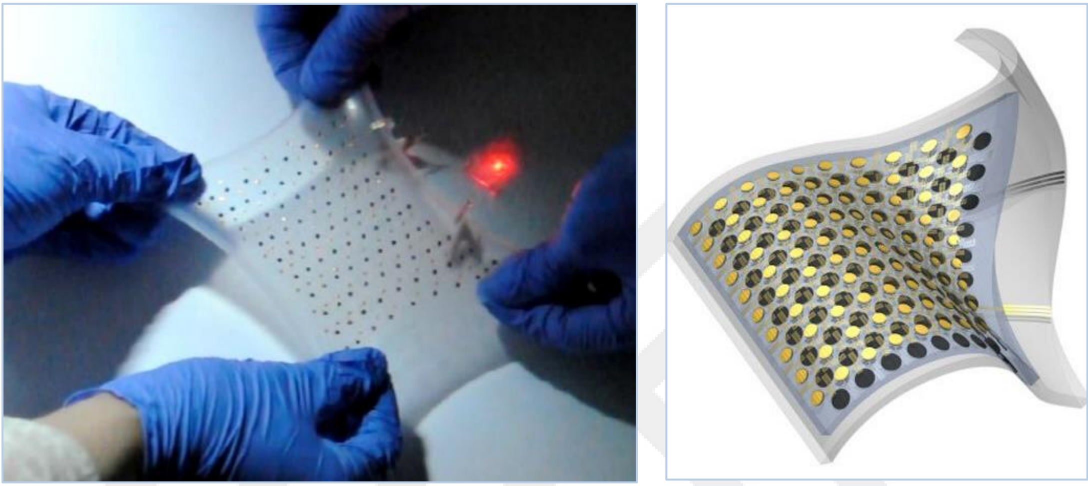


Figure 31. Flex Battery by University of Illinois

A team of researchers from the University of Illinois has created a novel battery that exhibits the remarkable ability to stretch up to three times its original length without sustaining any damage. This innovative battery design incorporates miniature lithium-based batteries into a silicone sheet, with the energy-storing components consisting of small lithium-ion batteries printed on a flexible polymer substrate (Stromberg, 2013). These components are connected by elongated, S-shaped wires that act as springs, allowing them to stretch out and cover greater distances when the polymer is pulled (Figure 31). The interconnecting lines within the battery unfurl in a wavy pattern, similar to the unraveling of yarn, and the battery's circuits are designed to straighten out as they are stretched, returning to their original positions when released. The team successfully demonstrated the functionality of the battery by powering a red LED while subjecting it to stretching and twisting. The researchers envision numerous applications for this innovative battery technology, including wearable devices, implantable brain-wave monitors, and other bionic devices. Although the battery's power output is not sufficient to sustain larger devices like laptops or large light bulbs, its potential lies in niche applications such as low-power biological implants. Further improvements could enhance its capabilities and expand its range of applications (Ghose, 2013).

Figure 32. Flexible Lithium-ion Battery by Panasonic

Panasonic Corporation has recently developed an ultra-thin flexible lithium-ion battery measuring only 0.55mm (0.022 inches) in thickness (Figure 32). This advancement addresses the need for internal components of card devices to withstand bending and twisting commonly experienced when carrying them in wallets or pockets (Photoxels, 2016). Conventional slim lithium-ion batteries used in these devices tend to degrade under such stresses, leading to reduced operational lifespan. However, Panasonic's new battery demonstrates enhanced durability against bending and twisting, making it suitable for application in smart cards, card keys, body-worn devices, smart clothing, and similar devices reliant on battery power. The company showcased three prototypes of this flexible battery at the CES electronics show in Las Vegas, exhibiting dimensions of 40mm x 65mm, 35mm x 55mm, and 28.5mm x 39mm, all with a thinness of 0.45mm. Notably thinner than a credit card, these batteries can flex up to a radius of 25mm or twist at an angle of 25 degrees (Grolms, 2016).

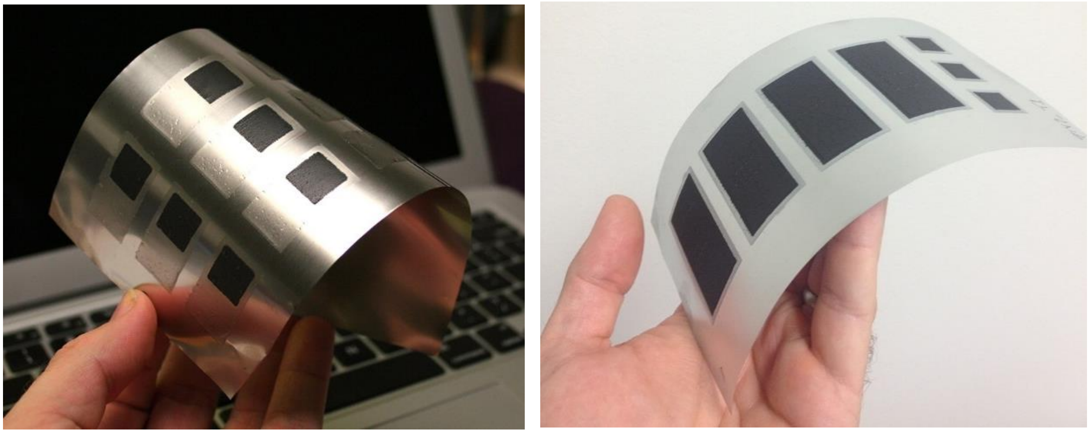


Figure 33. Imprint Energy, Almeda

Imprint Energy, a startup based in Alameda, California, is focused on the development of flexible and printable rechargeable batteries (Figure 33). Their innovative approach involves using commonly used industrial screen printers to produce these ultrathin zinc-polymer batteries at a low cost. Imprint Energy has conducted successful tests of these batteries in wrist-worn devices and aims to supply manufacturers in the fields of wearable electronics, medical devices, smart labels, and environmental sensors.

The primary goal of this approach is to ensure the safety of on-body applications while enabling product designs that were previously impractical due to the bulkiness of lithium-based batteries. The compact size and flexibility of these batteries make them particularly suitable for low-power wireless communication sensors, setting them apart from other types of thin batteries. Although thin-film rechargeable batteries are available, they often contain reactive elements, have limited capacity, and are expensive to manufacture. In contrast, printed batteries, which typically employ zinc, offer higher capacity and are more cost-effective (Nicholson, 2014).

Figure 34. Flexible and Washable Battery by University of British Colombia

Researchers at the University of British Columbia (UBC) have achieved a significant breakthrough by developing a battery that possesses both flexibility and washability, potentially making it the first of its kind. This battery retains its functionality even when subjected to twisting or stretching up to twice its original length, as well as surviving a cycle in the washing machine (Figure 34). The UBC team, led by Dr. Nguyen, has introduced several engineering advancements in this battery. Instead of using rigid materials for the internal layers typically found in conventional batteries, they opted for stretchable compounds—zinc and manganese dioxide—by grinding them into small particles and embedding them within a rubbery polymer (CBC, 2021). The battery consists of multiple ultra-thin layers of these polymers encased in the same flexible polymer, creating a waterproof and airtight seal that ensures the battery's integrity during repeated use. The battery has demonstrated remarkable durability, enduring 39 wash cycles, and further improvements are anticipated as the technology continues to be refined. The choice of zinc and manganese dioxide chemistry also brings an added benefit, as it is considered safer than lithium-ion batteries, which can release toxic substances upon damage or breakage—making it particularly suitable for devices worn close to the skin (UBC, 2021).

Figure 35. Strechable Battery by Stanford School of Engineering

Researchers at Stanford School of Engineering have successfully developed a soft and stretchable experimental battery that leverages a specialized plastic material for energy storage (Figure 35). This innovative battery design addresses safety concerns associated with conventional batteries, as the chosen plastic composition is deemed safer than the flammable formulations commonly used. Polymer electrodes, which have been employed in lithium-ion batteries for some time, serve the purpose of transporting negative ions to the battery's positive pole.

During testing, the experimental battery exhibited remarkable performance characteristics, demonstrating a consistent power output even when subjected to various forms of deformation, including squeezing, folding, and stretching. In fact, it maintained its power output levels at nearly twice the magnitude of conventional batteries. The research team is actively engaged in efforts to enhance the energy density of the stretchable battery. By increasing its capacity to store and deliver power, they aim to further optimize its performance and expand its potential applications. This ongoing work holds significant promise for advancing the field of flexible electronics and enabling the realization of diverse applications that require resilient power solutions (Tech Briefs, 2020).

### *2.4.2. Textile Components*

The selection of appropriate fabrics plays a critical role in the design and development of wearable devices, ensuring user comfort, breathability, moisture control, and protection of embedded electronics. Comfort is a key consideration, as wearables should provide a pleasant tactile experience without causing irritation or restricting movement. Breathability is essential to allow air circulation and heat dissipation, preventing discomfort from excessive perspiration. Effective moisture control helps in wicking away sweat from the body, maintaining a dry and comfortable microclimate. Additionally, fabric selection should provide adequate protection for the embedded electronic components, shielding them from environmental factors, such as moisture, dust, and physical impact. Achieving optimal performance in wearable products cannot be accomplished solely through a single fiber structure. Therefore, it is crucial to emphasize the integration of fiber structures possessing the desired properties within the fabric, under suitable conditions. The overall behavior of the fabric is primarily determined by the inherent properties of the constituent fibers. The fabric properties are influenced by various parameters, including the type of fibers used, the structural weave of the fabric, the weight and thickness of the fabric, as well as any applied chemical processes. Thus, in this part, considering the comfort, three fabric examples as CoolMax, Smartcel and Viloft, are given that can be used also in smart glove design/ production. Also, and 3D/ 4D knitted fabric images and information are placed in terms of the production method of the smart glove.

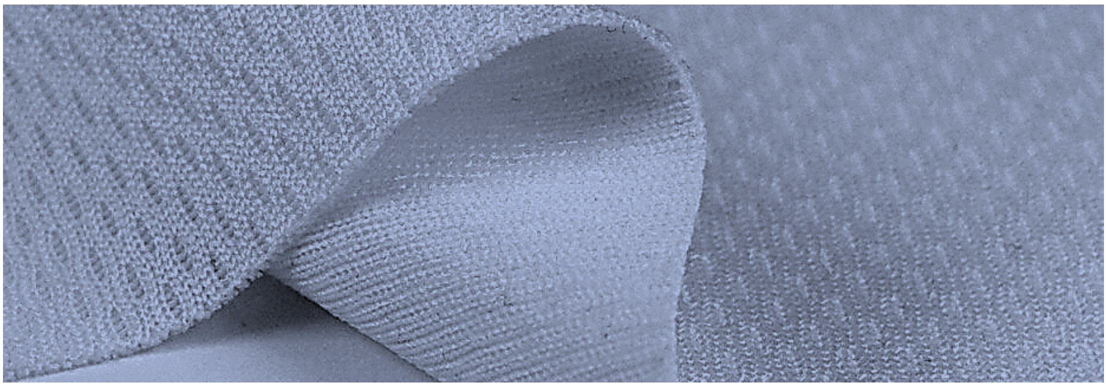


Figure 36. CoolMax Fabric by DuPont

CoolMax fabric, developed by DuPont Textiles & Interiors (now Invista) in 1986, is a specially designed polyester blend known for its enhanced breathability compared to natural fibers. Originally intended for extreme physical exercise clothing, CoolMax is now used in various applications, including everyday wear, mountaineering apparel, sports clothing, underwear, casual streetwear, and bedding. The fabric's unique 4-channel fiber structure efficiently expels sweat from the body, reducing the energy expended in sweating and promoting quick drying (Figure 36). The rectangular cross-sectional shape of the fibers facilitates moisture diffusion and evaporation, ensuring a greater surface area for enhanced evaporation rates. When used in socks, CoolMax keeps the feet cool, dry, and odor-free for a long time. CoolMax Fresh FX, a polyester-based variant, incorporates silver ions to provide permanent anti-bacterial and anti-fungal properties. It is compatible with the body, hypoallergenic, and prevents the formation of odors. Additionally, the anti-bacterial yarns used in CoolMax fabric have high heat resistance and do not require additional processes during dyeing and finishing (Karsu, 2023).

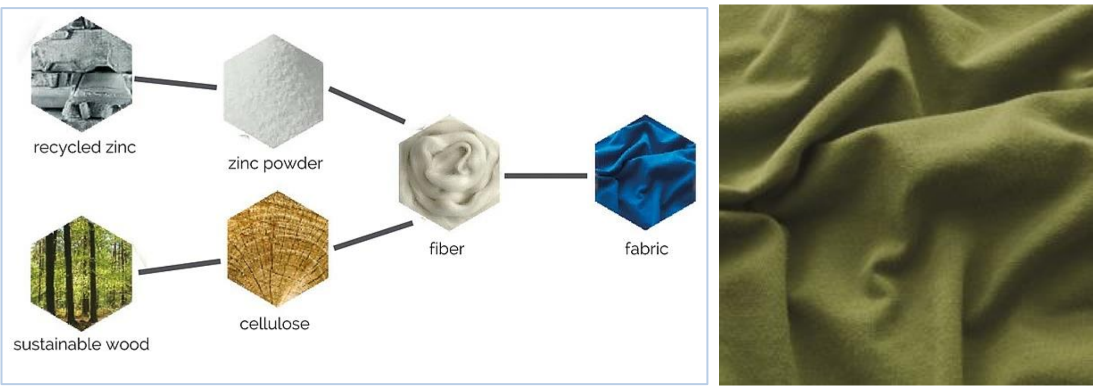


Figure 37. Smartcel™

Smartcel™ sensitive is a skin-friendly fiber that incorporates zinc oxide, known for its soothing and anti-inflammatory properties (Figure 37). This makes it particularly beneficial for individuals with sensitive skin or skin conditions like eczema or neurodermatitis. Zinc oxide directly interacts with the skin as it is a component of skin-building enzymes, fostering an active exchange between the fiber and the skin when the garment is worn. Moreover, zinc oxide acts as a protective barrier against harmful UVA and UVB radiation, offering up to 50 SPF depending on the percentage of smartcel™ sensitive used in the garment. Additionally, zinc oxide exhibits strong antibacterial properties, particularly against odor-causing bacteria, thereby prolonging garment freshness. The production of smartcel™ sensitive utilizes the eco-friendly Lyocell Process, ensuring a closed-loop system with no chemical release. With its compatibility with various applications and ease of combination with other fibers, smartcel™ sensitive adds a smooth, silky feel to fabrics, providing comfort and care for individuals leading an active, health-conscious lifestyle. The fiber is produced using high-quality pharmaceutical-grade zinc oxide, resulting in a biodegradable and eco-friendly product made solely from renewable raw materials (Karsu, 2023).

Figure 38. Lenzing Viloft

Viloft fiber, also known as modified viscose, is produced by Kelheim Company and offers improved thermal properties to fabrics by creating air spaces within the yarn, particularly when blended with fibers like polyester (Figure 38). It is commonly blended with fibers such as cotton, polyester, polyamide, and Tencel at a 50% ratio in textile products. The comfort properties of clothing made from cellulosic or synthetic fibers, including Viloft, are directly influenced by the cross-sectional structure of the fibers. Thus, they are known for their quick drying and breathable characteristics, rapid moisture transfer, and breathability, ensuring a comfortable micro-thermal environment near the skin. It also possesses moisture-wicking properties and inhibits bacterial growth due to its thermal properties. Furthermore, textiles made from Viloft are easy to care for as they are machine washable, and it derived from renewable materials, making them 100% biodegradable and environmentally friendly (Karsu, 2023).

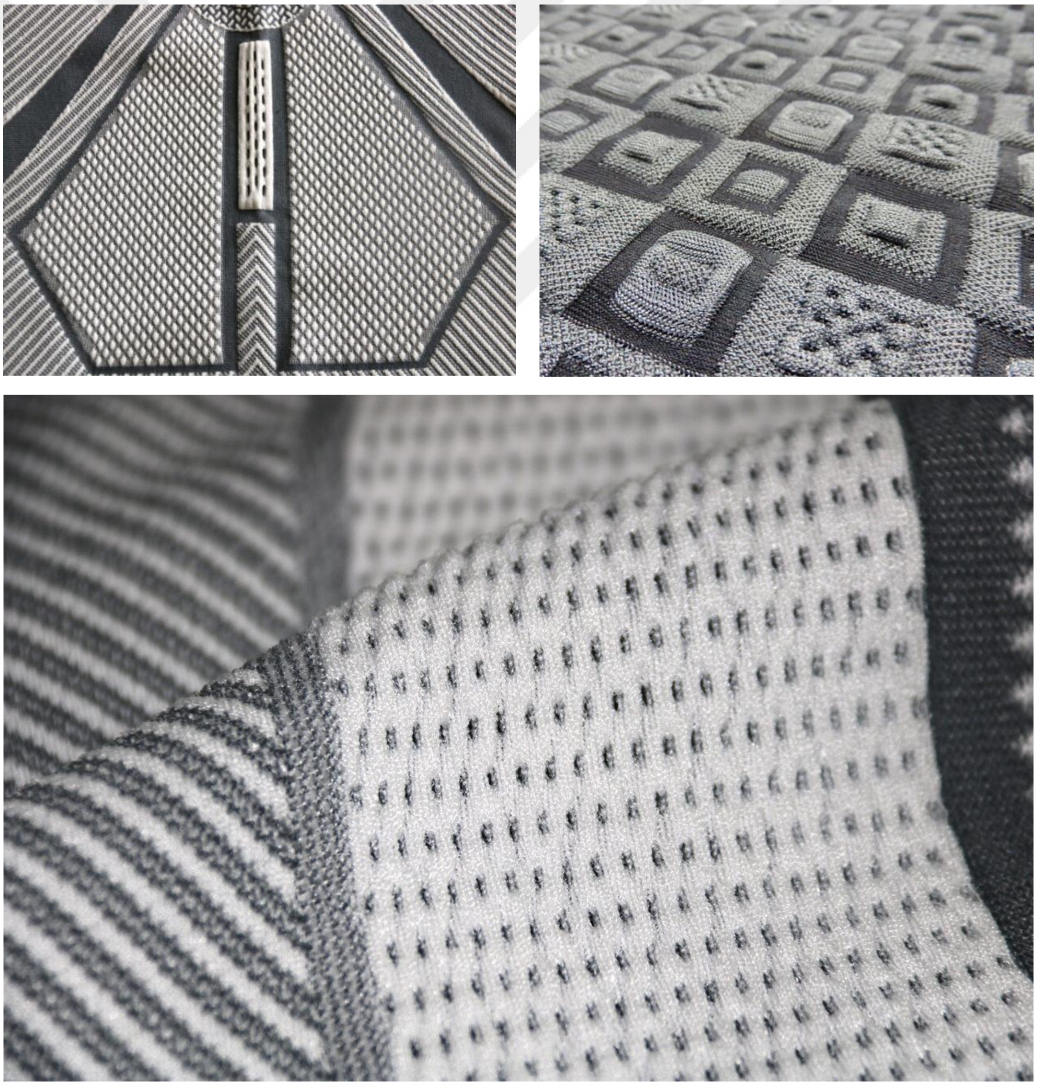


Figure 39. KARL MAYER Piezo-Jacquard Technology/ 3D & 4D Knitting

Through the implementation of an intelligent bar arrangement and technical configuration, in conjunction with high-quality KARL MAYER Piezo-Jacquard technology (Figure 39), this innovative double needle bar machine has a potential to be integrated in innovative fabric production. It enables the creation of fabrics exhibiting versatile and malleable patterns on both sides. The 3D motifs can be customized in terms of shape, positioning, and height, accommodating various design preferences. This machine allows for the realization of intricate details, ranging from small and flat reliefs to deep and bulky forms with cushioning, offering extensive design possibilities. Moreover, the design can incorporate strategically placed holes for creative solutions. These openings can serve practical purposes such as facilitating directed air flow or providing lighting effects. In addition, it accommodates the use of different yarns for coloration and shaping effects, enhancing the visual appeal and versatility of the fabrics produced. The resultant fabrics exhibit robust properties, designed to endure over time. They have been rigorously tested, withstanding over 20,000 cycles of abrasion without any signs of deterioration (Karl Mayer Company, 2023).

### *2.4.3. Integration of Electronics and Textile*

In recent years, there has been a significant increase in the development of the integration of electronics with textiles and wearable devices, which opens up new possibilities in the field of assistive technology. Advances in electronics and materials science are combined to create innovative solutions that blend seamlessly with clothing and accessories, enhancing the capabilities and functionality of assistive devices. With the integration of electronics into textile products and wearable devices, products emerge for disabled individuals that do not compromise on comfort and aesthetics, and that enable them to move independently. The integration of electronics with wearable devices encompasses a variety of methods and techniques. In this section, the samples are examined in two parts: printing/embroidery and covering/ layering.

### *Printing/ Embroidering*

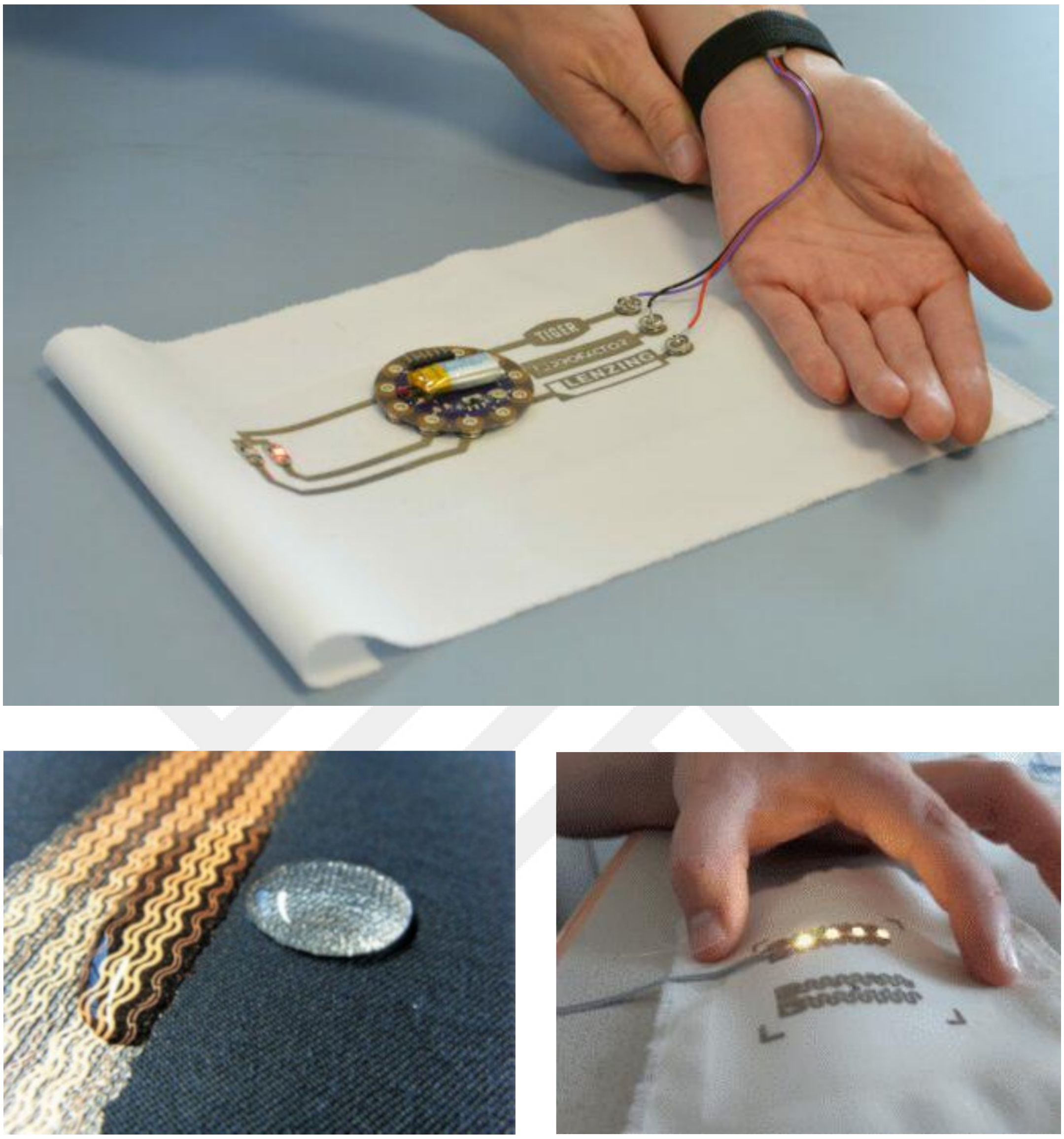


Figure 40. Profactor- Conductive Inkjet Printing

Profactor, a research organization, has explored different methods to apply electrically conductive materials onto textiles or 3D printed objects, including inkjet printing and dispensing (Figure 40). Inkjet printing with silver and copper inks, as well as dispensing pastes, are key materials for these advancements in printed electronics. Inkjet print heads can be utilized in larger devices or mounted on 6-axis robots for printing on complex structures. Metallic nanoparticles are used in the inks, which are selectively applied to specific areas, resulting in additive manufacturing. However, the printed structures require thermal post-treatment to achieve desired electrical properties. Dispensing, using a single nozzle, is another method employed by

Profactor, which does not require high resolution for conducting paths. This development of alternative processes in the PCB manufacturing industry, such as inkjet printing, offers innovative, cost-effective, simplified, environmentally friendly, durable, and market-driven solutions compared to traditional photolithography methods (Re-Fream, 2023).

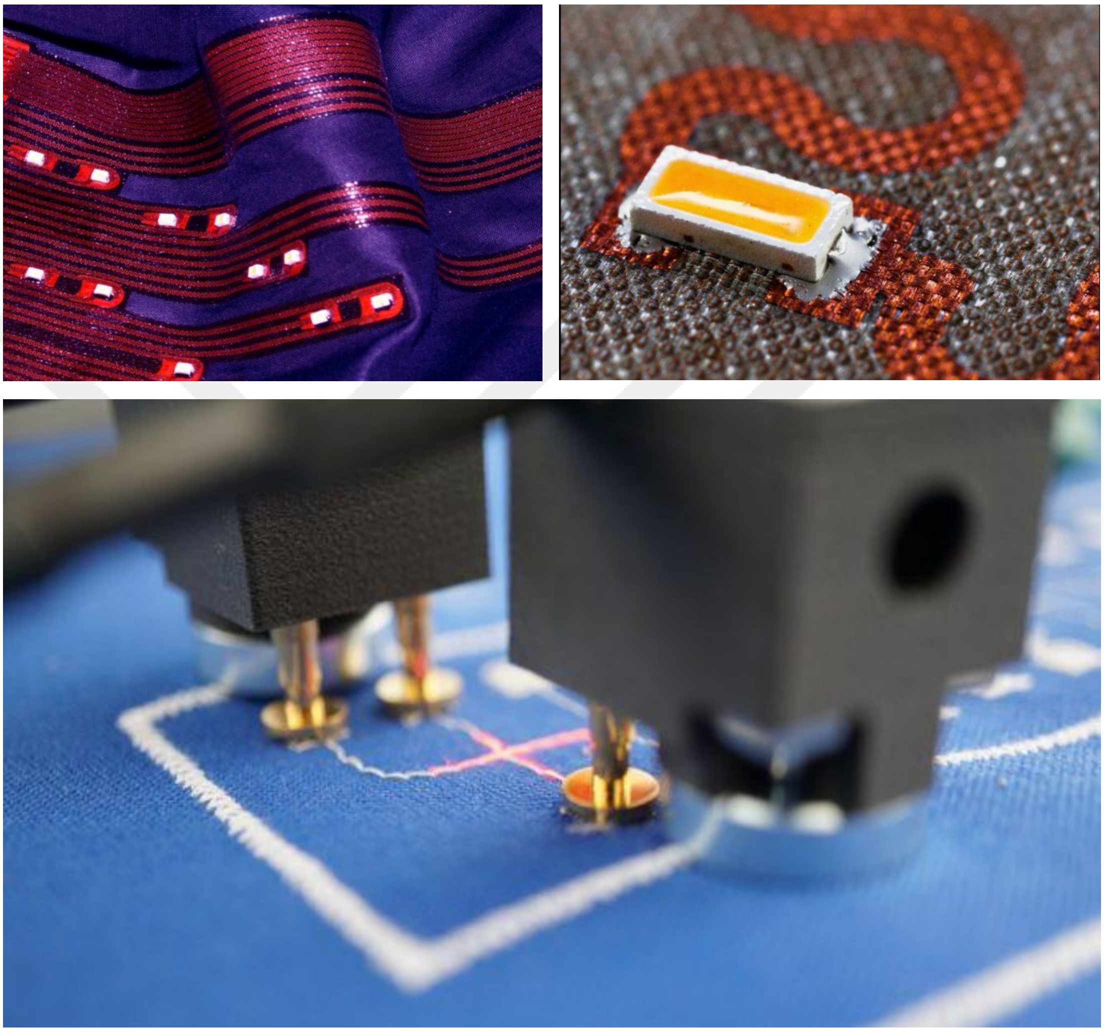


Figure 41. Fraunhofer IZM- Re-Frame Project

The integration of rigid electronic components with soft, flexible materials presents a significant challenge in the development of e-textile systems. Fraunhofer IZM specializes in the advancement of connection solutions compatible with textiles and offers access to cutting-edge technologies for this purpose. These technologies include non-conductive adhesive bonding, ultrasonic plastic welding, low-temperature soldering, and mechanical connectors (Figure 41). These options facilitate the development of sample batches, small series, and production of e-textile systems. The typical application areas for these advancements are in the field of smart textiles. In the Re-FREAM project, materials such as silver and copper are commonly employed for the integration of electronics into textiles (Re-Fream, 2023).

Figure 42. Q5D Technologies

Q5D Technologies, a UK-based robotics company, aims to revolutionize the wiring process by printing electronics directly onto component surfaces. The company's goal is to enhance safety, eliminate human errors, increase production speed and accuracy, improve connectivity, reduce weight and material costs, and minimize product recalls. By using computer-aided manufacturing software, Q5D can control the wire-laying or printing of electronic circuits onto various components, including vacuum-molded, sheet-metal, or injection-molded parts (Figure 42). The technology utilizes multiple printing techniques, such as miniaturized laser and ink deposition systems, to achieve its objectives. To ensure protection against arc-over events, each wire can be embedded in its own track, over-molded, and sealed, shielding them from environmental factors and potential damage. Additionally, Q5D's technology allows for the embedding of electric cables and wires directly into materials, offering flexibility in functionality and cost-effective customization options. This method, which was primarily developed for the automotive sector, has the potential to be integrated into the wearable technology field (Austin-Morgan, 2022).

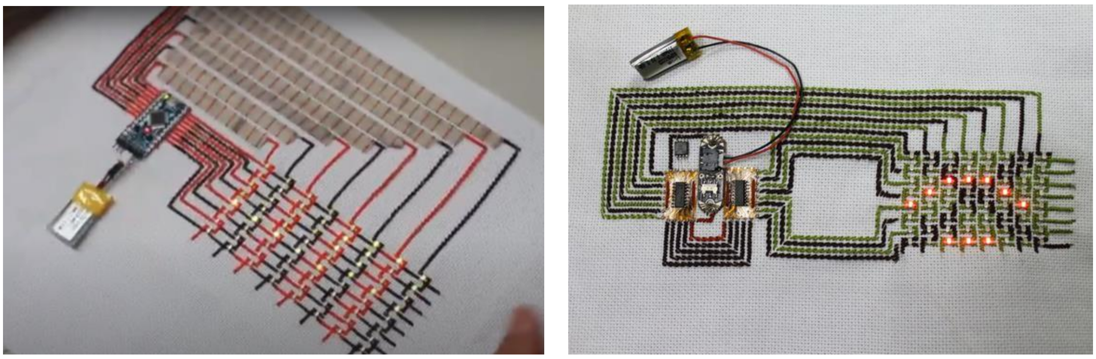


Figure 43. Embroidered Circuit Board by Chieh

In the "fabric projects" by Shis Wei Chieh, he has incorporated conductive threads obtained from Sparkfun and worked with Bandui Lab. These threads are composed of silver-plated copper and exhibit a resistance of less than 0.05 ohm per foot. The occurrence of short circuits in the system can be attributed to the connection between the printed circuit board (PCB) and the fabric (Chieh, S.W., 2013).

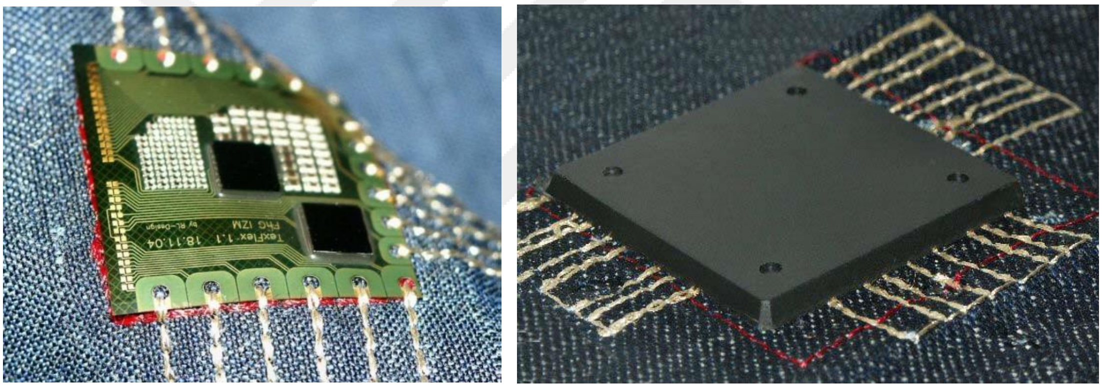


Figure 44. Embroidered Circuit by Linz et.al

The study by Linz et. al. aimed to produce an electronic test substrate and design a test layout for an embroidered circuit (Figure 44). The focus was on evaluating the conductance and contact durability of the textile interconnect under various conditions, as well as investigating the stress durability of the flip chip and resistor assembly as representative electronic components. The flexible substrate used in the experiments consisted of a 50µm polyamide foil with structured 17µm copper, 5µm nickel, flash gold, and 15µm solder resist on both sides. The module size was 25x25mm, with a total of 18 contact areas for the textile interconnect along three edges. Various substrates were designed for the study. To meet the requirements of conductivity and machine sewability, silver-coated polyamide threads were used. The test layouts were embroidered using a semi-professional embroidery machine. Encapsulation was deemed essential to protect the electronic components, interconnections, and embroidered interconnects, and molding was applied to achieve this purpose (Kallmayer et. al., 2005).

### *Layering/ Knitting and Weaving*

The integration of electronics with textiles or garments has opened up new possibilities for wearable technology, smart textiles, and interactive fashion. By layering, knitting, and weaving electronic components into the fabric, a seamless fusion of functionality and aesthetics can be achieved. This integration enables the creation of garments that can sense, respond, and interact with the wearer and the environment. Through innovative techniques, such as conductive yarns, flexible circuitry, and embedded sensors, electronic elements can be seamlessly integrated into the fabric structure.

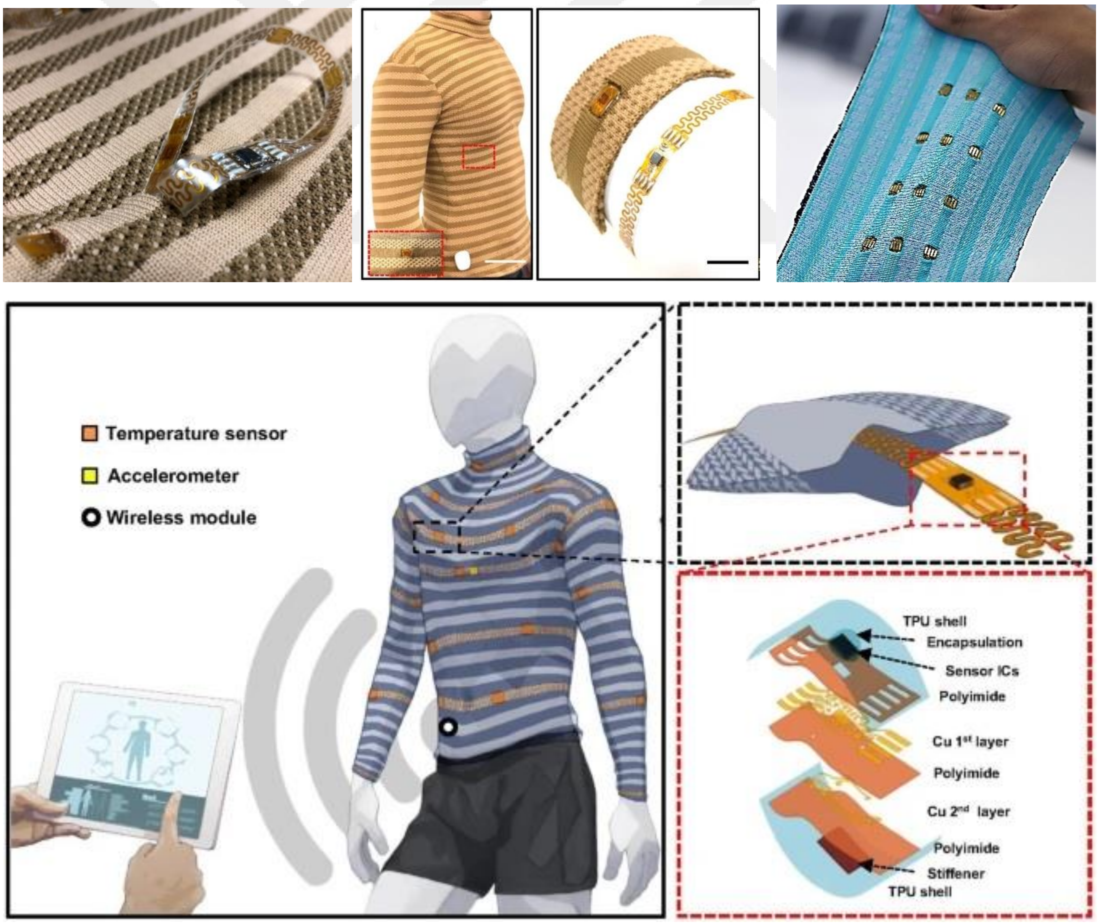


Figure 45. E-TeCS Project by Wicaksono et.al

In the study by Wicaksono et. al. (2020), a customized electronic textile conformable suit (E-TeCS) has been developed to enable extensive and multimodal physiological sensing in vivo. The E-TeCS platform offers the flexibility to tailor its form, size, and function using widely accessible and high-throughput textile manufacturing and garment patterning techniques. The suit's soft and stretchable nature facilitates close contact between the embedded electronics and the skin, promoting physical comfort and enhancing the precision of sensor readings. Notably, the E-TeCS demonstrates the capability to detect skin temperature, heart rate, and respiration (Figure 45). The knit textile electronics exhibit excellent mechanical and electrical performance, enduring up to 30% stretching under 1000 cycles without significant degradation. This research provides a promising foundation for the development of wearable electronic textiles that enable accurate and comfortable physiological monitoring (Wicaksono et.al., 2020).

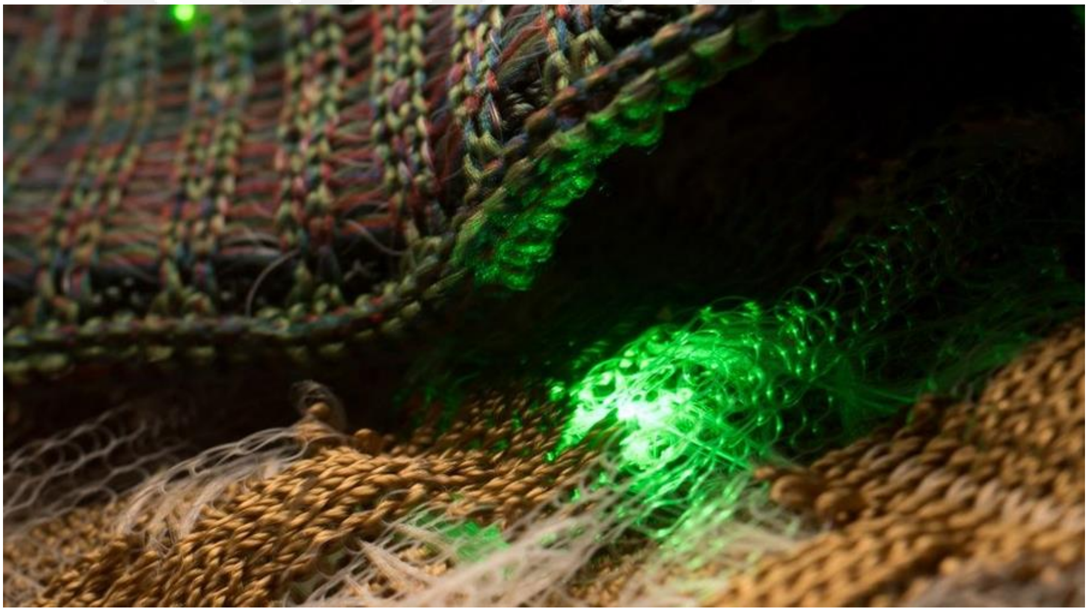


Figure 46. Smart Fabric by MIT and AFFOA

Researchers from MIT and AFFOA have successfully developed flexible fibers embedded with electronic components, allowing them to be woven into soft fabrics and utilized in wearable clothing (Figure 46). By incorporating high-speed optoelectronic semiconductor devices like LEDs and diode photodetectors into the fibers, they have achieved the creation of "smart" fabrics with sophisticated functionality. Previously, the challenge was integrating semiconductor devices into fabrics, which are essential for modern electronics. The breakthrough involved adding tiny semiconductor diodes and thin copper wires to the preform—a model of the fiber—before heating it and drawing it into a long fiber during the manufacturing process. The resulting fibers were woven into fabrics and demonstrated practicality through multiple rounds of laundering. The integration of components directly into the fiber material itself offers advantages such as inherent waterproofing (Chandler, 2018).

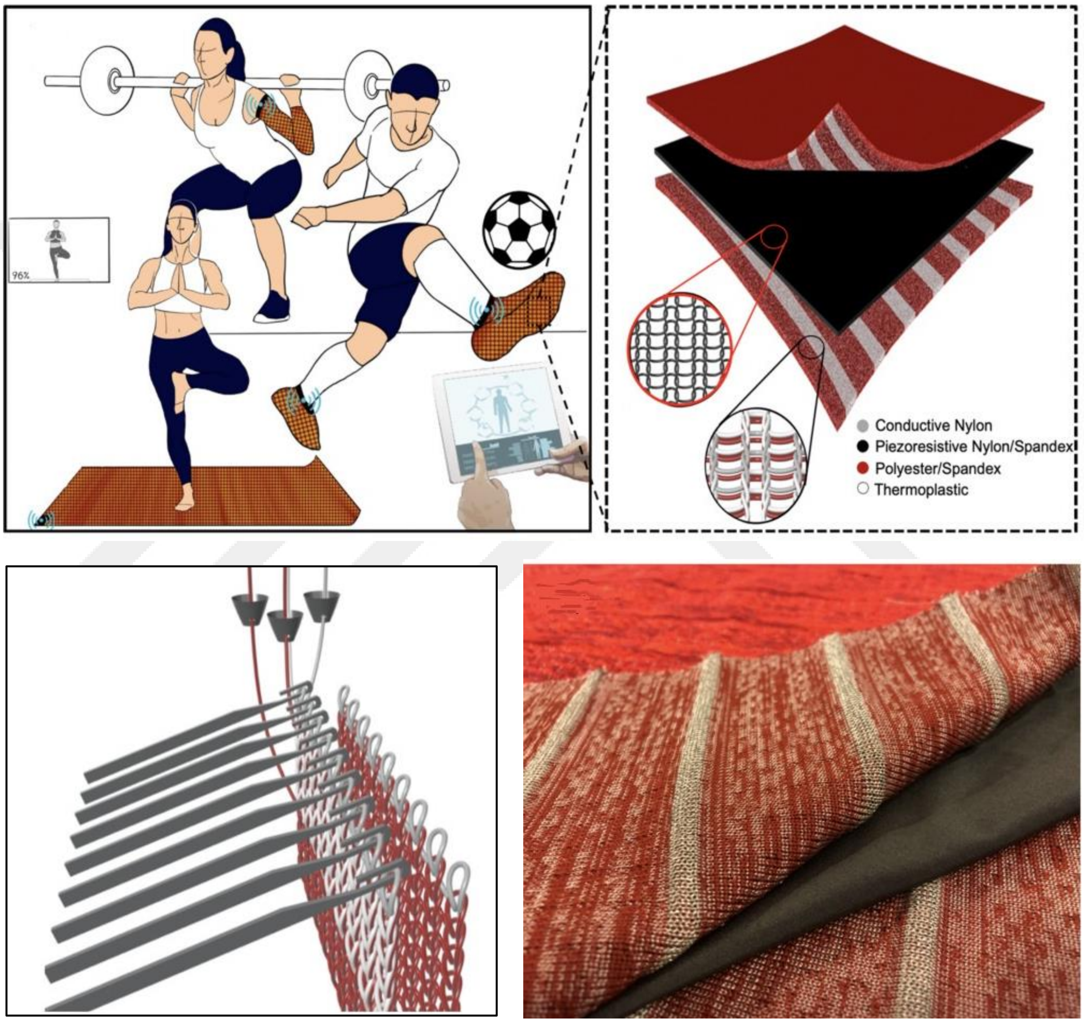


Figure 47. Intelligent Textile by MIT Researchers

In their study, MIT researchers propose an innovative approach to develop intelligent textiles that are seamless, scalable, and capable of sensing various movements and postures. They utilize digital flat-bed and circular knitting machines to combine functional and common yarns, enabling customization of both the aesthetics and architecture of the textile (Figure 47). By incorporating a melting fiber and employing thermoforming principles, they achieve a three-dimensional piezo-resistive fabric structure that conforms to the human body, ensuring comfort and intimate interfacing while minimizing sensor drifts and enhancing accuracy. Through the digital knitting approach, the researchers successfully create pressure-sensitive textiles such as an intelligent mat with 256 sensing pixels and a form-fitted shoe with 96 sensing pixels. The incorporation of machine learning allows for real-time interpretation of data from pressure sensors, achieving highly accurate predictions of user motions and yoga poses (Wicaksono et.al., 2022).

# CHAPTER 3: SURVEY ANALYSIS

After review of the AT and WT literature in general terms with the general purpose of developing a Smart Glove, it was observed that the examples are more related with navigation and text/object identification functions. Even though there are some wearable technology items in the market, the overview reveals that most commercial approaches include mobile phone applications for mobility and communication, while there is limited research and examples of AT and WT in the clothing field. The review addresses a lack of applications, especially in clothing related fields, which defined the focus of our subsequent survey. Since the UCD aims to involve users throughout the design process, surveys provide data that can inform the designer in decision-making, ensuring that design choices are grounded in user preferences. Thus, this survey evaluate the relationship of visually impaired individuals with design and clothing concepts, determines the problems they experience in the field of clothing, and presents their opinions about assistive and wearable technologies that guide the development of Smart Glove and its system construction accordingly.

## *3.1. Structure of the Survey*

The semi-structured survey consisting of 10 questions (including 3 closed-ended and 7 open-ended questions) was prepared. Thus, with open ended questions opinions of participants were obtained as qualitative data. The survey was conducted as face-to-face with 2 participants from associations and 22 participants in the form of web survey. Even though the survey reached many people (i.e., via e-mail to various related associations and via surveymonkey.com), and no personal identifiers were sought, few were willing to participate, therefore, evaluations were based on this limited number. Therefore, comments from 24 participants (5 with total blindness, 5 nearly blind, 1 very low sight, 12 low and 1 non-answered) were evaluated and discussed in this section. The survey consists of 10 questions as follows:

**Q1** Which of the following is your age range?
(a-15-24; b- 25-34; c- 35-44; d- 45 and above)
**Q2** What is your educational level and occupational status?
**Q3** Which of the following is your visual impairment level?

(a-Low; b-Very Low; c-Nearly Blind; d-Blind)

**Q4** Are design and aesthetic values in clothing important to you?

(a-Yes; b-No and comments)

**Q5** What are the factors that are important to you in the selection of clothes?

**Q6** In your daily life, what obstacles do you face in terms of clothing?

(During shopping, during use, etc.)

**Q7** Are there any methods you resort to in order to overcome these obstacles? If so, what are these methods?

**Q8** Do you have information about the assistive technologies that are designed or produced for individuals with visual impairment or blindness? Do you follow these innovations?

**Q9** Are there any assistive technologies (software, application, device, etc.) that you are currently using? If so, what are these?

**Q10** Would you like to use an assistive technology product in the clothing field? If you answered yes, what kind of assistive technology would you need, and for what purpose?

### *3.2. Survey Results*

The survey results indicated that all participants were able to independently manage their lives, carry out their professions and participate in social activities. However, they highlighted the main obstacles in daily life were caused by the social perception of "having a disability". Most problems they face are not due to the lack of sight, but social misperceptions and inadequate physical conditions, inaccessibility to open and close spaces, and the inadequate implementation of suitable designs. One participant claimed that even though creating spaces for disabilities is shown as a positive discrimination, it might lead to discrimination in other areas of life. Thus, he suggested that it would be more appropriate to create inclusive common spaces for all of society. Even though this is not within the scope of this research, this has been noted as one major complaint from the participants, where design can contribute to resolve such issues/problems. Similar complaints were outlined by other participants, such as the need to share public spaces equally, however, these were outside the scope of this project, therefore, were not included here in detail.

The first three questions of the survey consisted of information about the demographics and visual impairment level of the participants. According to the result of the first question, two participants are between the age of 18 and 24; six of them 25-34; eleven of them 35-44 and five of them are in the “45 and above” age category.

The question regarding educational level and occupational status, educational status was answered by 24 participants, revealing that two graduated from primary school, one is high school student, four graduated from vocational school, fifteen are either studying at university or have graduated with a bachelor’s degree and one has postgraduate degree (1 non-answered for educational level, but for job status). In addition, the occupation status was responded that it ranges from housewife to executive (one musician, one foreign trade expert, one academician, one retired, two teacher, one nurse, two civil servants, one housewife, one executive, one freelancer, one lawyer).

According to the total data of visual impairment level from 23 of all participants, the results include twelve low sighted, one very low sighted, five nearly blind, and five totally blind individuals (Figure 48).

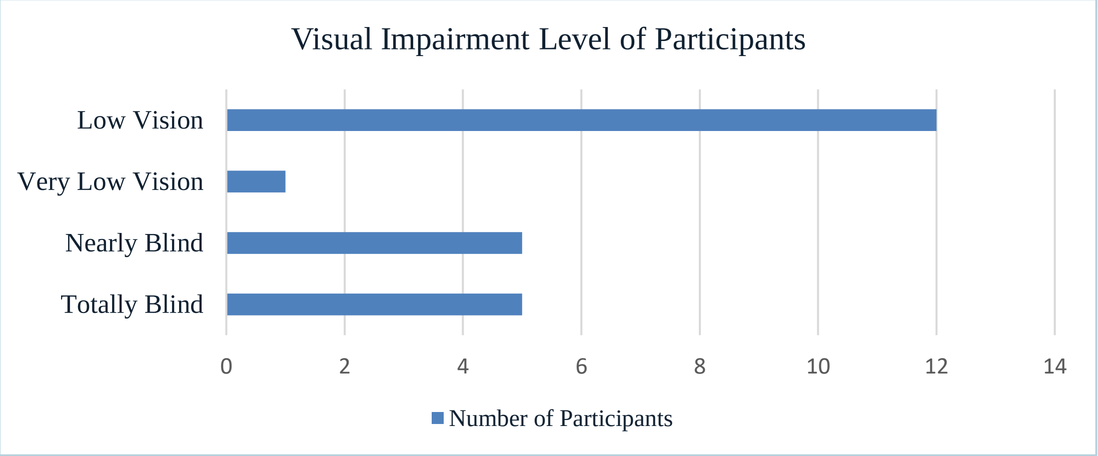


Figure 48. Visual Impairment Level of Participants

Following questions aimed to evaluate participants’ relationship with design and clothing, and to gain insight about the obstacles in this field as well as receiving their comments on ATs. Most of the survey participants agreed that the design and aesthetic values in clothing are important (Figure 49).

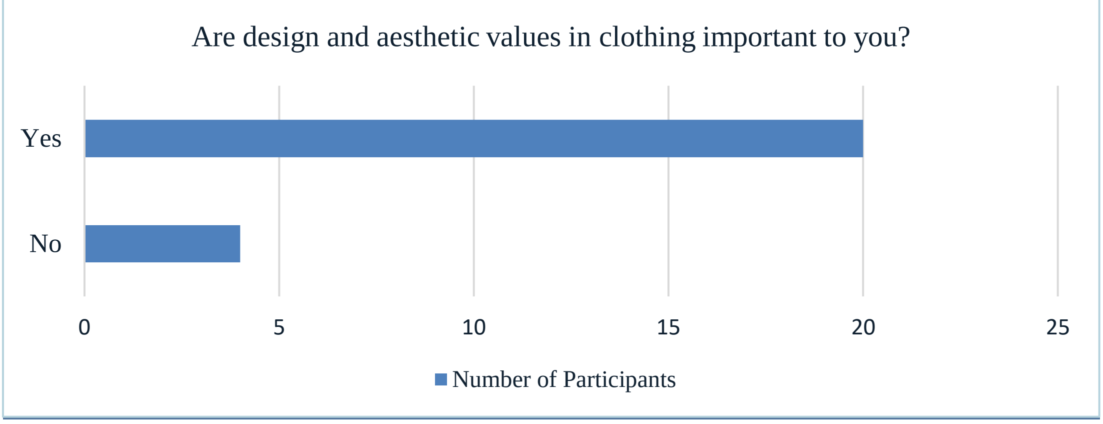


Figure 49. Responses for Design/ Aesthetic Values

Participants frequently stated that being visually impaired does not prevent them from taking part in social life, and that their priority in social settings is “appearance”. For this reason, one of them also noted that even if individuals with a visual impairment cannot see themselves, clothing must be appropriate for places and occasions for a good first impression and ensuring proper communication. When participants were asked about selecting clothing, they mentioned a variety of factors. In addition to garment related factors, such as quality, fiber content, price, fit, comfort and color, another factor mentioned by participants was a supportive shopping assistant. In addition, one participant commented that for her selection important factors were, first, the color harmony, and followed by fabric texture, ornaments, or decorations, which she sensed with her hands. She added that, as a personal opinion, for those who do not see, a visual image on the fabric alone does not mean anything without a pattern to detect and sense with hand. Besides, another participant remarked that, because she/he has a remembrance of color, and a sensitive touch, matching colors and matching materials by touching are two important factors in garment selection.

When considering obstacles faced by the participants in terms of clothing (during shopping, home use, etc.), one participant noted that for people with visual impairment, “clothing” is not just clothing one’s body, but is a rather long process starting with going to a store, choosing a product, combining, purchasing, and even continuing with caring/ washing the product according to the instructions given. Relatedly, one participant mentioned struggling with the washing process. The other answers are commonly about the problems in selection of colors, reaching the garment’s fabric, design, and price information. The same participant also argued that people whose blindness is not congenital can ask their family members, friends, or salesperson about the clothing/ product information, and can interpret this advice according to their own visual memories; however, people with congenital blindness have to rely on others' tastes and suggestions. On the other hand, one participant commented it was not always possible to trust salespeople, because sales-oriented person can mislead, or their design taste can be very different, adding "I don't know if a garment looks good on me. In daily life it is very difficult for me to adjust the color matching of my clothes by myself without anyone seeing." Another participant had a similar problem, in that when she/he goes shopping with a relative or friend, the most difficult and distressing occurrence is when they showed her/him the style that they themselves preferred. Thus, she/he experiences the most trouble in finding a garment in her/ his own style or what she/ he likes. The other person will often give various reasons for not liking it. The participant continued that just as sighted people can decide their own clothing by themselves according to their own style, people with visual impairments but who have not congenital vision loss should also be able to select their own style, or a service should be provided by a Professional (e.g. professional stylist, fashion designer etc.) in general.

Following on from the 6th question, in the 7th, participants were asked if they have any methods to overcome obstacles. Regarding this, one participant referred to LCW Sense application (given in Section 2.2.3), even though he had never tried it himself. On one hand, most of the participants noted that some just ask for the salesperson's opinion or go to shopping with friends/relatives for the help, especially for color combinations, while two participants try to read garment information and color info via their smartphone zoom application. On the other hand, one of the participants approached to the question in terms of the domestic use, i.e., she/he sorts clothes by colors - blue at the top and green at the bottom, but she/he doesn't find this method very effective because of the risk of confusion, which undermines self-confidence.

On the other hand, following the examination of participants' relationship with clothing, the last three questions were asked in order to examine their approaches to the AT/ WTs. Two of the participants stated that they have no idea about AT/WTs designed or produced for individuals with visual impairment or blindness, while another reported knowing a few examples but was not well informed on these technologies. However, most of the participants have knowledge about assistive technologies, follow the innovations and actively use them, especially the applications. Some participants commented as follows:

> “I'm very interested in technology. I follow the innovations closely, of course there are new works for us. We are also pleased with them, and we are expecting from the experts working on this subject, more productive, improving innovations for us.”,
> “Yes, I use technology. I like to use technology at every point which makes my job easier.”
> “I am actually interested in technology, but I do not know much about assistive technologies designed for disabled individuals. I've only heard of smart accessories being designed and manufactured on an increasing scale”.

Considering the comments of the participants, a more widespread information and outreach system should be established on assistive and wearable technologies and their uses. For active and technology conscious users, the designs of AT/ WTs should be updated with innovative approaches and a design-technology integrated understanding should be adopted in the production process of AT/ WTs.

In addition, most of the participants stated that they use smartphone including text reader and/or navigation applications. One participant gave as examples the TapTap See application and “Turkcell Hayal Ortağım” app that she/he used to reach information, such as reading books or newspaper columnists, watching films in the cinema, etc. Two other participants stated that they use Seeing AI app. The other one uses the Simpay application, Voice Over app on his/ her iPhone, and uses the phone library. However, only two participants mentioned any AT for clothing. These two participants indicated that they used only applications for identifying colors, and these were not always accurate, and do not work with nuances (Q9). Relatively, in the last question (Q10), it was asked whether they would like to use an assistive technology product in the clothing field, and what kind of assistive technology they would need. 20 participants answered “yes”, two participants answered “no” and two participants didn’t answer this question. Participants who said “yes” would most like to use an AT giving color, pattern, design and price information of a garment. Also, one participant would like to use an AT offering an easy-to-use identification for clothing items. Accordingly, some of the participants’ answers are as follows:

> “It is important for someone who is color blind to dress harmoniously. Fabric tones can be written on the labels so that they can know the colors and make the right combination.”
>
> “Yes I would. It is not an application that I use on my phone, but rather glasses, a camera, etc. that can help me read and distinguish colors. I would like to have a wearable technology product that I can carry on me”.
>
> “Yes. Maybe there could be an artificial intelligence-style application that tells every detail of the outfit”.
>
> “I would like to use applications that make labels easier to read and/or a smart, easily portable product-device that provides information about details about the product's features that I cannot easily see”.
>
> “Yes. It can be an audio device that tells the color of the clothes”.
>
> “My biggest problem is not being able to choose what size the clothes are, not being able to read the prices, and not being able to decide on the colors. I wish there was a technology for this”.
>
> “Of course, I would. For me, priority can be description of size, color, or even the entire outfit”.
>
> “Yes, it would be nice if there was a voice system that tells you the color, size, price and pattern”.
>
> “I never thought about this, but since we have the most trouble with colors, the color programs may be improved further, of course there will be different ideas. But I can't think of it right now”.

### *3.3. Evaluation of Results*

According to the comments obtained from the individuals with visual impairments, it was found that being visually impaired is not an obstacle to the importance of clothing and design values. It is emphasized that the appearance and the first impression are important in particular occasions such as a job interview or when entering a new social environment, etc. In addition, it was stated that people those whose blindness was not congenital, were able to ask their family members, friends or salespeople about their clothing/ product information and combine them according to their visual memory, but people with congenital blindness had to rely on the taste and suggestions of another person. They stated that this issue could be challenging both for themselves and the helper, and therefore they wanted to be able to carry out the shopping and clothing process independently as well as other daily living activities. The participants' approaches to overcoming obstacles, such as using technology applications like the LCW Sense app or seeking assistance from friends and family, underlines the potential for AT/ WT to enhance independence. However, the limited awareness of existing AT/ WTs for clothing-related tasks indicates a need for increased information spreading and education in this field. The participants' expressed interest in technology and their demands for innovations fitted to their needs emphasize the importance of a user-centred approach in the development of AT/ WTs.

The survey results support for a user-centred design approach that considers the entire lifecycle of clothing for individuals with visual impairments. Addressing challenges in garment selection, shopping, and clothing care requires collaborative efforts involving designers, technologists, and users themselves. The participants' openness to adopting assistive technologies for clothing-related tasks indicates an opportunity for innovation in this field. The findings call for an integrated approach that not only focuses on functional aspects but also considers the aesthetic and emotional dimensions, ultimately promoting independence, confidence, and a sense of personal style for individuals with visual impairments.

# CHAPTER 4: CONSTRUCTION OF SMART GLOVE

In Chapter 3 (Literature Review), the examples of the assistive and wearable technologies for navigation, communication and daily living activities were reviewed, so their utility and shortcomings were determined. Besides, innovative materials were discussed in terms of electronics, textile, and their integration. Moreover, above all, the user-centred design approach was examined both in order to evaluate these technologies and innovations from the user's perspective and to guide the design and production process of the wearable assistive technology product “Smart Glove”.

In this chapter, the construction of the Smart Glove is discussed under three subheadings. First, one is “Purpose of the Smart Glove” in which the reasons why “the glove” is chosen and the main idea of the Smart Glove are explained. The second part includes the “Creation of the User Scenarios”, where it is discussed how the user scenarios were constructed and how they guide the design and prototyping processes. Following, “Design Development” part includes design and development process of the glove itself, so material selection and design details were discussed.

## *4.1. Purpose of the Smart Glove*

The main goal of Smart Glove is to provide a versatile (e.g., defining the color, silhouette, details and pattern of the garment) wearable assistive technology product to address the problems of visually impaired individuals in the field of clothing. The primary reason for choosing the glove, which is a wearable assistive technology product, is the sense of touch used by visually impaired individuals to perceive their environment and objects. For this reason, the most used organ in daily living activities is the hand/ fingers. In addition, using hand is important to fulfil the hand-brain coordination and motor skills. Also, touching the garment provides an idea about the garment, the fabric and some details. However, there are insufficient points of touch alone and it is necessary to transfer information to visually impaired individuals through technology-supported projects in order to improve their quality of life. On the other hand, as seen with the survey outcomes and the review of AT/ WT examples, many of them exist for mobility, reading, and for getting the product information via barcode reading. In this regard, the number of mobile applications as a branch of ATs is increasing day by day, but it is not suitable for all applications to be installed on both iOS and Android. Besides, the operating speed of the application, the image quality (for image processing-based apps) and the accuracy of the information transmitted to the user may depend on the performance of the user’s mobile devices. Installing different apps for different purposes can slow down the mobile phones’ performance after a while, and they can shorten the battery life. These can be mentioned as the negative sides of the applications which can also be considered as reasons for choosing the glove for this purpose. Also, blind individuals rely heavily on mobile applications to obtain essential information such as current location, route planning, and navigation while traveling. However, accessing mobile phones while on the move can pose challenges and inconveniences. This process is notably slower for blind individuals compared to sighted individuals due to two primary factors as that blind individuals must allocate additional attention to their surroundings, and the use of a cane or guide dog occupies one of their hands, limiting their efficiency in operating mobile devices (Feng 2016).

Smart Glove which is an interdisciplinary project in terms of the joint work of design and engineering disciplines is important as a social responsibility project in order to increase the quality of life for visually impaired individuals. With Smart Glove, it is aimed to produce a prototype that will not be discriminating in society in terms of design and can be used comfortably by means of developing technological infrastructure, minimizing material weights and integrating technological materials with the gloves to be produced. Accordingly, the main idea of Smart Glove is based on taking photo of the garment with glove’s camera, and image processing. Thus, the glove informs the user about the garment’s details, and optionally offers combination alternatives for one of the selected occasions (e.g., casual, office and chic) and gives audio feedback to the user.

### *4.2. Creation of the User Scenarios*

Considering the obstacles faced by the people with visual impairment, in terms of clothing, it is noticed that “clothing” is not just clothing one’s body, but it is a rather long process starting with going to a store, choosing a product (identifying its color, model, pattern etc.), combining garments, purchasing, and with caring/ washing the product according to the given instructions. All of these are referred as the user scenarios. In order to create these scenarios, this study adopted user-centered design approach, which refers to a multidisciplinary approach based on understanding of user, and task required iteration of design and evaluation (Mao J. et al., 2005) as shown in the Table 3 for this study.

Table 3. User Needs, Requirements, Tasks, Limitations and Possible Barriers (Adapted from the study of Mao J., et al., 2005)

| USER’S | GLOVE ITSELF | SYSTEM |
|---|---|---|
| **Needs** | Comfort,<br>Aesthetic appearance | Define the garment and make combination suggestion |
| **Requirements** | Breathable fabric<br>Moisture management<br>Washability<br>Protection of electronics<br>Protection of skin | Quality image capture with camera<br>Correct classification<br>Conveying the product information to the user as audio output in an understandable manner |
| **Tasks** | Seamlessly knitting the glove<br>Using the proper yarn/ fabric | Micro/nano camera taking the picture of the garment<br>Microcontroller processing the info from camera<br>Via micro/ nano speaker, garment info is given to the user as audio output |
| **Limitations & Possible Barriers** | Size and comfort<br>Limited functionality<br>Learning curve<br>Cost | Accuracy and reliability<br>Limited feedback<br>Environmental limitations<br>Cost |

According to the Table 3., the first step is to determine what the user expects from the glove itself and the smart system to be developed, that is, its needs. It is a crucial aspect to be taken into account pertains to the ergonomic considerations of the smart glove. The design must prioritize the encapsulation of all electronic components, providing durability and support for selected elements, all the while ensuring optimal comfort for the user. Therefore, as the second step, the user's comfort and satisfaction with the wearable glove are main considerations. Furthermore, the solution must be lightweight and breathable, and also provide moisture management. It is priority that the wearable does not cause any harm or irritation to the user's skin. Additionally, the solution should not prevent the user's freedom of movement. Besides, the design should encompass all electronic components seamlessly, ensuring their effective integration within the glove.

In terms the system requirements, the camera is required to take the garment's picture in good quality. The camera, speaker and the battery must be connected to a microcontroller capable of processing its signals and have enough input/output pins. The control system should be configured to understand the user requirements, so it should make the correct garment classification. The microcontroller should not prevent the user in their free moves. Also, the micro speaker must convey the garment information in an understandable way.

On the other hand, it is important to note that as technology advances, some of these limitations and barriers may be eased or overcome. However, it is crucial to consider these factors when designing and implementing wearable and assistive devices for visually impaired individuals to ensure they are usable and effective. In terms of size and comfort, smart glove may not fit all hand sizes comfortably, which can be a significant barrier for individuals with larger or smaller hands. The discomfort caused by an ill-fitting glove can affect the user's ability to wear it for extended periods. It may also have limited functionality compared to other assistive devices. It is designed specifically for a certain task but lack versatility for a wide range of activities. Besides, operating a smart glove can require training and practice. Users may need to learn specific gestures, hand movements, or touch patterns to interact effectively with the glove's interface. This learning curve can be a barrier for some individuals, especially those who are not accustomed to using technology.

In terms of the system side, the accuracy and reliability of the smart glove's camera can be a limitation. There may be instances where the glove fails to detect or accurately identify the garment or put in the right classification. In addition, the absence or inaccuracy of auditory feedback can make it difficult for users to correctly interpret the information provided by the glove. Also, certain environments may interfere with the smart glove's performance. For instance, a colorful or messy background may affect the accuracy or reliability of the glove's sensors and functionality. And the last but maybe the most important barrier is the cost of the glove itself and the smart system. Some innovative approaches that will provide the comfort and aesthetic appearance of the glove and minimize the system hardware may make this product costly.

All points related to 'needs,' 'requirements,' 'tasks,' and 'limitations' mentioned above were taken into consideration in the '5. Testing the Smart Glove and Results' section. The explanation includes whether the produced smart glove prototype fulfilled these points or in which aspects it fell short. Considering the approach as shown in Table 3., the bidirectional user scenario in this part shows how users can act to achieve the goal of the smart glove, so the interaction with the smart glove in their daily life, specifically for the clothing process. The first scenario refers to in home usage (Figure 50) and the second scenario refers to the processes throughout shopping (Figure 51). For building up the user scenarios, initially, a user persona, which represents the stakeholders and their expectations (Reeder B. and Turner A. M., 2011) from the smart glove, was created based on one of the participants’ anonym types of information in the survey stated at the previous chapter. The name of the user persona of this study is defined as Denise who is 40 years old and has a bachelor’s degree. She works as a teacher. She gives importance to the design and aesthetic notion in her appearance in terms of social communication. She is nearly blind, and the most problematic point in home usage is not being able to perceive the colors of the garments and not being sure when combining them. In addition, she cannot trust salesperson every time, and desires to shop independently. Based on these scenarios smart glove concept is developed.

Starting from the Denise’s story, in the first scenario (Figure 50), when she is ready for dressing up, she puts on the glove, and picks up a top/ bottom piece from her wardrobe, lays it onto a flat and white/ grey backgrounded surface, and open up glove’s camera by switching the key on the glove. When it’s open, the glove gives audio feedback as “your device is open”, subsequently, if the garment is laid out on a table of average height, she reaches out the glove at chest level so that the garment can be seen from above, and the camera takes the picture of the garment with one short tap. The point that Denise should pay attention to here is that she should keep her hand as steady as possible and make sure that the environment is in daylight / brightness.

Subsequently, the image of the garment is processed, and the garment is defined with its main category (e.g. *top*– shirt/ blouse or *bottom*– pants/ skirt etc.), and subcategories (e.g. its silhouette, color, pattern etc.) by matching with the pre-defined dataset. If the system cannot classify the garment, it gives audio feedback. If she wants to continue with the combination suggestions, she can optionally follow one of the two directions (Figure 50). She can pick a piece from bottoms now if the previously defined piece is from top or vice versa. Again, she takes the picture of the garment via glove with one short tap, and after taking the picture, with two short taps she can ask which occasion the combination of these two pieces is suitable. The Smart Glove matches the top and bottom pieces with their pre-defined codes in the system and find this new code among the dataset of style combinations. Afterwards, the system gives feedback for a suitable occasion for this combination. On the other direction, she can demand a possible match with initially defined garment for her selected occasion. In this case, she should make three short taps for “casual look”, four short taps for “office look”, and “five short taps for “chic look”. The system can offer predefined general top 5 combination recommendations according to the selected garment category.

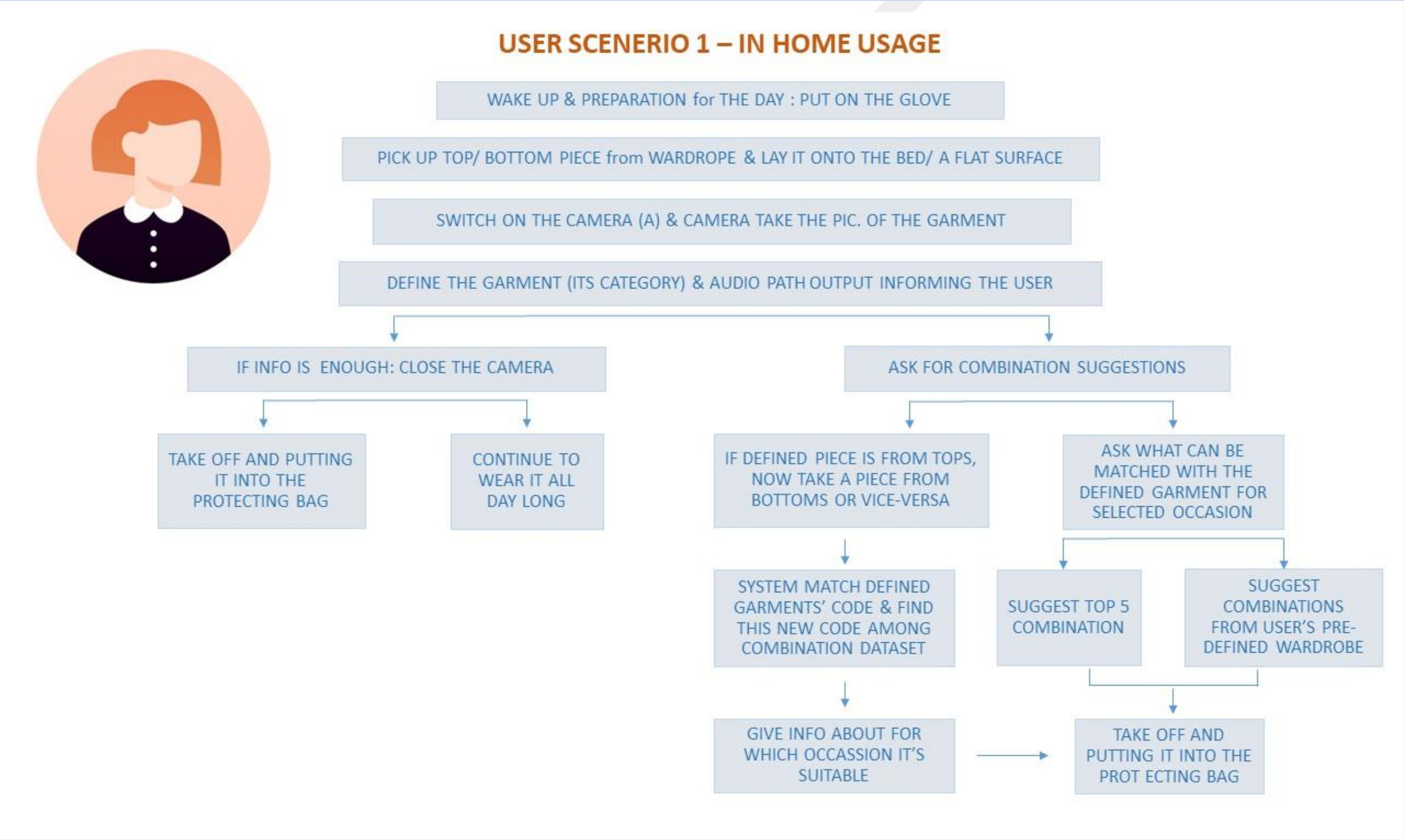


Figure 50. User Scenario 1: In Home

As another option, the Smart Glove can offer combinations by matching the garments in her own wardrobe. For instance, Denise selects a blouse from her wardrobe, and she asks with which trousers she can combine that blouse for an office wear. This time, the system offers combination suggestions specifically from her own wardrobe. In addition, the system learns the fashion taste of Denise and can give combination or garment suggestions accordingly, and in a customized way. This option requires working on advanced stage of deep learning method, so in this study, it is mentioned just as a concept, and it will be considered in detail in the further studies.

In the second -in shopping- scenario (Figure 51), Denise goes to a store for shopping, and she lays a garment onto a table in the store. She switches on the glove’s camera and follows the same steps as in the scenario 1 to identify the garment. After the glove recognizes the garment, she can ask for combination suggestions through similar procedures. Then according to the systems feedback, she can ask salesperson for the garments if they are available or not in the store. After all these scenarios, in the end of use, she closes the Smart Glove through the same way as in the opening, by switching the key. Besides, if the system stays open for 30 minutes, it automatically closes itself. In addition, it gives a sound warning when the battery is about to run out.

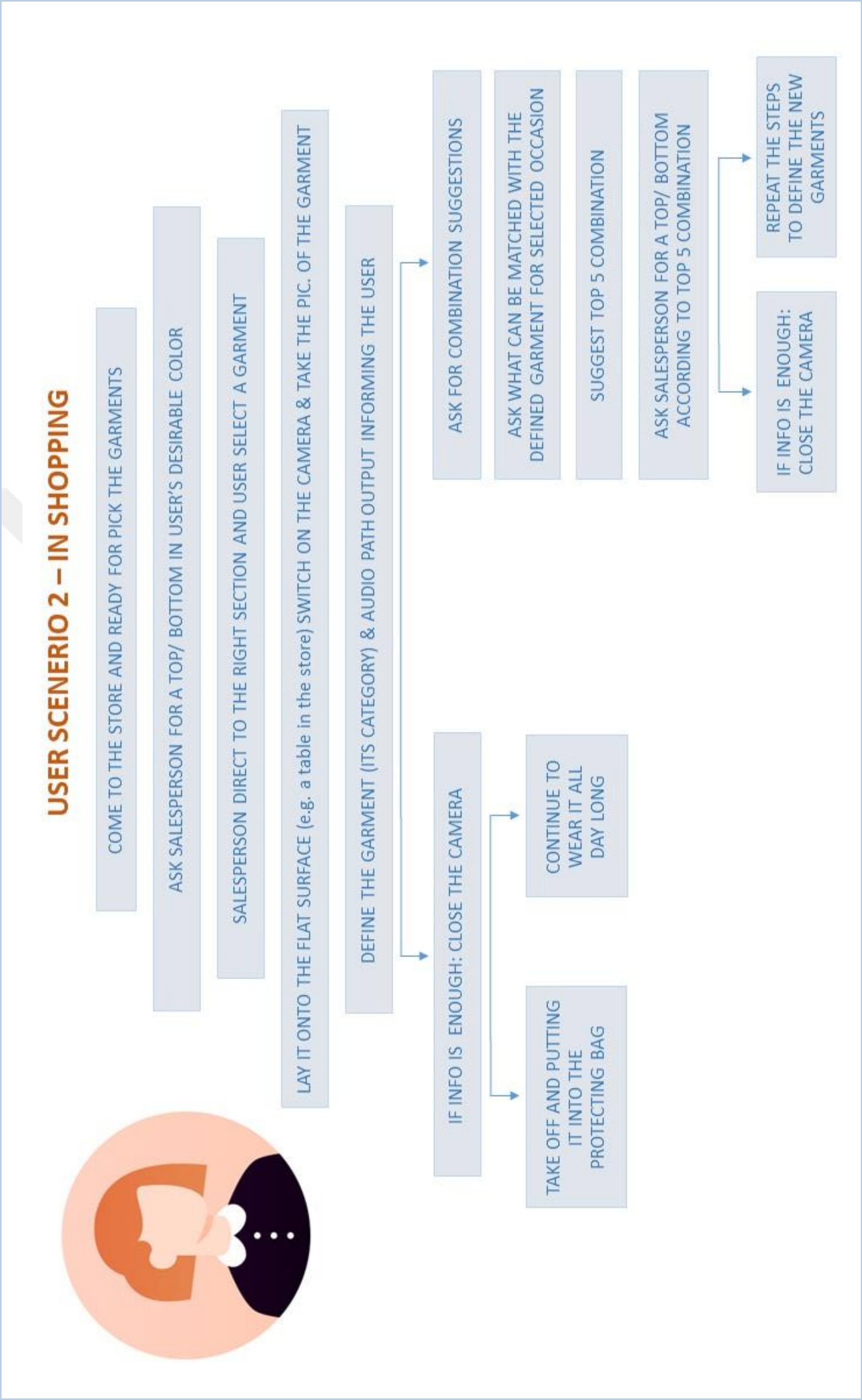


Figure 51. User Scenario 2: In Shopping

Based on user scenarios and learning paths, a user manual prepared in braille alphabet for the smart glove was printed. The user manual contains instructions for the entire process, from starting up the smart glove to closing it down. Accordingly, locations of the opening/ closing switch; the button to be pressed to take a photo of the garment and ask for combination suggestions; headphone and charging port were described. Additionally, information was given about feedback and waiting times, and instructions were included for the use of buttons.

### *4.3. Design Development*

Considering the “User Scenarios”, in this part, the design development details of Smart Glove are discussed. Before presenting the design processes of the glove, design considerations based on user experience notion are mentioned in terms of “pragmatic and hedonic qualities” and “performance requirements”. Following, electronic components used in the smart glove are introduced in terms of their technical features and their functions. Afterwards, the design details of the first glove, the design details of the second glove and the comparison of these two gloves regarding material and design are presented, respectively.

#### *4.3.1. Design Considerations of Smart Glove*

Before commencing the design and production of the glove, extensive research was conducted to determine how the glove would be handled in terms of user experience and to identify the necessary requirements it should meet. Therefore, the discussion of user experience has been made by diverse fields, leading to the various definitions within the literature. The most cited definition of user experience is provided by the International Organization for Standardization (ISO), which characterizes it as an individual's perceptions and reactions arising from the utilization or expected utilization of a product, system, or service. According to the ISO, “User experience covers a broad range of elements such as emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviours, and achievements that occur before, during, and after engaging with a product” (ISO, 2010). Besides, it has three main factors as user, design (product, system, service) and context of use (Bongard-Blanchy and Bouchard, 2022). Regarding this, Hassenzahl (2004) introduced a user experience evaluation model that comprises pragmatic and hedonic qualities.

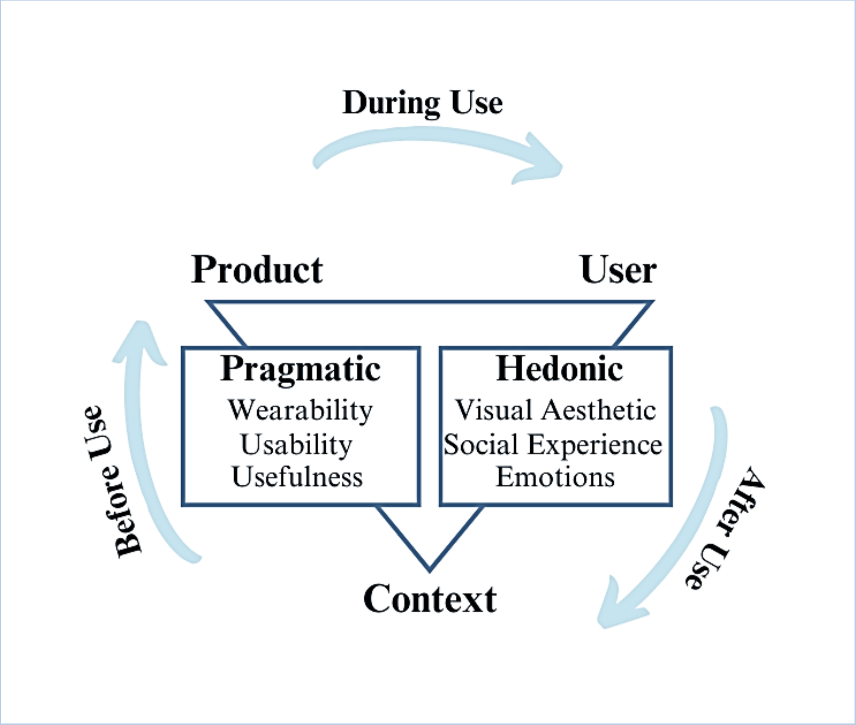


Figure 52. User-experience Framework of the Study (Adapted from the Study of Başkan and Goncu-Berk, 2022)

Pragmatic qualities involve features facilitating the product's functionality and usability, while hedonic quality focuses on features that draw positive emotional responses tied to the user's psychological state. Besides, based on the pragmatic and hedonic model, Başkan and Goncu-Berk (2022) outlined three pragmatic qualities (wearability, usability, and usefulness) and three hedonic qualities (visual aesthetic, social experience, and emotions) for wearable technologies (Figure 52). While pragmatic qualities include product-essential qualities such as thermal comfort, fit, ease of use, performance and understandability, hedonic qualities include user-related subjective elements such as perceived aesthetics, social experience and emotions.

Accordingly, pragmatic features were taken into consideration when designing smart gloves; and the specific set of performance requirements are determined as follows: functionality and connectivity, wearability, durability. Therefore, firstly, to determine functionality and connectivity elements, the questions that were answered in electronic components of the system towards the objective of the dissertation, are as follows:

- What types of electronic components are required?
- What type of camera is required?
- How many cameras are needed to capture image clearly?
- What type of microcontroller is required?
- What is the required power consumption for the system?
- Which types of power supplies are required?
- What is the most useful placement for those components?
- How the data will be processed, which types of signal processing units are required?
- What algorithms are needed to provide accuracy in processing data gathered by cameras?

Thus, the functionality and connectivity of the Smart Glove system required that it can detect and identify a garment with the attached camera and microcontroller unit. The glove camera should be able to connect to microcontroller units to compute the acquired data. On the other hand, wearability required that it be lightweight, breathable, conformable to the skin, comfortable to wear, and easy to assemble with electronic components.

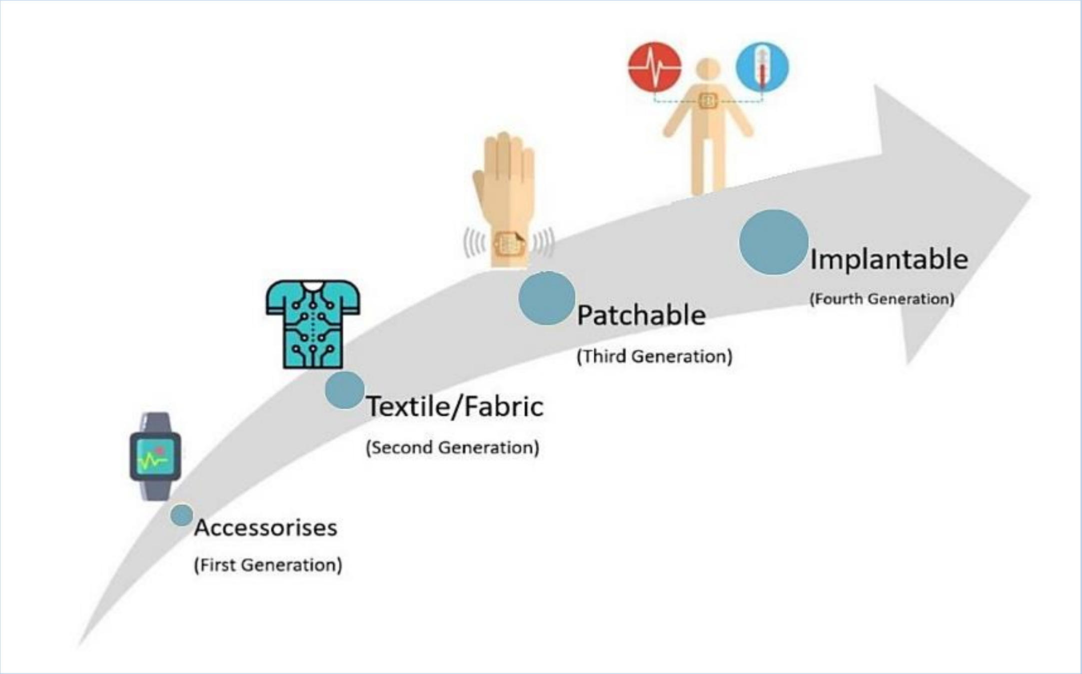


Figure 53. Types of Wearable Technology (Başkan and Goncu-Berk, 2022)

Wearable technology products can be placed on various parts of the body, depending on their functions and usage contexts. They come in different forms (Figure 53), including portable personal accessories like glasses and watches, mobile devices like pocket step trackers, smart clothing and textiles, and direct skin applications such as tattoos (Seneviratne et.al., 2017). Regarding the study by Başkan and Goncu-Berk (2022) on user experience that made a comparison between textile-based wearable product and accessory-based one, it was found that specifically the textile-based wearable technology provided more positive experiences in terms of wearability and related to fit, mobility, sensory adaptation, and thermal comfort compared to the accessory-based product. This finding is also one of the points guiding in the creation a textile-based wearable assistive technology product -Smart Glove- in this dissertation.

According to the Figure 53, the Smart Glove in this dissertation refers to the second-generation wearable technology product, so it presents a textile based wearable assistive product integrated with electronic components. The last critical requirement was the durability to endure repeated deformation due to use over-time. Thus the study aimed to achieve these design components by carefully selecting materials and employing suitable production techniques. In the following part, electronic components used in the glove and two different types of gloves are discussed in terms of the aspects mentioned above.

### *4.3.2. Electronic Components*

After the creation of the user scenarios and determining some design considerations, certain procedures were followed to construct the smart system. Considering the questions stated in previous part (4.3.1), first, the electronic components integrated with the glove were determined, and then the created data set was embedded into this system and processed to provide audio feedback to user. Accordingly, in this part, the technical characteristics of the electronic components used in the smart system and their functions in the system are stated; then, this part guided also the glove design process. The smart system construction involves the integration of several components to enable advanced functionalities. The hardware consists of three main parts as camera, processor, and feedback unit (Figure 54).

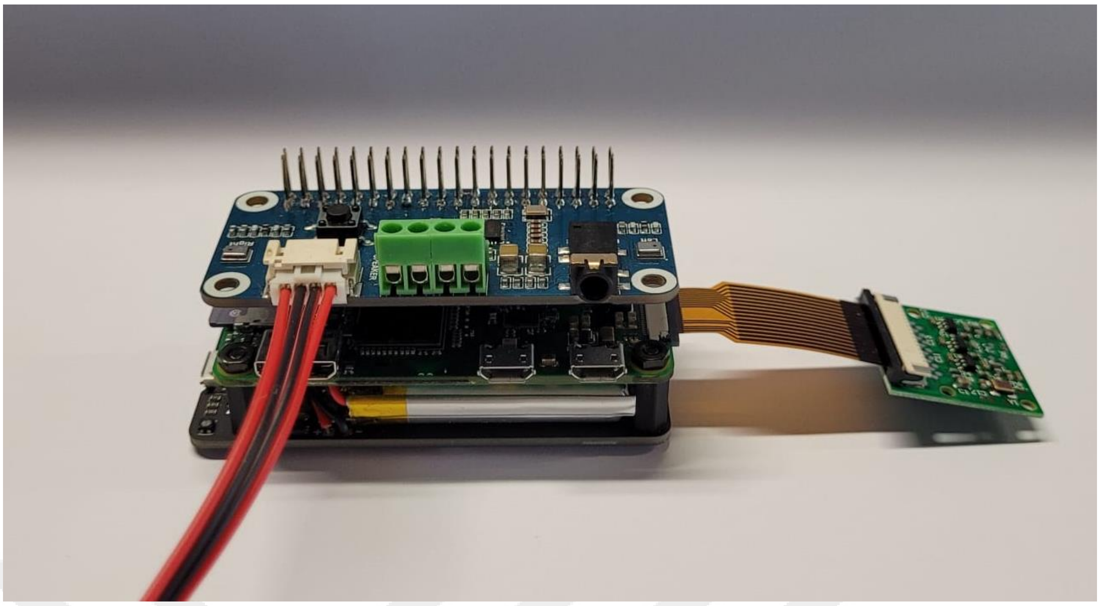


Figure 54. Electronic Components of the System

Accordingly, the technological/ technical items to be used and their dimensions are specified in the Table 4.

Table 4. Electronic Items of the Smart Glove

| Name of the Item | Intended Use | Dimension of Item |
|---|---|---|
| **MICRO CAMERA:**<br>Raspberry Pi Camera V1.3 | Visual data acquisition | 24 x 24.5 x 9mm |
| **PROCESSOR:**<br>RASPBERRY Pİ ZERO Zero Sets | Processing the obtained visual data | 65 x 30x 5mm |
| **SOUND CARD:**<br>WM8960 Audio Expansion Board Sound Card Module HAT | Getting sound over Raspberry Pi Zero | 65 x 30x 5mm |
| **BATTERY:**<br>Raspberry Pi Zero 0 W UPS power board | Power supply of Raspberryi Pi Zero | 70 x 30x 10mm |
| **MICRO SPEAKER:**<br>1 W Hoparlör | Transmission of audio feedback | 1.5 DIA |

**Camera:** One of the crucial elements in this setup is the Raspberry Pi micro camera, which serves as the visual input device. The camera captures high-resolution images, providing a comprehensive visual feed to the system.

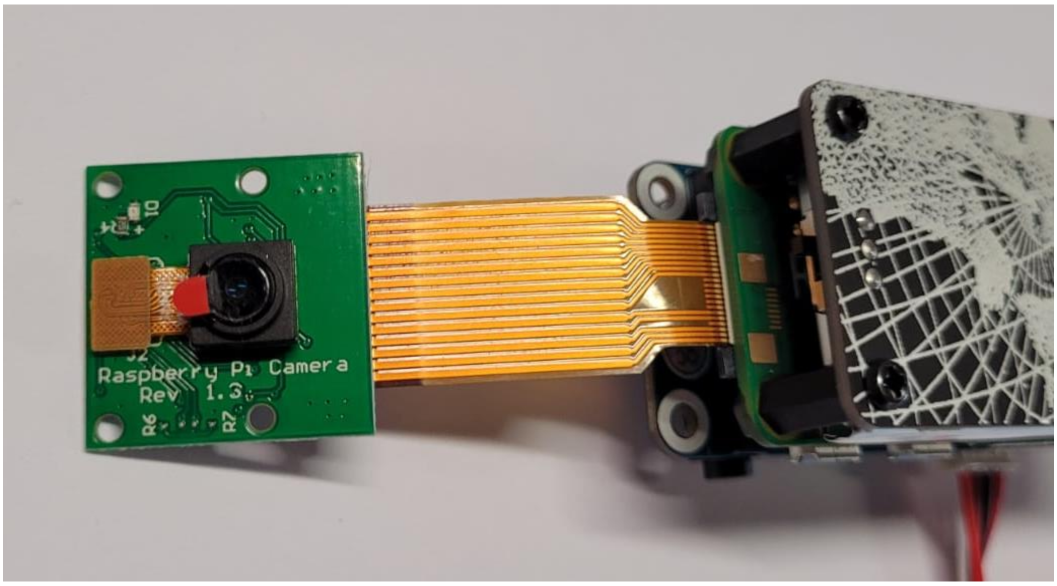


Figure 55. Raspberry Pi Camera V1.3

The Raspberry Pi Camera Board plugs directly into the CSI connector on the Raspberry Pi (Figure 55). It's able to deliver a 5MP resolution image, or 1080p HD video recording at 30fps. The Raspberry Pi Camera Board features a 5MP (2592 x 1944 pixels), OmniVision 5647 sensor in a fixed focus module. The module attaches to Raspberry Pi, by way of a 15 Pin Ribbon Cable, to the dedicated 15-pin MIPI Camera Serial Interface (CSI), which was designed especially for interfacing to cameras.

**Processor:** To process the captured visual data and perform advanced computations, the Raspberry Pi Zero processor is employed (Figure 56). This compact microcontroller is capable of handling complex algorithms and executing tasks efficiently. Its low energy consumption makes it an ideal choice for portable and battery-powered applications.

Figure 56. Raspberry Pi Zero Board

Pi Model Zero is equipped with 1 GHz Broadcom BCM2835 processor and 512 MB RAM. In the WH version, the GPIO connectors have been factory-produced using a 2.54 mm gold pin strip. The board of the minicomputer has been equipped with WiFi, Bluetooth, mini HDMI port, micro USB OTG slot, 40 GPIO and microSD card slot.

**Sound Card:** To enhance the audio capabilities of the system, the WM8960 Audio Expansion Board Sound Card Module HAT is utilized (Figure 57). This module provides high-quality audio input and output functionalities, enabling clear sound capture and playback. With built-in audio processing features, it provides the overall audio experience, ensuring crisp and immersive sound reproduction.

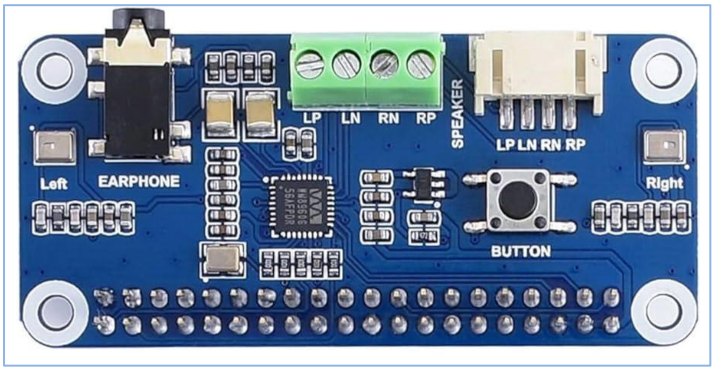


Figure 57. WM8960 Audio Expansion Board Sound Card Module HAT

Sound card HAT designed for Raspberry Pi, low power consumption, supports stereo encoding / decoding, features Hi-Fi playing / recording, and it can directly drive speakers. WM8960 Audio HAT with standard Raspberry Pi 40PIN GPIO extension header, supports Raspberry Pi series boards. Comes with development resources and manual (python demo code for playing / recording). onboard standard 3.5mm earphone jack, play music via external earphone; dual-channel speaker interface, directly drives speakers.

**Battery:** To power the Raspberry Pi Zero and its associated components, the Raspberry Pi Zero 0 W UPS power board is utilized (Figure 58).

Figure 58. Raspberry Pi Zero 0 W UPS power board

UPS-Lite is a UPS power board specially designed for Raspberry Pi Zero integrates serial port function (CP2104), fuel gauge chip (MAX17040G), and a 1000mAh polymer lithium battery (Figure 58). The installation method of the thimble is simple and generous. The actual test standby time is up to 6 hours (test condition: zero w turns on the network and prints the power parameter every 2 seconds). Its charging current: 400mA, and output voltage is 5V ±0.1V. Electricity measurement accuracy is ±2% error.

**Micro Speaker:** To ensure that the audio feedback is audible, a micro speaker is incorporated into the system. This small and portable speaker delivers clear and distinct audio, making it suitable for various applications such as notifications or audio feedback (Figure 59).

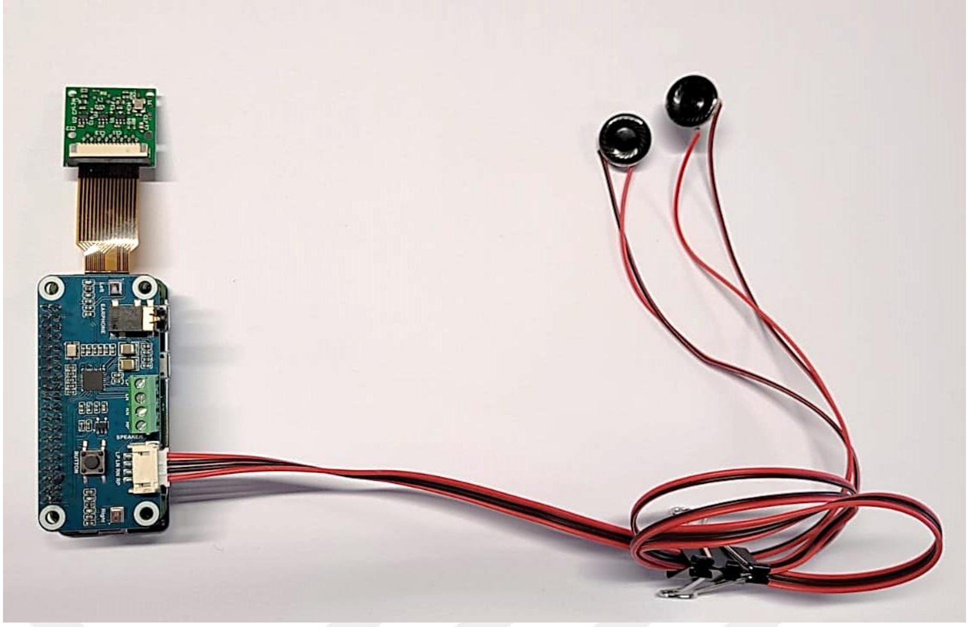


Figure 59. Micro Speakers

### 4.3.3. System Integration Scenario 1: Knitted Smart Glove

In the development of Smart Glove, considering the comfort, ease of use, washability, and flexibility, the first step was to decide the fabric/ yarn for the glove. The second step was to decide the placement of the electronic components in terms of hand-finger position. Following, in order to protect these components and to provide their integration easily, a textile-based cover was designed. Accordingly, 2D patterns and technical drawings of the Smart Glove- 1 and the cover were developed.

The smart glove is expected to be worn daily for at least one hour, so thermophysical comfort of the glove is important regarding wearability parameters. The comfort aspect is linked to the overall tactile characteristics of the hand, encompassing attributes like softness, smoothness, air permeability, moisture management and stretchability. The glove should provide physiological comfort and be breathable with soft cloth handle, so should eliminate overheating and sweating. Regarding those requirements, glove samples were knitted at the Textile Engineering Department at Ege University (İzmir/ Türkiye) for the Scenario 1, and textile material used in this scenario was selected based on the research mentioned in Section 2.4.2 (Textile Components). Thus, high-performance polyester based yarn “Coolmax ®” was selected, which is composed of rectangular cross-sectional shape of the fibres and can facilitate moisture diffusion and evaporation, ensuring a greater surface area for enhanced evaporation rates. Through its breathability, easy drying feature and easy evaporation of sweat, the body does not lose anything from its comfort due to sweating. Also, it is easy to care for and can be washed in the washing machine. Besides, for fitting, and shape retention ability, 70 Denier polyester multifilament yarn and Lycra were blended with Coolmax® (Figure 60).

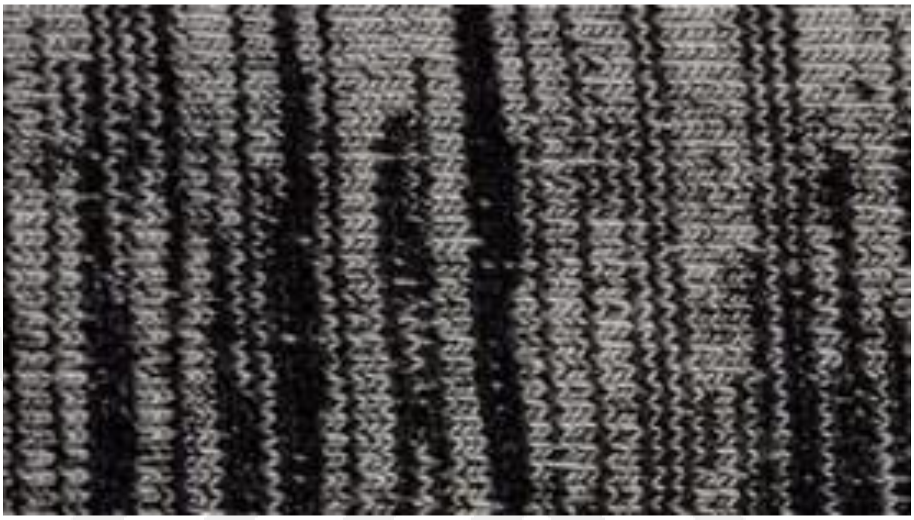


Figure 60. Fabric of Scenario1 Knitted Glove

On the other hand, strategically arranging the electronic components within the smart glove is a crucial step in its design. Besides, since touching is one of the most important senses in daily life of people with visual impairment, index finger and thumb should be left free. Therefore, answers were sought to the questions such as: (1) which area of the hand can capture the angle to take a photo of the garment from above, (2) which area has the space and stability to carry the processor, battery, and sound card together, and (3) which area has the position to hold the speakers closer to the ear to receive audio feedback. In a short summary as seen in the Figure 61, the palm region of the hand hosts the micro camera, while the inner part of the wrist accommodates the processor, battery, and sound card together. For optimal positioning, the micro speakers are placed on the inner left part of the wrist.

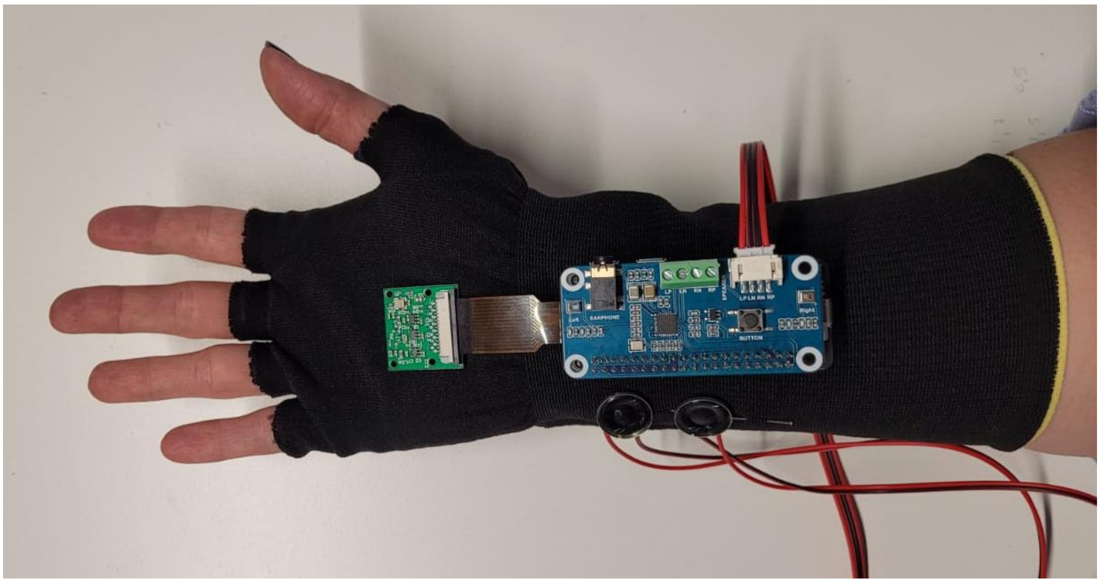


Figure 61. Placement of the Electronic Components

In detail, it was found that the best scenario is to use a single camera, and the camera position plays a big role in detecting clothes. It was taken into consideration that it should be placed in an area that would not restrict hand movement, would not hinder the sense of touch, and where the shooting angle could be well adjusted. Within this concept, there can be three alternative zones: middle finger, wrist part or palm of the hand (Figure 61). Considering the camera board dimensions mentioned in the previous electronic components part (2.4 x 2.45 x 0.9 cm), middle finger was not found suitable. Also, since the processor will be located on the wrist, as it is the largest area, and a certain connection distance must be left between the processor and the camera, this area has also been eliminated among the alternatives for positioning the camera. Therefore, to make comfort and provide the right angle, the most suitable placement was determined as palm area of the hand.

After the decision of camera's placement, the positions of microcontroller, power supplies and sound card were planned out. Due to the circuit and resistance constraints, microcontroller, power supplies and sound card should be placed as close as possible to each other. Thus, they were placed on top of each other (Figure 62).

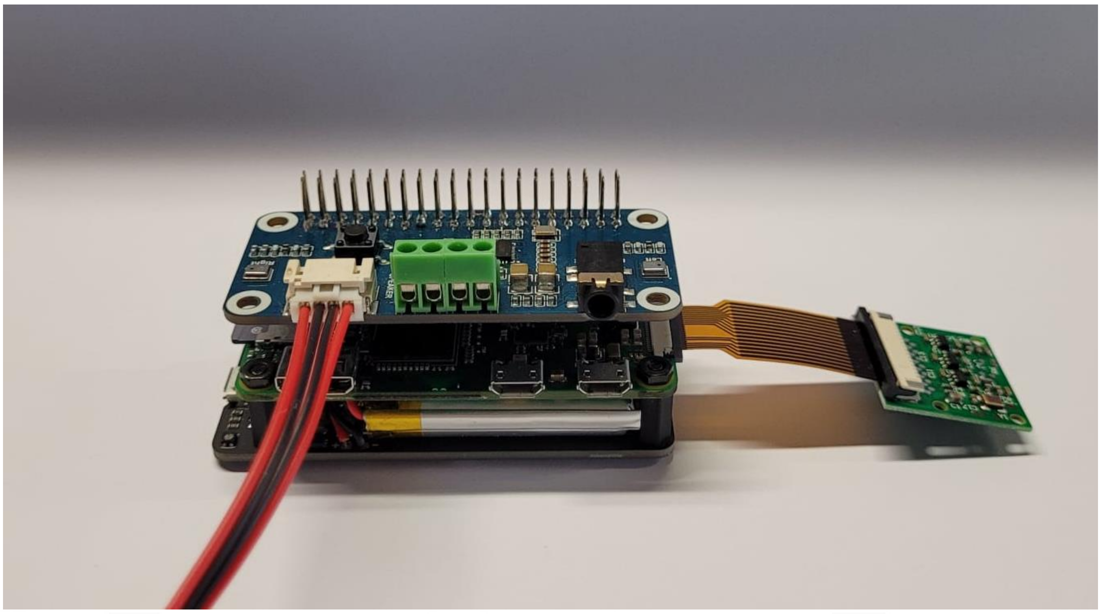


Figure 62. Multi-layered Electronics (Including Microcontroller Board, Sound Board, Battery Board, Micro Camera and Micro Speaker Cable)

When considered as a multi-layered kit and their total dimension, the most suitable area for this trio to be positioned on the glove was determined to be the wrist area. Also, in terms of aesthetic appearance, it is more appropriate to position this kit in the inner region of the wrist rather than the upper part.

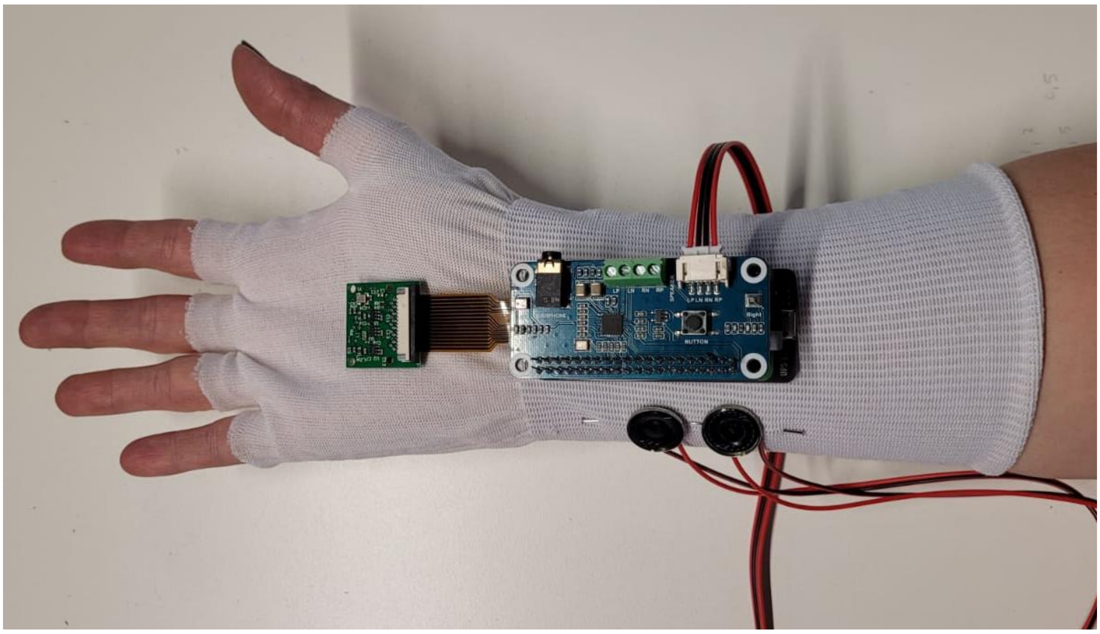


Figure 63. All Electronics and Speakers on a Sample Knitted Glove

As the last electronic component, micro speakers are placed inner left side of the wrist in terms of their plug-in and wires' positions, and, in this way they could also provide the optimum angle to be approached towards the ear (Figure 63). Once the position of the electronic components had been determined, it was time to decide how these components would be brought together with the glove. Accordingly, considering that the components used should not come into contact with water and that the glove should be washable, the electronic components must be integrated into the glove in a removable structure. Besides, the materials on the glove should be ensured that they are completely protected against external factors., and electronics should not meet skin for both safety and comfort. Therefore, firstly to ensure both durability and user-friendliness, a textile-based protective case was developed to encase all electronic components. This case allows for easy attachment and removal from the glove, minimizing the risk of damage. The following steps were followed while creating the protective cover:

- technical drawings of the electronic components were prepared, and their measurements were taken (Figure 64),
- 2D FABRIC patterns were developed according to the measurements taken,
- suitable fabric has been determined,
- laser cutting was applied to the fabric according to the patterns and the cover was sewn with plain stitching.

The further details of the process are given below.

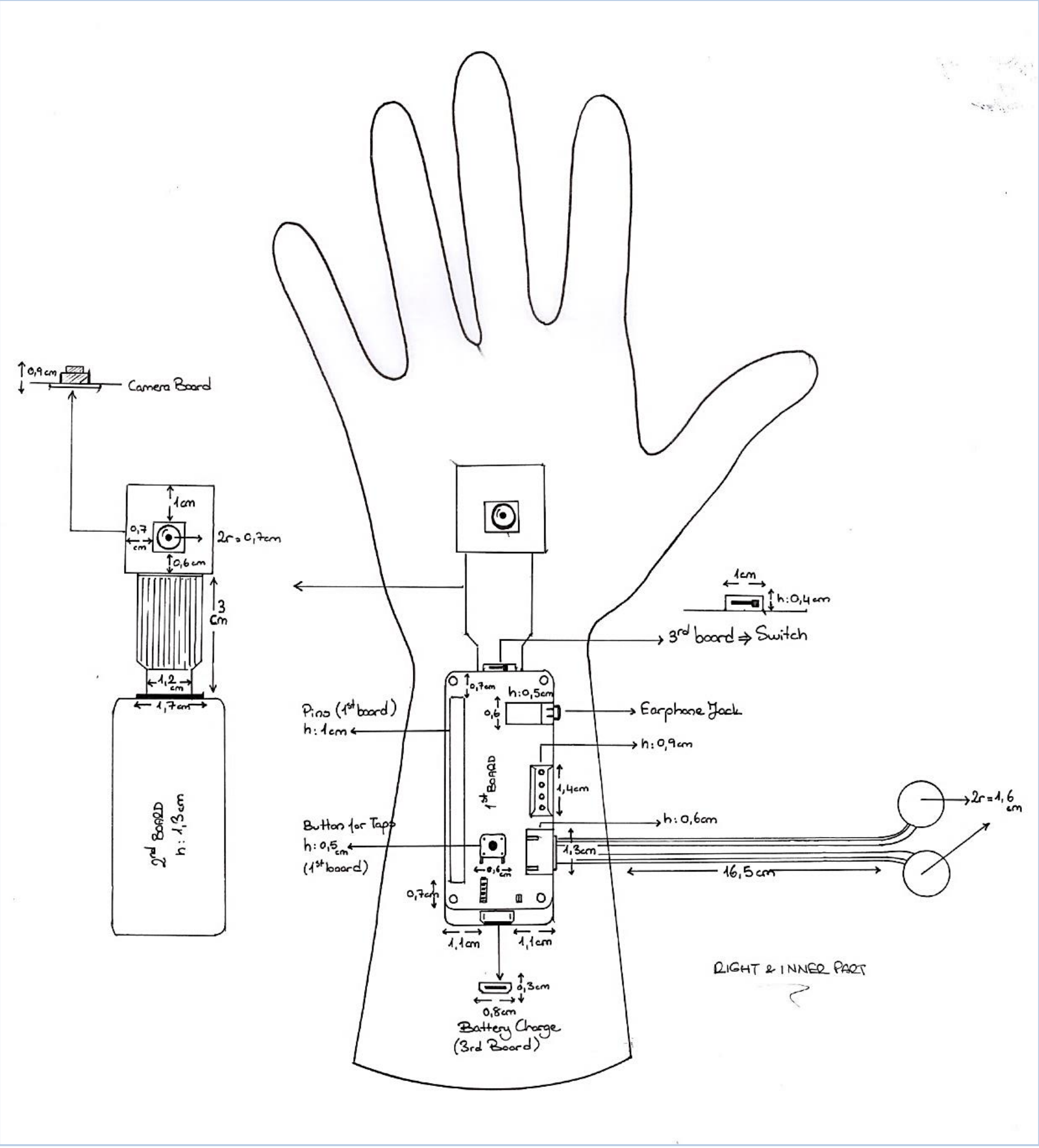


Figure 64. Measurements of the Electronic Components

**Step1:** In the first step, as seen in the Figure 64, electronic components were technically drawn with their measurements; the dimensions and positions of the areas that should be exposed on each board layer, such as the on/off switch, tap button camera input, speaker input, charging and microphone inputs, were determined.

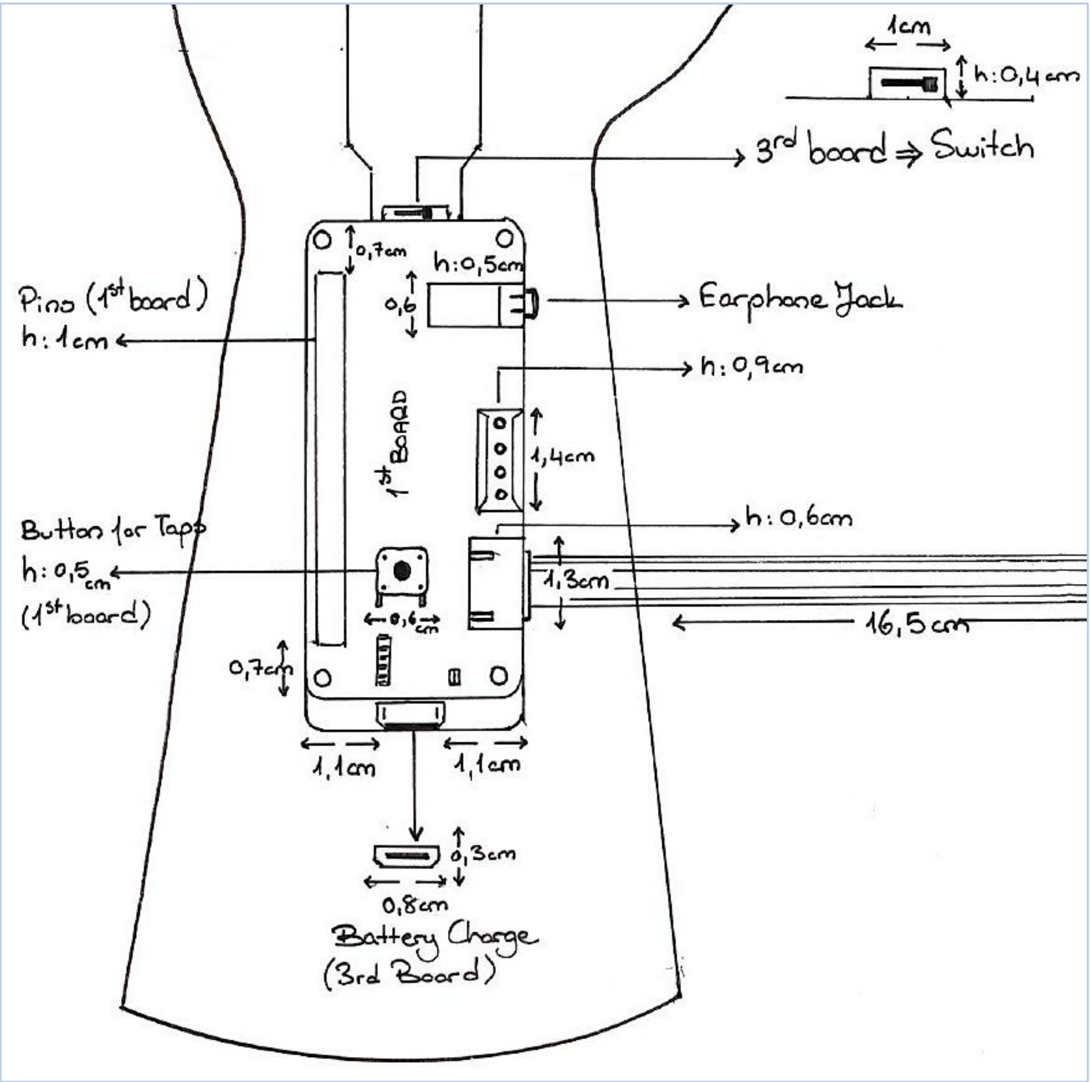


Figure 65. Measurements of the Camera & Camera Board

As shown in the Figure 65, the first, top layer is sound board (6.5 x 3 x 0.5 cm), including 1cm high pins (at left side of the board), 0.6 cm high speaker, 0.5 cm earphone connection and 0.9 cm high LP-LN-RN-RP port (at the same axis, right side of the board).

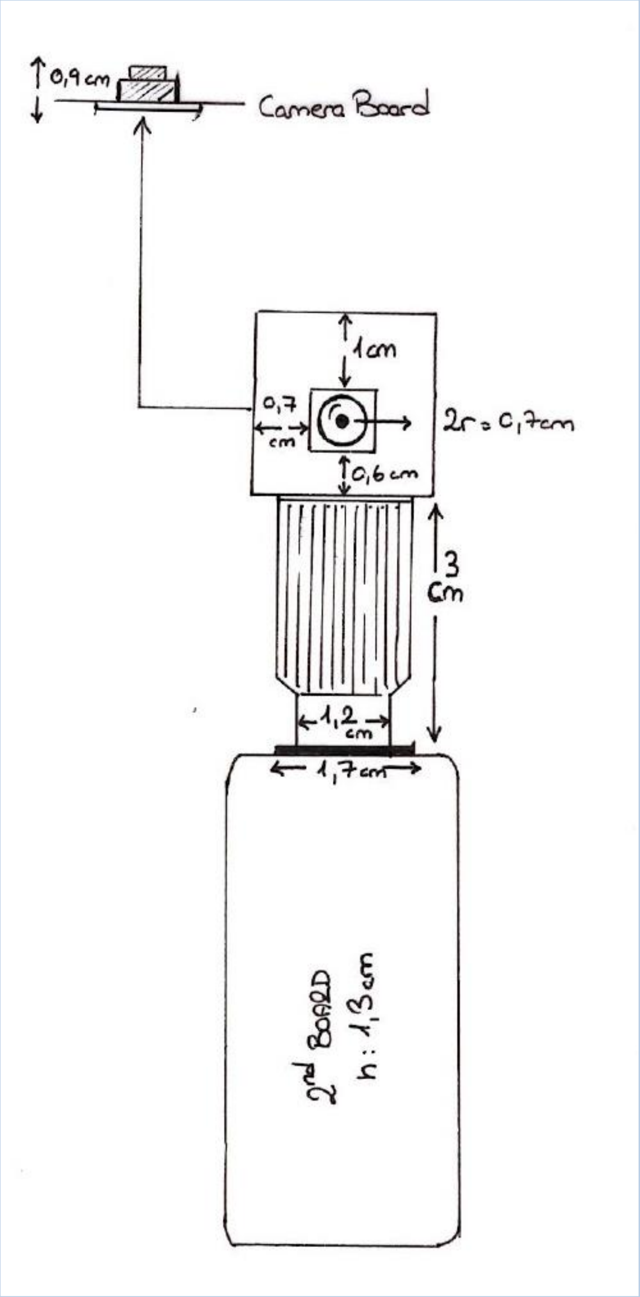


Figure 66. Measurements of the Camera & Camera Board

Then, the second, middle, layer is microcontroller board (6.5 x 3 x 0.5 cm) with camera connection part 1.7 x 0.1 cm. The last, 3rd board is the battery board (7 x 3 x 1cm) including the charging port with dimensions 0.8 x 0.3 cm, and 1 x 0.4 cm open/ close switch.

**Step 2:** In order to protect the camera board and the camera itself, first of all, the plastic cover that came from the Raspberry Pi Zero kit itself was reduced and reshaped according to the size of the camera board (Figure 67).

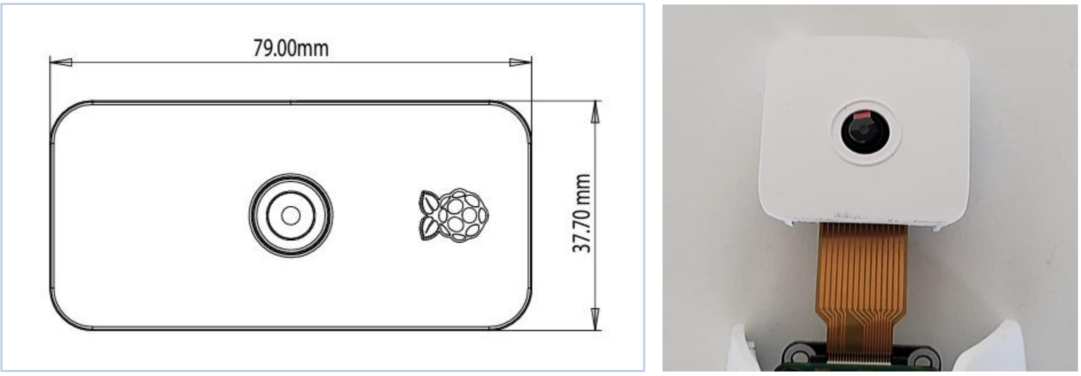


Figure 67. Modified Camera Case

**Step 3:** In addition, similarly the cases from the kit itself were used for the both side of the microcontroller-battery-sound boards (Figure 68). In this way, the pins on the boards were prevented from getting stuck in the fabric, the fabric was ensured to wrap around the board more smoothly, and a more solid structure was created.

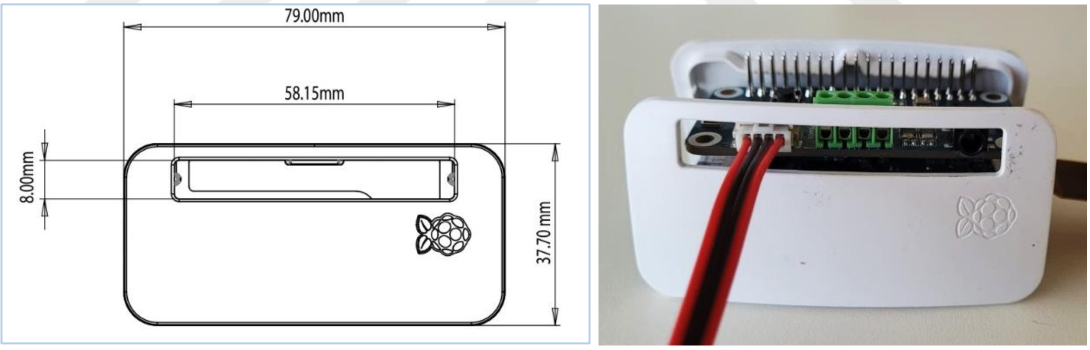


Figure 68. Raspberry Pi Zero Case

**Step 4:** Besides, regarding these measurements, pattern of the protective cover for both boards and camera was prepared (Figure 69). While preparing the cover pattern for boards, the area where the charging port, speaker and microphone inputs, camera connection and on/off switch are located were taken into account and considering their dimensions and placement, these areas were left exposed. In similar, the camera cover pattern was created to leave the camera lens exposed.

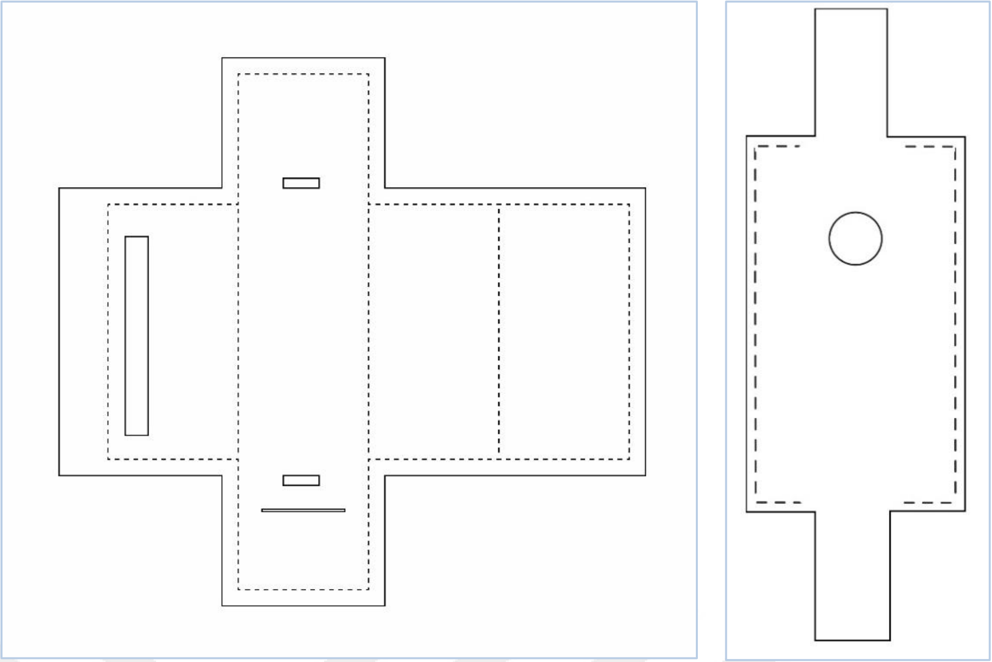


Figure 69. Protective Case 2D Pattern Development (Microcontroller & Camera)

**Step 5:** After pattern making, suitable fabric has been determined as neoprene fabric in terms of some advantageous features. The fabric is composed of 54% polyester 42% modal and 4% spandex, and its weight is 320g/m2. It is lightweight with smooth surface, but also, it’s durable, waterproof, and quick drying fabric. In the next step, as shown in the Figure 70, laser cutting was applied to the fabric according to the patterns made and the covers were sewn with plain stitching.

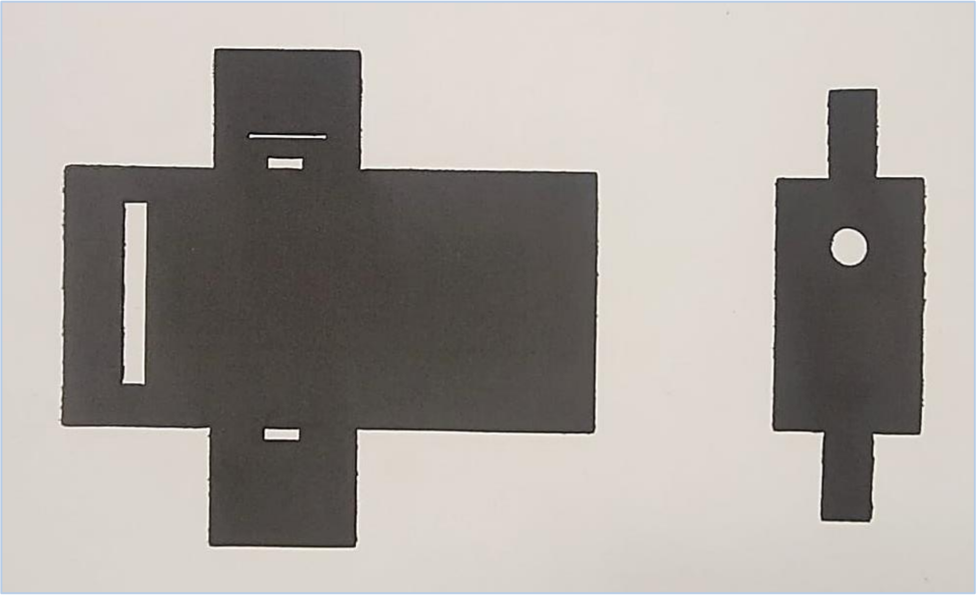


Figure 70. Lazer Cut for Boards and Camera Cases

Since the height of the taps button is less than the height of the pins and other outputs on the board, ornamental stitching has been placed on that part of the fabric to indicate the location of the button. Similarly, a protective cover was sewn for the speaker cables (Figure 71).

Figure 71. Sewn Protective Case

In order to obtain a flat and solid surface on the base part of the case, which corresponds to the wrist, but not to increase the weight, the base part was sewn as two layers of fabric with cardboard between them. Finally, to integrate electronic components with gloves; Velcro tape is sewn to the base and back of the camera part, so that the protective case can be attached/ detached to the glove.

After creating the protective cover, the next step was to design and manufacture the glove itself. In this process, first of all, the glove was knitted seamlessly at Ege University Textile Engineering Department (İzmir, Türkiye), based on standard women's hand sizes. Due to the characteristics of the knitting machine used, the glove was first knitted with all fingers, and then the structure of the glove was modified. After making changes to the basic part of the knitted glove, design ideas for the integration of the protective cover were conveyed by making a technical drawing of the glove (Figure 72).

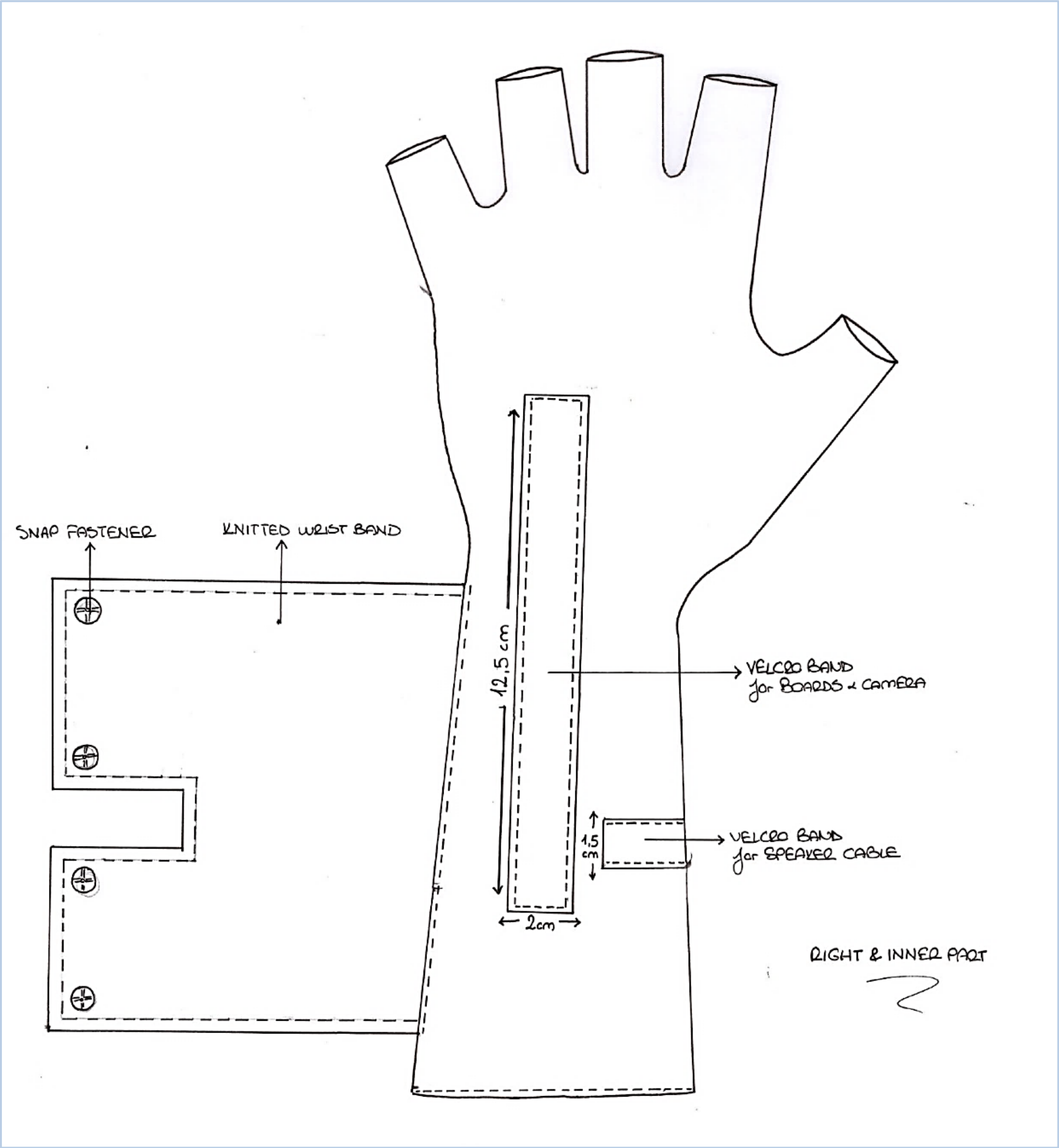


Figure 72. Technical Drawing of the Knitted Glove (Opened Wristband)

Accordingly, the area where the protective cover will be attached on the glove was determined (Figure 72) and Velcro tape was sewn to the wrist and palm parts of the glove.

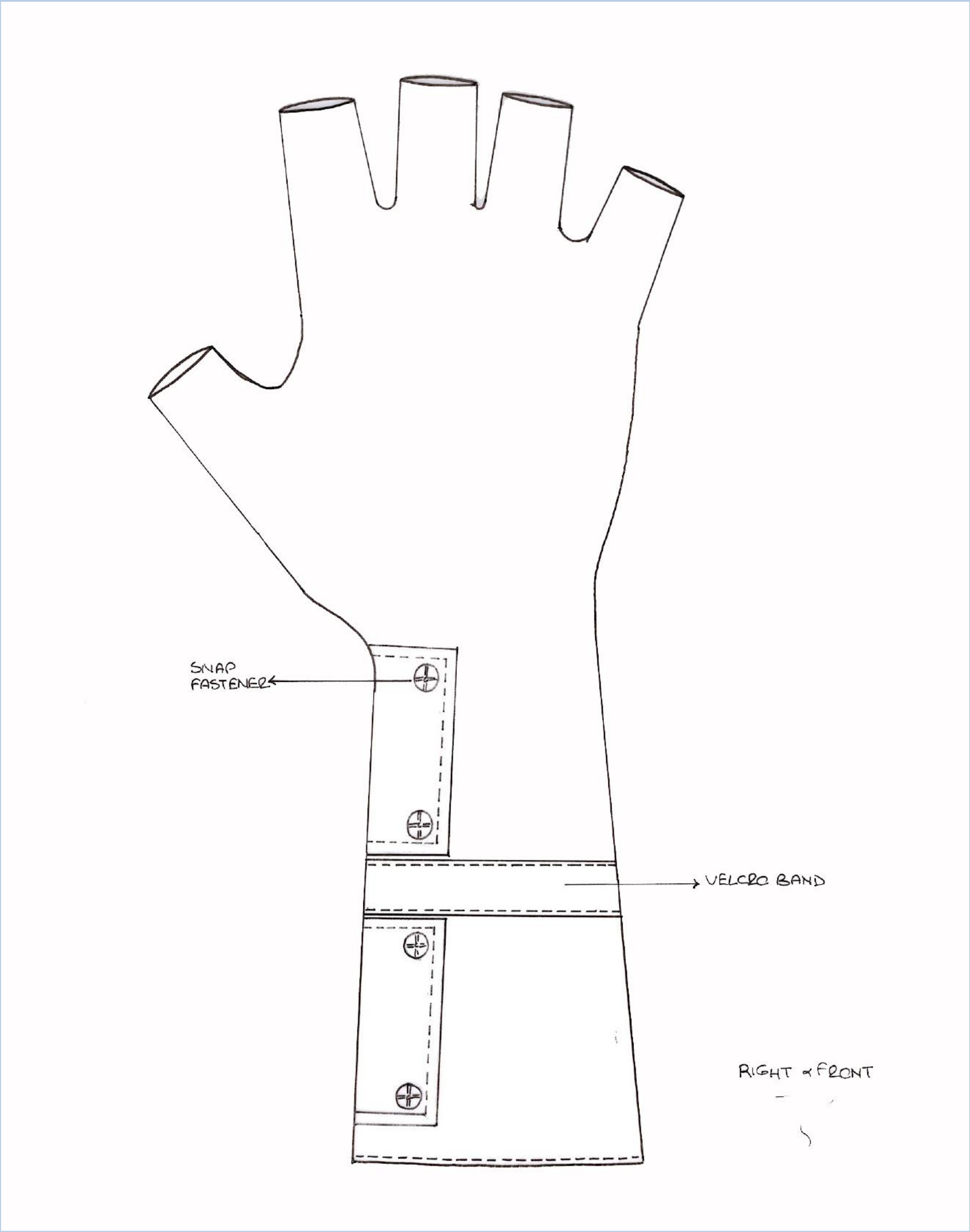


Figure 73. Technical Drawing of the Knitted Glove (Top View)

Taking into account the positioning of the speakers on the inner left part of the wrist, velcro tape was applied to the cable case and glove in the same way (Figure 72-73). At the same time, due to the multi-layered nature of the boards, resulting in increased height and weight, external support in the form of a knitted fabric band around the wrist (Figure 72) possess the necessary strength to support the electronics, and give more aesthetic appearance by covering the electronics.

Figure 74. Final Prototype of Knitted Smart Glove

Fig. 74 shows the final knitted smart glove prototype worn by author. The weight of the glove itself is 34g, whereas the final prototype including all electronic components is 134g. Knitted smart glove which enables to identify the garment and offer combination offers is easy to handle, light enough to put on and carry, and washable when removable parts are detached from the main structure.

### *4.3.4. System Integration Scenario 2: Patterned Fabric Smart Glove*

The development of a patterned fabric smart glove involves a multi-step process including preparing the patterns and combining each small section by sewing. For this scenario, since ready-made fabric is used, instead of yarn decision, fabric selection was realized for the glove. Neoprene, which is the same fabric as used in protective case was chosen for its lightweight (320g/m2 weight) and flexible nature, ensuring optimal comfort, and fit for users during wear. After choosing the suitable fabric, technical drawing of the glove was made to introduce design details (Figure 75 and 76).

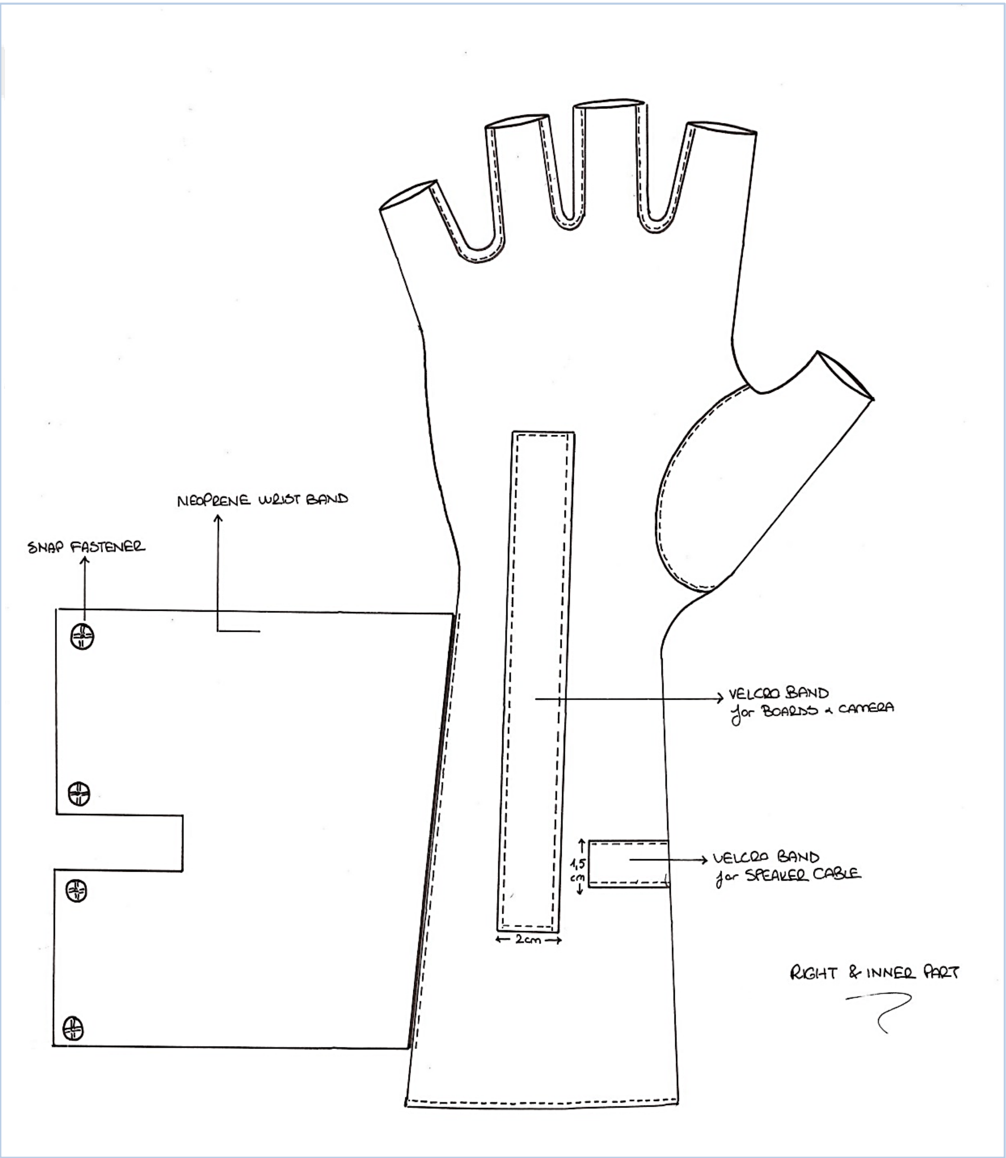


Figure 75. Technical Drawing of the Neoprene Glove Right & Inner Part

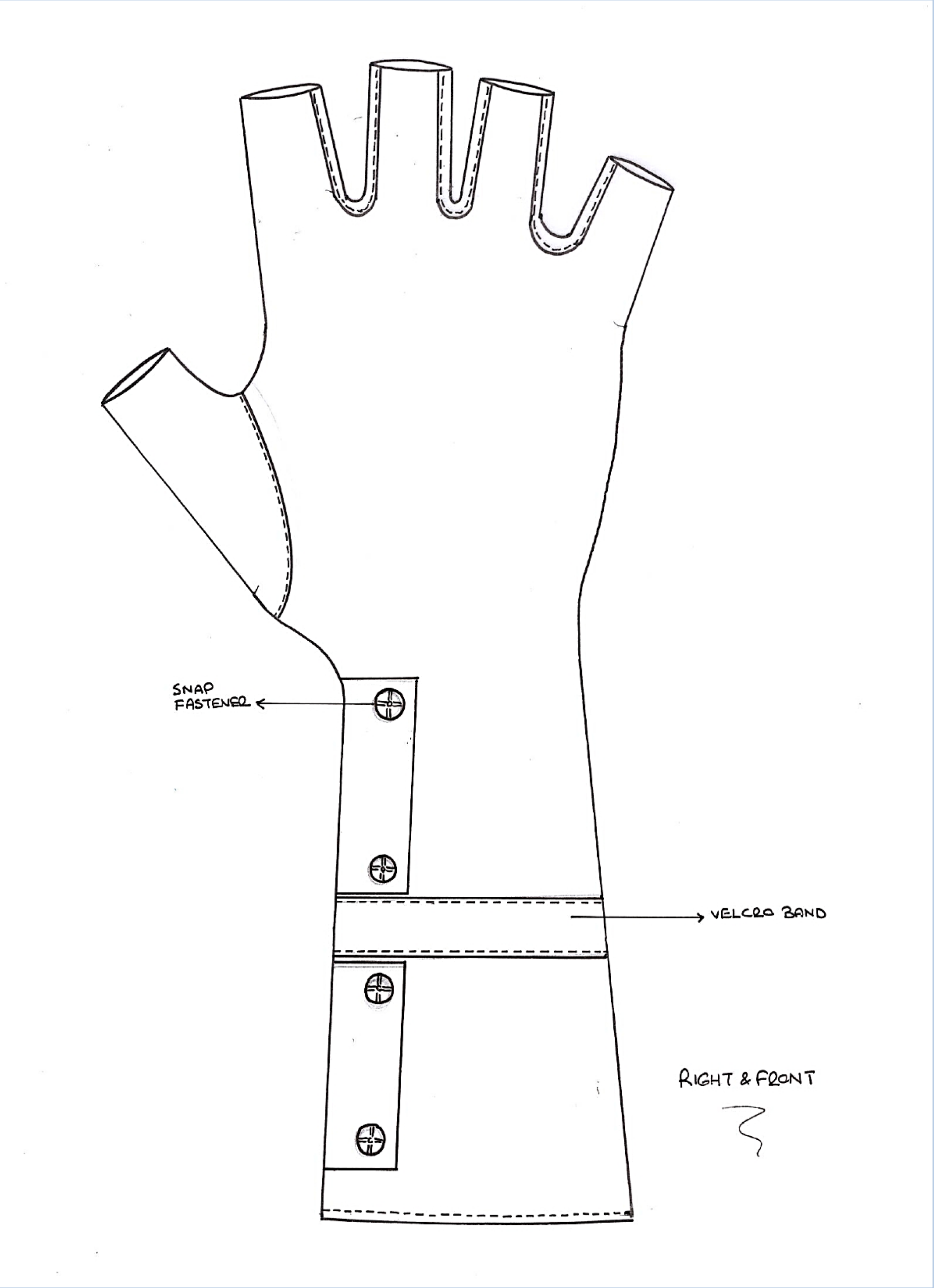


Figure 76. Technical Drawing of the Neoprene Glove Right & Front Part

Then the pattern of the glove was prepared based on a specific persons (the author’s) hand and finger measurements (Figure 77). 2D Patterns for the parts to be sewn on the basic hand, thumb and between fingers were prepared separately.

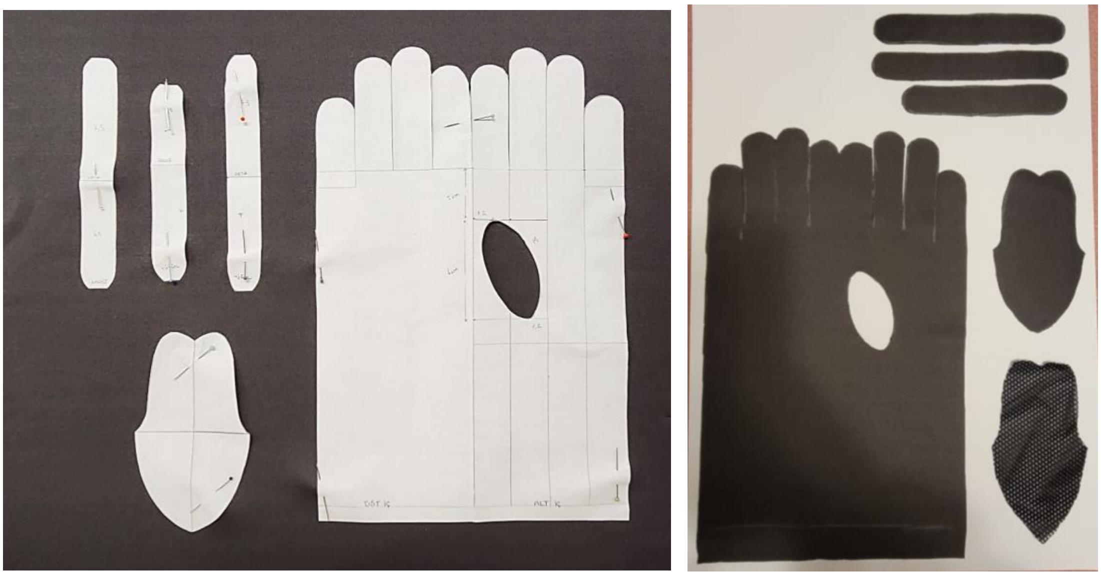


Figure 77. Pattern of the Neoprene Glove (Left: 2D Pattern, Right: Laser Cuts)

The fingertips were first sewn closed, then they were cut, and the ends were folded with adhesive interlining to obtain a clean finish. Just like the knitted glove, an additional piece of its own fabric was prepared and sewn on the wrist part of this glove to both support the electronic components and provide an aesthetic appearance. Again, just like the knitted glove, the electronic components, together with their protective cases, are attached to the glove with a velcro tape. Snaps were used to close the additional piece on the wrist. Fig. 78 shows the final Patterned Fabric Smart Glove prototype worn by the author.

Figure 78. Final Prototype of Neoprene Glove

The weight of the glove itself is 34g, whereas the final prototype including all electronic components is 134g. This neoprene smart glove is easy to handle as in knitted glove, light enough to put on and carry, and washable when removable parts are detached from the main structure as in the knitted glove.

### *4.3.5. Comparison of SIS1 and SIS2*

In this section, the two gloves whose design and prototype processes were mentioned above are compared, taking into account their pragmatic features (4.3.1). Advantages/disadvantages of both gloves have been determined from different perspectives as stated in the Figure 79.

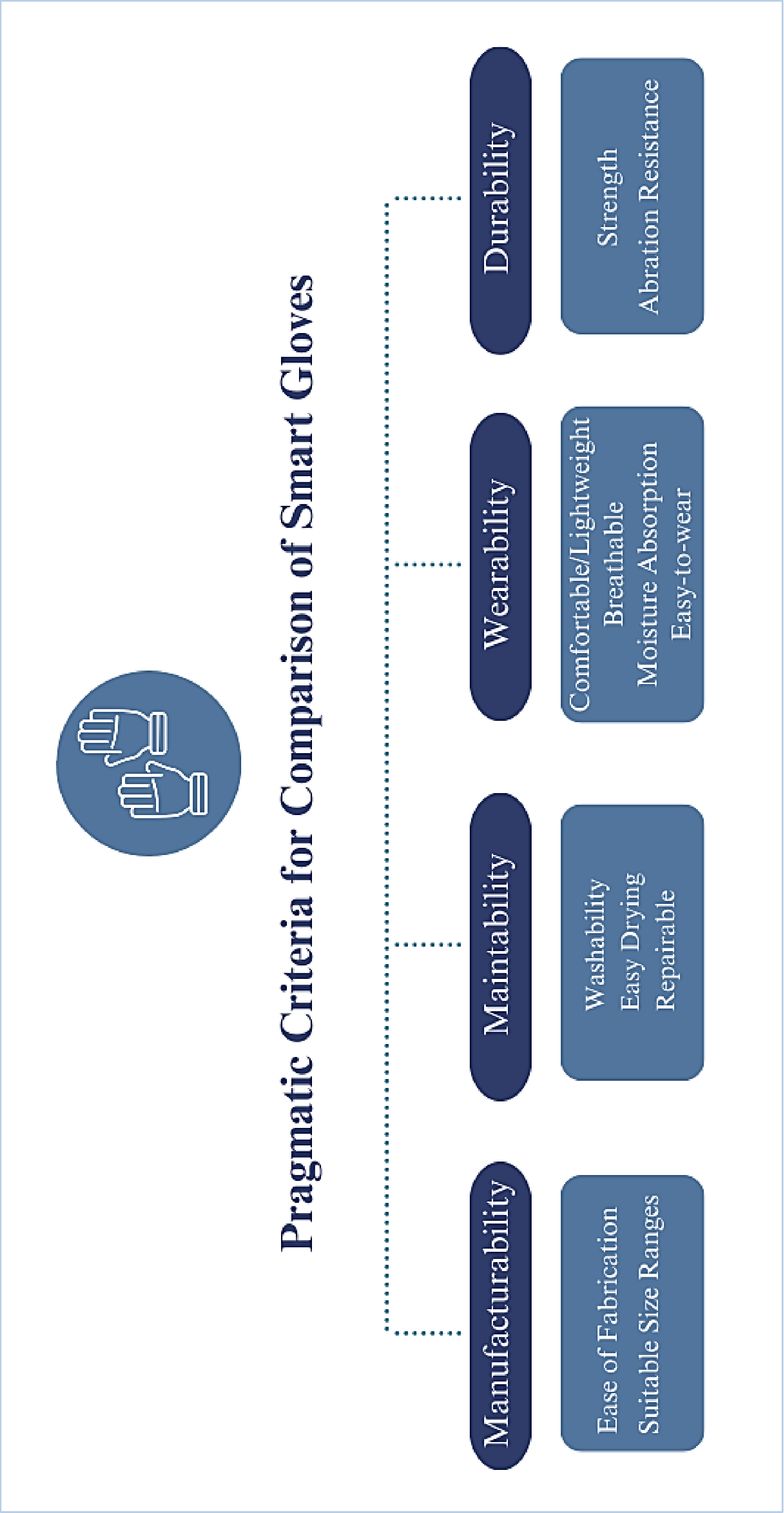


Figure 79. Pragmatic Criteria for Comparison of Smart Gloves

Accordingly, when examined in terms of manufacturability, which is the first of the pragmatic features, neoprene glove in this dissertation were simpler to manufacture due to the material being easy to cut and sew. Especially due to the structure of the fabric, it is very suitable for laser cutting and allows for a clean finish, so it does not curl or run away at the fingertips and wrist ends, as in knitted gloves. Regarding the size range, the base of both gloves can be produced accurately with the measurements given during the production stage. However, when considering the protective cover, laser cutting on neoprene fabric by preparing its pattern provided better results than applying it on a knitted fabric, since the connection points and cable entries must be left open millimetrically. Considering maintainability including washability, easy drying and repairable criteria, since the electronic components can be attached/ detached onto the glove, both gloves are washable. However, in the washing and drying test performed under the same conditions, it was determined that the neoprene glove dried faster.

Figure 80. SIS1 Knitted Glove and SIS2 Neoprene Sewn Glove

On the other hand, regarding wearability, it was seen that Coolmax yarns provide an advantage to knitted gloves compared to neoprene fabric in terms of thermal comfort as air permeability, moisture management. While neoprene is water-resistant, it may not be as breathable as knitted materials, but it has been determined that glove sewn with neoprene fabric perform better in terms of waterproofness, softness, and fit. In terms of lightness, both gloves measure equal weight.  Considering usability, both gloves have similar patterns and design details, so the usability and usefulness of both gloves can be said to be at a similar level. The last item is in terms of durability, neoprene glove is more durable in terms of strength with better abrasion resistance compared to knitted glove.

When these two gloves are compared considering hedonic qualities, the smoother surface appearance of the glove sewn with neoprene provides more advantages than the knitted glove, both in terms of aesthetics and the feeling it provides to the user's skin. A more detailed comparison in terms of hedonic features is included in the following 5.4. User Test section based on the feedback from the  users.

# CHAPTER 5: TESTING THE SMART GLOVE AND RESULTS

This chapter includes the stages and results of the testing process of the gloves designed and prototyped in the previous section. Accordingly, first of all, information is given about the data set for women's clothing, specially prepared for this study, in order to test the functionality of the smart system. Afterwards, the stages of embedding and processing this data set into the smart system are detailed. Finally, the methods and results of both system operability tests and usage tests emphasizing the user experience of smart gloves are presented.

## *5.1. Creation of the Dataset*

The first step of creating the smart system of the glove is the creation of dataset comprising (pre-defining) the main garment categories, their silhouette, color and pattern definitions. For this reason, a total of 5014 pieces of garment images/photos, 2570 pieces from the tops and 2444 pieces from the bottoms, were collected from the fashion brands' websites (i.e., both mainstream and luxury brands) and were classified based on some criteria explained in following part. Thus, the steps for garment identification were determined as follows.

- identification of basic garment categories
- identification of garment silhouettes and details for both tops and bottoms
- identification of primary and secondary colors
- Identification of frequently used patterns/ prints in ready-to-wear.

Therefore, garment classification is made on the two main categories as *tops* and *bottoms* at first, then these parts are subdivided as *shirts* (984 pcs.) or *blouses* (1622 pcs.) under the tops; and *pants* (928 pcs.) or *skirts* (1516 pcs.) under the bottoms according to their design details (Table 5).

Table 5. Garment Classification

| | CATEGORIES | COLLAR/ NECKLINE | SILHOUETTE | COLOR | PATTERN |
|---|---|---|---|---|---|
| TOPS<br>U<br>(2570 pieces) | 1.Shirt<br>(948 pieces) | 1. Attached Collar | 1.Fitted (Regular Fit)<br>2.Loose Fit (Oversize) | 1.Black<br>2.Grey<br>3.White<br>4.Brown<br>5.Red<br>6.Pink<br>7.Purple<br>8.Blue<br>9.Green<br>10.Yellow | 1.Plain<br>2.Circular (Floral & Leopard & Polka Dots etc.)<br>3.Linear (Stripe & Checked & Geometric etc.) |
| | 2.Blouse<br>(1622 pieces) | 1.V Neck<br>2.Round Neck | | | |

| | CATEGORIES | LEG TYPE | COLOR | PATTERN |
|---|---|---|---|---|
| BOTTOMS<br>A<br>(2444 Pieces) | 1.Pants<br>(928 pieces) | 1.Regular (Straight & Skinny & Tapered)<br>2.Wide Leg (Flared & Bootcut) | 1.Black<br>2.Grey<br>3.White<br>4.Brown<br>5.Red<br>6.Pink<br>7.Purple<br>8.Blue<br>9.Green<br>10.Yellow | 1.Plain<br>2.Circular (Floral & Leopard & Polka Dots etc.)<br>3.Linear (Stripe & Checked & Geometric etc.) |
| | | SILHOUETTE | | |
| | 2.Skirt<br>(1516 Pieces) | 1.Pleated<br>2. Fitted (Pencil Skirt)<br>3.A-Line (Flared) | | |

Relatedly, in order to identify the garment in detail, an uppercase for the main categories and number for each sub-category are given as referred in the Table 5. Considering, the Table 5, as seen in the Figure 81, for the main categories, tops are coded as starting with "U", and bottoms with "A". Besides, each garment in tops are tagged with five-digits code (e.g. **U1.**1.2.3.1 for shirt with attached collar, loose fit, white, plain shirt), while those in bottoms category are tagged with four-digits codes (e.g. **A2.**1.8.2 for a pleated skirt with blue color, circular pattern).

Figure 81. U1.1.2.3.1 and A2.1.8.2

After main categories, for tops, the classification continues with the *collar/ neckline* types (e.g., U1**.1.**2.3.1) that “attached collar” refers to all types of shirt collars, while “V neck” refers to v neck, plunging, surplice, sweetheart etc. types of necklines for blouses. Besides, “Round Neck” includes the boat neck, crew neck, keyhole, scoop neck and turtleneck for blouses category (Figure 82).

Figure 82. Neckline Types for Womens Tops

Following the collar/ neckline category, *silhouette* (e.g., U1.1**.2.**3.1) of the tops are determined as “fitted” also including regular fit and “loose fit” covering oversize too. In order to determination, some reference points on the shirts and blouses are selected and the visual samples are evaluated accordingly (Figure 81). If the shoulder measurement (A) is greater than the waistline (B) and the hemline (C) of the shirt/ blouse, it refers to “fitted”. On the other hand, if the hem of the shirt or blouse has a wavy or flowing appearance, it indicates a loose fit. Also, if the shoulder measurement (A) is narrower than the waist measurement, or if it is the same as the waist measurement but narrower than the hem measurement, the shirt/ blouse is “loose fit” including oversize (Figure 83).

Figure 83. Reference Points to Identify the Silhouette for Shirts

In the third category, the *colors* (e.g., U1.1.2**.3.**1) are identified; so as “primary colors” red, blue, and yellow; as “secondary colors” grey, brown, pink, purple, green; in addition to them “black and white colors” are selected mainly. Tertiary colors and the tones are included by these selected ones. Some of them are stated as follows:

- Red: rose, fire red, mars red, burgundy etc.
- Blue: denim, cobalt, turquoise, dark blue, midnight blue, sky, regal blue etc.
- Yellow: gold, neon yellow, sun, yellow-orange tones etc.
- Green: sage, olive, khaki, rainforest, kiwi, oak leaf, jade, mint etc.
- Brown: beige tones, camel, chestnut, copper, chocolate tones etc.
- Purple: lavender, lilac, orchid, plum, violet, grape, amethyst, eggplant etc.
- Pink: magenta, powder pink, bubblegum, fuchsia etc.
- White: optic white and light cream tones
- Grey: silver, smoke grey, iron etc.

After the identification of colors, the last digit code number refers to the *pattern/ print* (e.g. U1.1.2.3**.1**) of the garment. Thus, three main tags are used that the “plain” refers to non-printed or embroidered garments; “circular” includes all kinds of leopard, floral, dot and circular geometric prints or embroidery; as the third one, “linear” refers to stripes, checked, plaid, or linear geometric patterns (Figure 84).

Figure 84. U2.2.1.8**.1** & U2.2.1.8**.2** & U2.2.1.8**.3**

Following the classification of the tops, in terms of the bottoms first category is *pants* (**A1**.1.8.2) and *skirts* (**A2**.1.8.2), and the classification continues with *leg type* (for pants A1**.1.**8.2) or *silhouette* (for skirts A2**.1.**8.2). Leg types are divided in two which are “regular” including straight, skinny and tapered; and “wide leg” including all types of wide, flared and bootcut leg types (Figure 85).

Figure 85. **A1.1**.8.2 and **A1.2**.8.2

In terms of the skirts, this categorization is made as “pleated” (i.e. box pleat, accordion, hip pleat etc.), “fitted” (i.e. pencil, tulip, sarong, straight etc.), and “A-line” (i.e. flared, godet, semi-circular, circular, ruffle etc.). The *color* and *pattern/ print* categories are created the same as in the tops (Figure 84).

Figure 86. Classification of Skirts **A2.1.**8.2 & **A2.2.**8.2 and **A2.3.**8.2

In the wake of the product classification, a total 16226 combination recommendations for casual, office and chic occasions are created. In the creation of these recommendations, beside the acknowledge based on trend forecasts and analysis by WGSN company, regarding the color theory, some of the main concepts about the use of color in fashion have been advanced. For instance, these are the analogous colors, complementary colors, triadic colors, tonal and monochromatic (Figure 87).

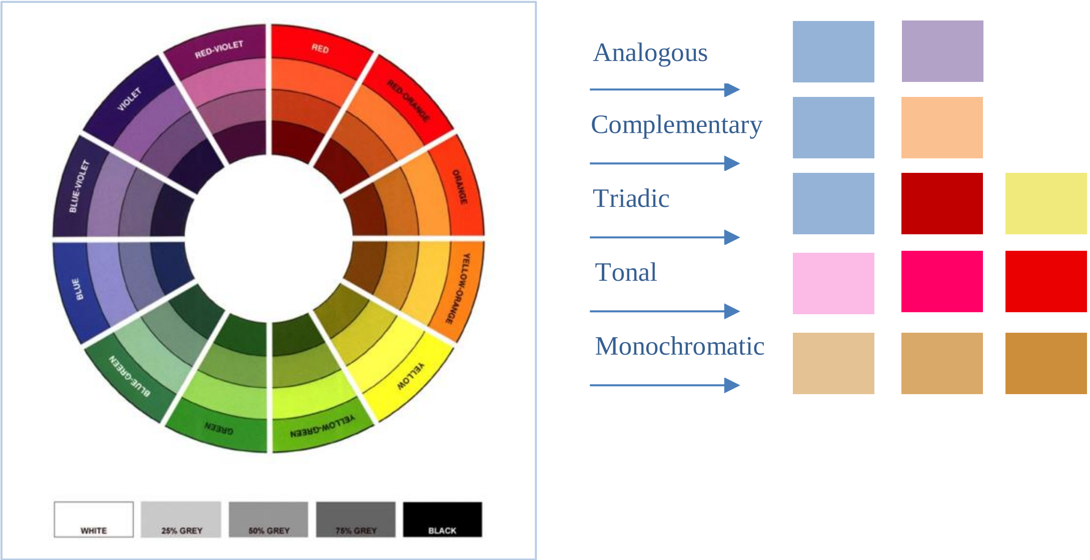


Figure 87. Color Wheel & Color Combinations

The first one, “*analogous colors*” are collocated in the color wheel. They are similar to each other such as pink and red; blue and purple; green and blue; orange and burgundy giving a cohesive feeling and soft gradation of color. Secondly, the “*complementary colors*” which are colors exactly opposite each other on the color wheel make a contrast when they are combined with each other. Thus, this content creates a remarkable look. For instance, yellow and purple; green and red; blue and orange; blue-green and red-violet can be given as examples. The third one is the “*triadic colors*” which are equidistant on the color wheel (e.g. orange, purple and green; red, yellow and blue), create a balance rather than a contrast when those three colors are used together. In the other concept, “*tonal*”, different shades of the same hue of a color are used together. For instance, pastel pink, magenta pink and bright red could be combined in an outfit. However, in this study pink and red colors are handled separately. The last one, “*monochromatic*” color scheme refers to use the same shade of a color, from head-to-toe, so it differs from the tonal at that point. The monochromatic look creates an elegant look and a body-lengthening effect (Figure 87).

On the other side, unity and harmony are important points in fashion and clothing, so when creating the combination offers, proportion, matching of colors and prints/ patterns are considered. Thus, in order to stay at the safety zone, if there is a pattern in top piece, the bottom piece is selected from the matching plain colored ones, and vice versa. In addition, the three main occasions are identified such as casual, office wear and chic wear, so the garments’ colors, prints/patterns and top & bottom matches are selected accordingly. For instance, while brighter colored or printed garments can be selected for casual occasion, for an office wear more naturel/ neutral-colored garments or black, white and blue colors are suitable. Besides, the recommendations are created through again the product codes, so the combination of the code of the top piece and the code of the bottom piece creates a new code that refers to the combination offer. For example, as seen in the first line of the Table 6, the code “A1.1.3.1.U1.1.2.8.3” is a new code that means the user can combine “pants with regular leg, white color, plain pattern and shirts with attached collar, loose fit, blue color and linear pattern for a casual occasion”.

Table 6. Example of the Garment Combination Table

| **BOTTOMS** | | | | **TOPS** | | | | | **OCASSION** |
|---|---|---|---|---|---|---|---|---|---|
| | L/ S | C | P | | C/ N | S | C | P | |
| A1 | 1 | 3 | 1 | U1 | 1 | 2 | 8 | 3 | **CASUAL** |
| A2 | 1 | 8 | 3 | U2 | 2 | 1 | 3 | 1 | |
| A1 | 1 | 1 | 1 | U1 | 1 | 2 | 3 | 3 | **OFFICE** |
| A2 | 2 | 1 | 1 | U2 | 1 | 2 | 1 | 2 | |
| A1 | 2 | 3 | 2 | U1 | 1 | 2 | 5 | 1 | **CHIC** |
| A2 | 3 | 1 | 2 | U2 | 1 | 1 | 3 | 1 | |

Based on the combination table (Table 6), below are examples of the lines of code marked in the table. Accordingly, the first images are the combination created for casual wear (Figure 88), the second example is for office wear (Figure 89), and the last combination recommendation is given as an example for the chic occasion (Figure 90).

Figure 88. Combination Codes for Casual Occasion (A1.1.3.1.U1.1.2.8.3)

Figure 89. Combination Codes for Office Occasion (A1.1.1.1.U1.1.2.3.3)

Figure 90. Combination Codes for Chich Occasion (A2.3.1.2.U2.1.1.3.1)

Therefore, the working principle of the smart system in terms of using the dataset is that firstly the system processes the garment’s image, which is take a photo, and considering its features, matches the garment with dataset; then it classifies the garment via the codes and inform the user. Also, optionally, it can offer combination recommendations through the combined codes of top and bottom pieces.

### *5.2. Data Processing*

After the creation of the data set specifically for this study (i.e. 5.1. Creation of the Dataset), the layered structure of the model architecture is designed. The smart system has been created with the necessary technical components, based on image processing and object recognition, to inform the user about the garment photoshoot through the glove. Accordingly, training the model for classification of the garments' data requires several steps including pre-processing, data transfer and data processing.

In the data processing, various computing layers are involved, but wearable and IoT devices often perform minor filtering processes due to limited computational and storage resources. Early "pre-processing" is crucial for these devices to manage data efficiently, as they lack the capacity to process unnecessary information. The collected data often contain errors, duplicates, and inconsistencies, necessitating preparation before processing, whether locally or in the Cloud. This involves filtering, structuring, cleaning, and validating the data to enhance its quality. Efficient data preparation reduces processing time and ensures better decision-making. Thus, in data preparation representative data were gathered, cleaned, and validated to identify and address quality issues like duplicates, outliers, and missing values. Techniques such as removing missing values, eliminating outliers, and merging duplicate data were applied to enhance data quality.

Following the pre-processed "data transfer" phase is an essential part of the wearable device data chain that includes encryption level, coding and transmission schemes, modulation, and cyclic prefix, which are also individually defined depending on the used technology. The most commonly used data transmission technologies in wearables include Near Field Communication (NFC), Bluetooth Low Energy (BLE), Wireless Fidelity (Wi-Fi), ZigBee, Low- Power Wide Area Network (protocols) (LPWAN), and other cellular or non-cellular IoT transmission technologies (Ometov et.al. 2021), that in this dissertation Wi-Fi was used in data transmission.

In the "data processing" phase, a variety of methods are used to extract meaningful insights from input data. This involves the extensive application of machine learning (ML) techniques such as clustering, regression, and classification, which can be executed through batch processing, real-time processing, and online processing. Specialized ML techniques are essential for building predictive models, but pre-processing steps are equally vital for achieving desired outcomes. Architecturally, models like Convolutional Neural Network (CNN), Long Short-Term Memory (LSTM), Bidirectional Long Short-Term Memory (BLSTM), Multilayer Perceptron (MLP), and Gated Recurrent Units (GRU) play significant roles in the processing and analysis of data. In this dissertation, the deep learning algorithms were used in image processing to success and to solve complex image processing problems. In order to take an input image and separate various views or objects in the image, Convolutional Neural Network (CNN) as a type of Artificial Neural Network (ANN) that basically consists of two main parts, feature learning and classification was applied. It was mainly used for classifying images, clustering by similarity, and object identification.

The pre-processing step begins with image is obtained by pressing the button in the WM8960 Audio Card. After that Raspberry Pi Zero W sends the obtained image to the computer using Wi-Fi and “ssh” command. Then the image is classified using an algorithm that consists of 7 different models that are trained to classify different aspects of the clothing item in the image. After that, the classification results are overwritten to a .txt file which is then sent back to the Raspberry Pi Zero W. During this time Raspberry Pi Zero waits for 15 seconds and reads the .txt file that is updated during the waiting period. Once the training was complete, the model was tested with different images per class. Considering the large number of classes that are asked to classify, a 7-model structure is implemented where there are 7 models that classify different aspects of the input image. All these models utilize the TensorFlow library and consist of Deep Learning models with varying depts, epoch numbers and batch sizes. TensorFlow 2.0 has been chosen as the machine learning library because TensorFlow has been updated recently and has good documentation support, so the model was converted to TensorFlow Lite format allowing the TensorFlow library to be run on arm processor, Raspberry Pi Zero to perform real-time tests.

- **Model 1 (Main Categories):** Classifies the images into 4 categories namely: Shirt, Blouse, Pants and Skirt.
- **Model 2 (Neck Types):** Classifies the images into 2 categories namely: V Neck and Round Neck.

- **Model 3 (Leg Types for Pants):** Classifies the images into 2 categories namely: Regular and Wide Leg.
- **Model 4 (Silhouette for Skirts):** Classifies the images into 3 categories namely: Pleated, Fitted and A-line.
- **Model 5 (Silhouette for Tops):** Classifies the images into 2 categories namely: Fitted and Loose Fit.
- **Model 6 (Color):** Classifies the images into 10 categories according to their color and this model
- **Model 7 (Pattern):** Classifies the images into 3 categories according to their pattern and this model

For instance, first the image is classified using the Model 1 and if it is a blouse, it is classified according to its neck type using the Model 2. If it is pants it is classified using the Model 3 and if it is a skirt, it is classified using the Model 4. If the image is classified as a top (shirt or blouse) it is also classified using the Model 5. The color and pattern of the clothing item is found independently from their previous classification. Thus, the Models 6 and 7 are used for all the images.

After reading the results the Raspberry Pi Zero W gives the classification results by playing the appropriate audio feedback. Thus, to create this feedback, author herself recorded 40 .mp4 audio file including all categories separately, and some directive info such as “device is open”, “this piece is a…”, “please make three short tap for casual look” etc. Then, all these .mp4 files has been converted to .wav files and embedded into the system, so audio files recorded with the same name as the classifications are automatically retrieved via Python.

Following the classification feedback, the system asks for user to press the button 3 times for casual, 4 times for an office or 5 times to choose the chic occasion for the combination suggestions while extracting the combination suggestions from the developed excel file. Then, it voices the corresponding outfit suggestion to the user and the whole process repeats if the user takes another picture.

### *5.3. Initial System Testing*

In this section, the functionality of the electronic components and the algorithm was tested. First of all, when the device is switched on, a "device is open" audio feedback was heard, after a waiting period of 35 seconds. By pressing the tap button on the top layer of the electronic system once, a photograph of the garment was taken and the product identification was completed with an average image processing time of 15 seconds. Afterwards, combination suggestions were received with 3 tap (casual), 4 tap (office) and 5 tap (chic). At this point, through the Raspberry Pi Zero to perform real-time tests it was observed that the system achieved success in product identification with following accuracies:

- Model 1 (Main Categories): This model had a 90% test accuracy.
- Model 2 (Neck Types): This model had a 64% test accuracy.
- Model 3 (Leg Types for Pants): This model had a 90% test accuracy.
- Model 4 (Silhouette for Skirts): This model had a 74% test accuracy.
- Model 5 (Silhouette for Tops): This model had 69% test accuracy.
- Model 6 (Color): This model had approximately 95% test accuracy.
- Model 7 (Pattern): This model had approximately 77% test accuracy.

Although the system is generally successful, some limitations were also detected in the tests. For instance, the first one was that the speakers' sound level was not enough to hear in a noisy environment, so they should be searched for the alternatives without increasing the size. Secondly, the distinction between u-neck and V-neck for blouses could not be determined correctly in some examples. A similar situation occurred in the pants group. It is planned to increase the dataset with new samples in further studies. Also, in the combination suggestion section, the algorithm could not apply to which combination of upper and lower product groups would provide the appropriate combination as stated in the 4.2. Creation of the User Scenarios part. Likewise, the first five combination suggestions for the desired occasion after the product definition could not be implemented at this stage because it would cause the connection and transfer times of the audio files to be prolonged. In future studies, efforts will be made to shorten audio feedback times and make them more fluid.

### *5.4. User Testing: Wear Trials*

In this section, considering the user-centred design approach followed in the dissertation, both gloves were tested with 5 users (the author, the thesis advisor and 3 random person who will experience the gloves for the first time), and the ergonomics of the gloves, and ease of use were tested (Figures 91-94). A user manual (i.e. Appendices part) was created for users who will experience the Smart Glove for the first time, and the user was guided by reading this user manual first during the tests. Users performed the test with their eyes covered with a light-proof fabric tape.

In order to receive systematic feedback from users, a short survey of 5 questions was prepared and the users filled in the test results. The survey includes the following questions:

1. If you evaluate the glove in terms of ease of use, was it easy for you to turn the device on/off in accordance with the instructions given?
2. Could you easily find the tap button on the device? Did ornamental stitching help orient you?
3. Were you able to charge the device easily?
4. Are you satisfied with the design details such as the weight of the gloves, their pattern and sewing, and their touch? Which glove made you feel more useful, comfortable, and good?
5. When you think like a visually impaired individual, would you prefer this type of wearable technology product or an application that you will install on your phone?

   Finally, do you have any comments you would like to add?

Figure 91. Smart Glove User Trials1

Figure 91 shows the process of first user trial, so the user 1 answered the questions as follows:

Q1. In line with the instructions given in the user manual, I had no difficulty in wearing the gloves even though I tried them for the first time, it took me a little time to find the right direction. I found the on/off switch relatively convenient.

Q2. The decorative stitching on the device definitely helped me find the touch button.

Q3. I found the charging port of the device relatively easy, but I had difficulty inserting the charging end. I could not fit the charging end as the device slid a little in the case. It can be closed with a harder material or the gap can be kept smaller.

Q4. I was satisfied with the weight and fit of the glove, the neoprene glove felt softer and more comfortable.

Q5. I might prefer gloves rather than holding an extra phone, but it would be better if the electronic parts were more compact.

Figure 92. Smart Glove User Trials2

Figure 92 shows the process of first user trial, so the user 2 answered the questions as follows:

Q1. In terms of ease of use, I did not have any difficulty in wearing the gloves or placing the electronic part, but the location of the on/off switch is a little lost between the boards, it could be positioned higher.

Q2. I was able to find the touch button easily. Ornamental stitching became a guide.

Q3. I was able to find the charging location of the device, but I could not connect the charging tip.

Q4. The neoprene one felt better in terms of fit, texture and comfort in my hand. The knitted one squeezed my hand and its touch felt harder.

Q5. If smaller sized electronic components are used, I prefer gloves.

Figure 93. Smart Glove User Trials3

Figure 93 shows the process of first user trial, so the user 3 answered the questions as follows:

Q1. I didn't have much difficulty in using it, it was easy.

Q2. I was also able to find the touch button easily.

Q3. No, I was able to find the charging port easily but had a hard time fitting it.

Q4. Since my hands are smaller than standard, the pattern of the knitted gloves felt more comfortable and was easier to wear. I was pleased with its stitching, weight and touch.

Q5. I prefer wearable technology products, I internalize them more as a user, it makes me feel like such a product is more uniquely designed for me.

Figure 94. Smart Glove User Trials4

Figure 94 shows the process of first user trial, so the user 4 answered the questions as follows:

Q1. The glove was comfortable and easy to wear, and I had no difficulty in placing the device on the glove according to the instructions given.

Q2. I was also able to find the touch button easily. Ornamental stitching is good in terms of orientation.

Q3. I had no difficulty finding the charging port, but I could not place the charging tip. That part slides a little, the field can be made to remain stable.

Q4. I was more satisfied with the neoprene glove in terms of its stitching, weight and touch.

Q5. I may prefer a wearable technology product, but the board part could be smaller and the headphone cable part could be shorter. Also, the charging part should be more visible/fixed.

Figure 95. Smart Glove User Trials5

Figure 95 shows the process of first user trial, so the user 5 answered the questions as follows:

Q1. The gloves are easy to put on, easy to find snaps, easy to find velcro straps. I had a little trouble finding the on/off switch.

Q2. Tab button found easily. Ornamental stitches helped.

Q3. The charging location is problematic, even if it is found, it cannot be charged.

Q4. The glove is comfortable and covers the wrist very well. Maybe in some areas, mesh fabric can be used on the palm/upper part of the glove or between the fingers, so that it can breathe a little more. But, in general, it covers the hand nicely, it gathers the electronics well, the electronics do not create too much weight, it does not create the feeling of carrying something heavy or bulky in the hand. It is also very easy to use and can be carried around during the day. Finger parts can be kept a little shorter. It may even end directly at the beginning of the finger. It doesn't need to be this long because it makes you sweat a little as it is. When I compare the two gloves, although the knitted one is a little tight, I think it will be more comfortable than the neoprene glove if it is adjusted according to the knitting density and hand size.

Q5. Having such an experience was good and much more enjoyable. I'd prefer having everything in one glove as a wearable tech product rather than a mobile phone app. Also it is suitable to be customized, so I can choose its color or design details.

Additional Comments: Maybe different bar tack stitches can be made for each area to indicate the location of the buttons and the charger input. Thus, for example, while a circle-shaped stitch makes the tab button visible, a direction that the hand can follow can be made by stitching towards the place where the switch button is. Or, the area around the laser cutting area and the charging area can be highlighted with stitching. The charging location can be indicated by zig zag stitching. On the other hand, maybe the gloves can be made with right and left hand alternatives.

Considering the feedback obtained from user tests, both hedonic and pragmatic, the gloves were generally satisfied with their weight, stitching, fit and feel. In this regard, while 3 users preferred neoprene gloves, two user preferred the knitted one due to its fit and moisture management feature. Thanks to the information/guidance in the user manual and the ornamental stitching on the top board, the on/off and touch button of the device can be easily found. One user commented that it would be more convenient if the location of the on/off button was in a more accessible, prominent spot. Charging has been identified as a limitation. The location of the charging port was easily found, but the charging port could not be installed. The design aspect will be strengthened in future studies on this subject. Finally, users have stated that they may generally prefer such a wearable technology product, but that minimizing the device part with new technologies may be more effective in terms of design.

# CHAPTER 6: CONCLUSION AND FURTHER STUDIES

In this research, a versatile wearable assistive technology product, specifically a Smart Glove, was developed to address the challenges faced by visually impaired individuals in the realm of clothing (e.g., defining the color, silhouette, details, and pattern of the garment). The research involved a comprehensive review of assistive and wearable technology examples for people with visual impairments, spanning areas such as mobility, communication, and daily activities. It has been observed in the literature that assistive and wearable technology products developed for visually impaired individuals are mostly aimed at navigation and written and verbal communication tools. It has been determined that research in this field on a subject that is socially effective, such as clothing, is limited. Especially in Turkey, no assistive wearable technology product has been found specifically for clothing for visually impaired individuals. Also, it was found that the examples in the literature often lack aesthetic appeal and functionality due to high weight and size of technical materials, and also insufficient integration of those electronics into clothing and textiles.

Recognizing the limited attention to clothing-related assistive wearable technologies in the literature, the study adopted a user-centred design approach to address the specific needs and challenges identified through a survey of visually impaired participants. Parameters such as the user's abilities, restrictions, and specific needs, as well as the context of use and the features of the technology itself, play important roles in the investigation and development process. By considering these factors, the 10-question survey was conducted via different medias, and when the feedback from participants in the survey were evaluated, it was noted that selecting proper clothing might be an issue for people with visual impairment. Relatedly, when designing an assistive technology in the field of clothing, it is necessary to address this area as a whole, from shopping to domestic/ in-house use. Considering the participants' comments, the most troublesome issues are that they cannot perceive garments' colors and prints/ patterns or create suitable color and style combinations at home and during shopping.

Considering literature review and survey results, and based on the user-centred design approach, the construction of the Smart Glove which involved detailed consideration of user needs, requirements, tasks, limitations, and barriers was carried out. Thus, user scenarios demonstrating the using process of the Smart Glove in home and in shopping were created separately. In the next stage, the Smart Glove was designed, the electronic components that run the algorithm were determined and brought together. A textile-based protective case has been produced to protect the user's skin from possible damage caused by electronics, the electronics from external factors and to ensure the washability of the glove. Finally, two different glove prototypes were produced, in which the electronics would be integrated with the case. These two glove alternatives were evaluated for pragmatics, and hedonic qualities in terms of their advantages/disadvantages by testing the initial system and by testing the glove itself with 5 users.

With regard to initial system testing, the system works properly and the process works as stated. The image is captured with a micro camera, processed, and audio feedback is provided to the user. However, some limitations have been identified. Therefore, generally high accuracy was achieved in product description, only in some blouse samples, the V-neck and U-neck difference could not be caught unless it was very obvious, the accuracy remained at 64%, and silhouette of some blouses could not be detected effectively, remained at 69%. On the other hand, some of the classification can be modelled by dividing into two phases for more details of the garments, and for the convenience of the user when taking photos of the product via the Smart Glove. For instance, pants can be classified according to their waist and leg types separately. Besides, combination suggestions were not provided as systematically and detailed as in the user scenarios. In future studies on the subject, the accuracy percentage will be increased by enhancing the number of data. Additionally, considering changing fashion trends, the dataset needs to be updated at least seasonally. For this purpose, the dataset will be increased constantly with current product images of both high street and high end fashion brands. On the other hand, the loudness provided by the speakers used in the prototype is not at a level that can be heard in noisy environments; therefore, it is planned to improve the speakers. Apart from these, for further studies, the user's own voice can be recorded or AI generated and used for commands and feedback. In addition, in this study, an English voice recording was made at the first stage, but it is planned to provide language diversity in the future.

When both gloves were examined in terms of *manufacturability*, which is the first of the pragmatic features, neoprene glove in this research was simpler to manufacture, as the material was easy to cut and sew. Especially due to the structure of the fabric, it is very suitable for laser cutting and allows for a clean finish, so it does not curl or run away at the fingertips and wrist ends, as in knitted gloves. Regarding the size range, the base of both gloves can be produced accurately with the measurements given during the production stage. However, when considering the protective cover, laser cutting on neoprene fabric by preparing its pattern provided better results than applying it on a knitted fabric. Regarding *maintainability* including washability, easy drying and repairable criteria, since the electronic components can be attached/ detached onto the glove, both gloves are washable. However, in the washing and drying test performed under the same conditions, it was determined that the neoprene glove dried faster. In addition, it was stated that in terms of *wearability* as the other pragmatic feature, Coolmax yarns provide an advantage to knitted gloves compared to neoprene fabric in terms of thermal comfort as air permeability and moisture management. While the glove sewn with neoprene fabric perform better in terms of waterproofness, durability, touch and fit. Thus, in terms of usability, both gloves have similar patterns and design details, so the usability and usefulness of both gloves can be said to be at a similar level. The last item, *durability*, neoprene glove is more durable in terms of strength with better abrasion resistance compared to knitted glove.

On the other hand, when these two gloves are compared considering hedonic qualities, the smoother surface appearance of the glove sewn with neoprene provides more advantages than the knitted glove, both in terms of aesthetics and the feeling it provides to the user's skin. The Smart Glove prototypes demonstrated success in meeting the identified needs and requirements, providing both comfort and aesthetic appeal. Despite some limitations, including size considerations and device charging, the study suggests potential avenues for future research, such as integrating AI-based garment recognition and recommendation systems into wearable assistive technologies for enhanced independence and style assistance for individuals with visual impairments.

On the other hand, the iteration of design is a crucial process in the development of innovative solutions, such as the creation of the Smart Glove for visually impaired individuals. Through constant refinement and feedback, the Smart Glove can be enhanced the functionality, usability, and overall user experience of the glove. Further studies can be conducted to enhance the design of the smart glove, specifically focusing on the integration of electronic components with the glove. Improving the electronic components' functionality, efficiency, and integration within the glove structure is crucial for optimizing the overall performance and usability of the device. By utilizing micro or nano-sized electronic materials, the glove can achieve a more streamlined and lightweight design, enhancing user comfort and mobility. Additionally, the use of flexible and stretchable electronic materials can facilitate better integration with the fabric of the glove, ensuring a seamless and ergonomic fit. Another point for further studies is the development of innovative methods for embedding electronic components into the glove. Techniques such as textile-based circuitry or conductive thread can be explored to seamlessly integrate sensors, microcontrollers, and other electronic modules into the fabric of the glove. Moreover, the integration of energy harvesting technologies or efficient battery solutions, can contribute to long term usage and reduce the need for frequent recharging. Accordingly, for further studies, a comprehensive 3D smart glove design was developed, incorporating material research (2.4) and considering the previously established user scenarios (4.2). The modelling process utilized the 3D s max program to ensure accurate representation and visualization (Figure 96).

Figure 96. Smart Glove Concept- 3D Models

Various perspectives of the glove, including different angles, were presented to show the fabric selection, and the integration of alternative electronic components. The design phase focused on seamlessly incorporating these electronic components into the glove structure, optimizing functionality and user experience.

Figure 97. Smart Glove Concept- Fabrics

The glove is produced with seamless 3D/4D knitting technology to cover the middle finger where the camera will be placed, the thumb to support the stance of the glove, the palm area where the connection will be made with the processor, and the wrist where the system components will be integrated. Fingertips are left free in order not to interfere with the sense of touch. Different knitted appearances are used considering both aesthetic appearance and breathability. The frequency of knitting increases in terms of the placement of the hardware on the wrist. Coolmax Fresh FX, Smartcel or Viloft fibers/yarns mentioned in the fabric research section are alternatively used in the fabric of the glove (Figure 97).

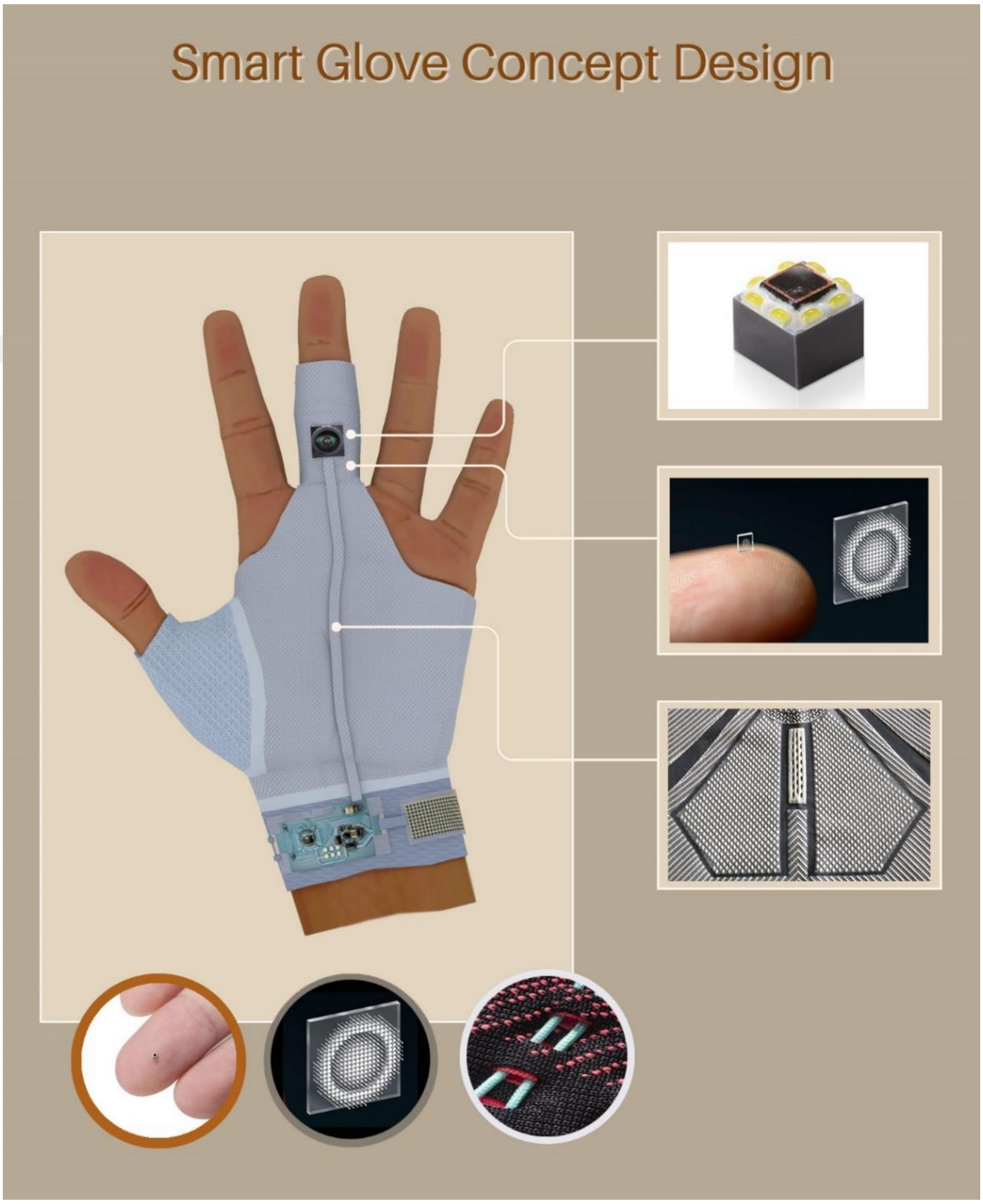


Figure 98. Smart Glove Concept- Camera and Tube 1

The camera that will take the photograph of the garment on the middle finger of the glove is preferred among the nano camera samples discussed in the electronic components research section. In the case of a metasurface camera, it connects wirelessly to the processor. On the other hand, when the camera developed by The

Fraunhofer Institute is used, the connection with the processor will be provided by conductive cables integrated into the glove thanks to the 4D knitted tube. The other alternatives are the application of these conductive connections to the glove surface by printing method or using conductive yarns in the knitting process (Figure 98).

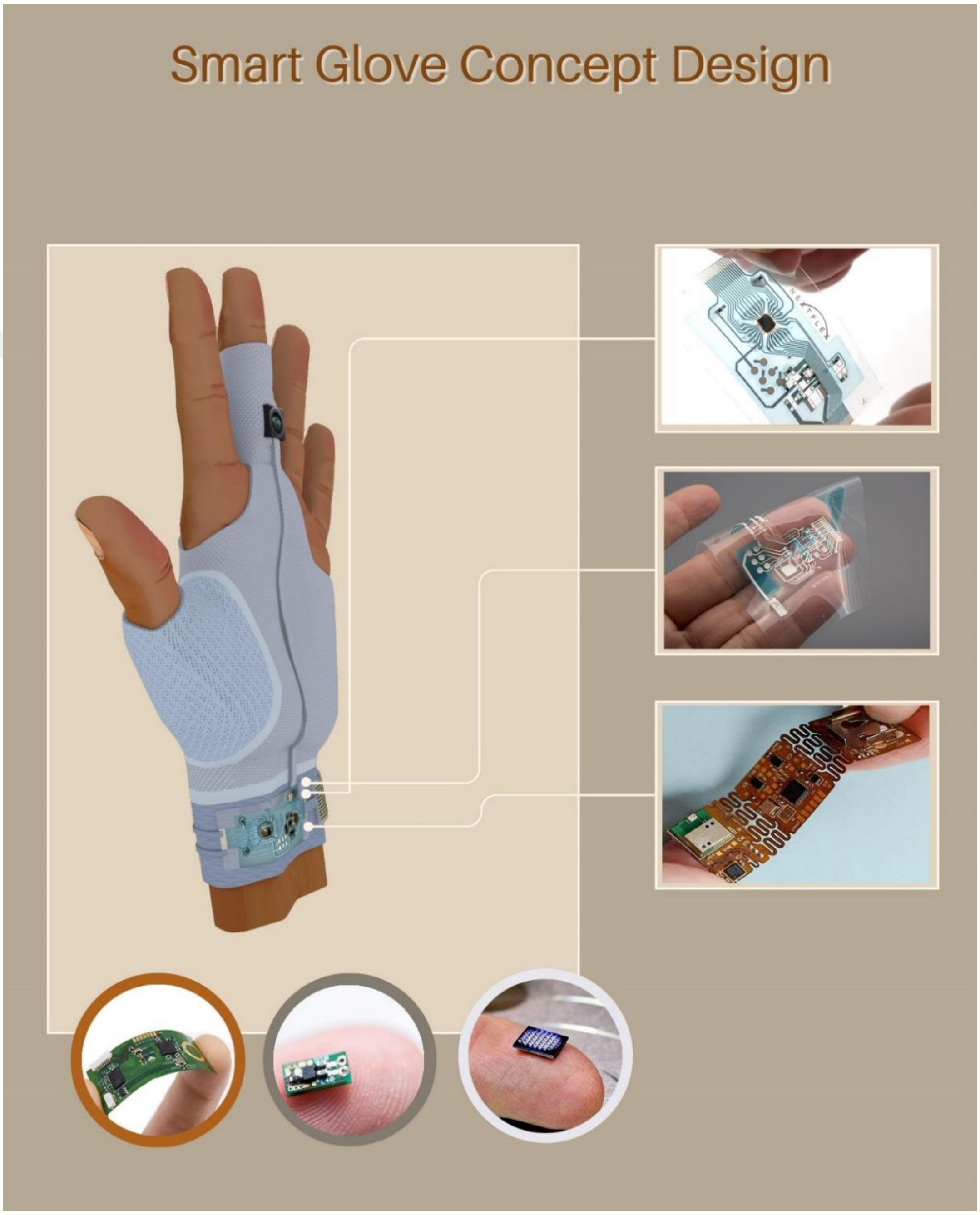


Figure 99. Smart Glove Concept- Microcontroller/ Processor

Firstly, flexible processors are used to process the image taken from the camera. In another alternative, rigid but minimized processors can be used (Figure 99).

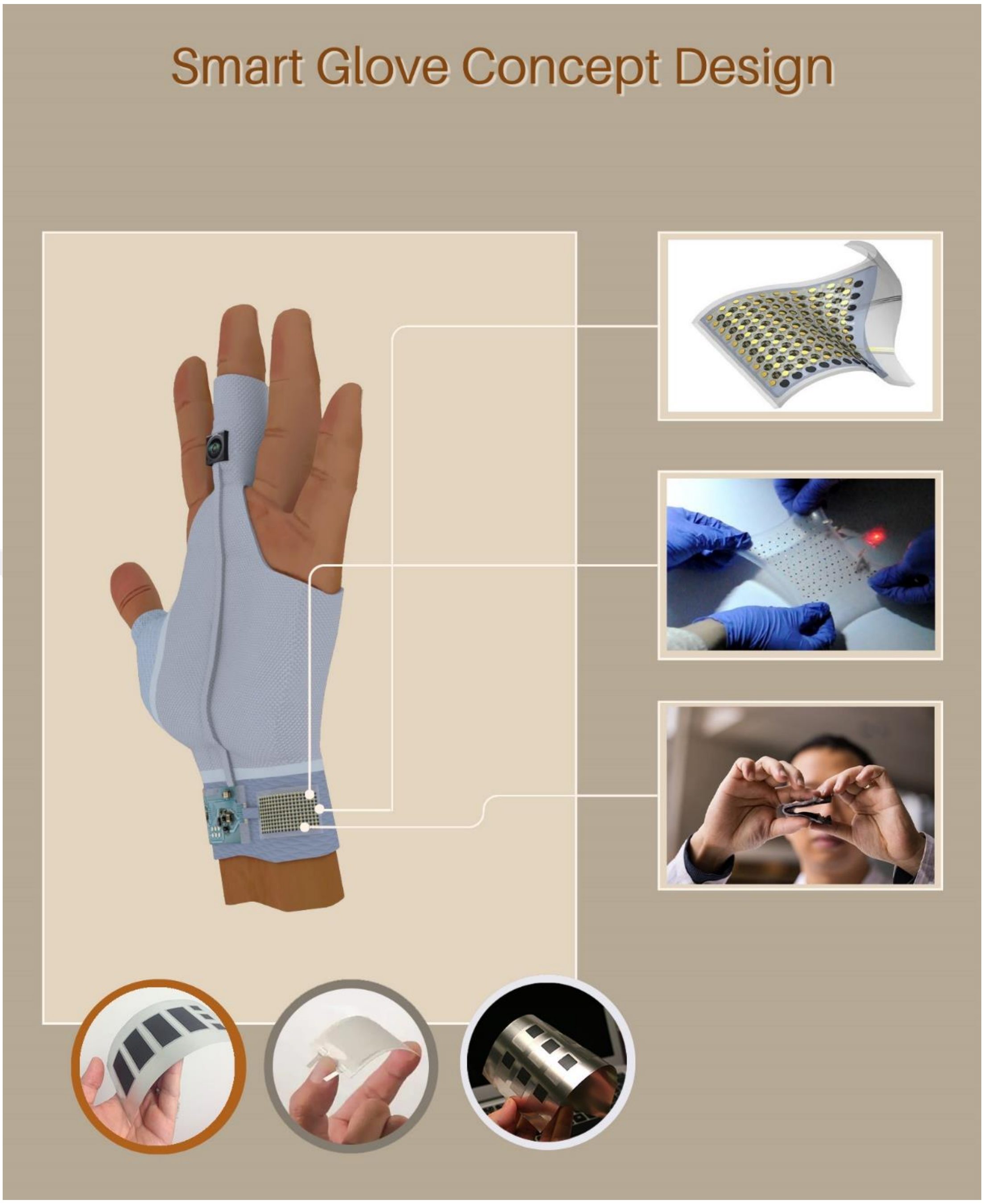


Figure 100. Smart Glove Concept- Flexible Battery

As the energy source of the glove a flexible and washable battery (UBC, 2021) is used. The connection between the processor and the battery is provided by either knitting tube, printing or conductive yarns, as in the camera connection (Figure 100).

Figure 101. Smart Glove Concept- MEMS Speaker and Microphone & Tube 2

Finally, the information coming from the processor is transferred to the user as auditory output from the MEMS speaker with its minimized dimensions. Likewise, the user transmits commands such as 'define the garment' or 'what can I combine this garment with for the office' to the system via the MEMS microphone. Speaker, microphone, and processor connection is provided by the use of printing, embroidery or knitted tubes, as well as other connections (Figure 101).

In conclusion, further studies should concentrate on improving the integration of electronic components within the smart glove, including the utilization of advanced electronic materials, innovative integration techniques, enhanced connectivity options, and refined usability. Also, it should explore the integration of deep learning algorithms to provide combination suggestions and enable the smart system to learn user preferences, further enhancing style recommendations according to the user’s wardrobe specifically and during the shopping process. Thus, these advancements will contribute to the development of a more efficient, ergonomic, and user-friendly smart glove for individuals with visual impairments.

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# APPENDICES

## APPENDIX A: Ethical Committee Approval

**SAYI :** B.30.2.İEÜ.0.05.05-**020**-*269*
28.02.2023

**KONU :** Etik Kurul Kararı hk.

**Sayın Doç. Dr. Arzu Vuruşkan ve Başak Süller Zor,**

**“Görme Engelliler İçin Yardımcı Teknolojilerin Kullanımı: Giyim Alanında Akıllı Eldiven Tasarımı”** başlıklı projenizin etik uygunluğu konusundaki baş vurunuz sonuçlanmıştır.

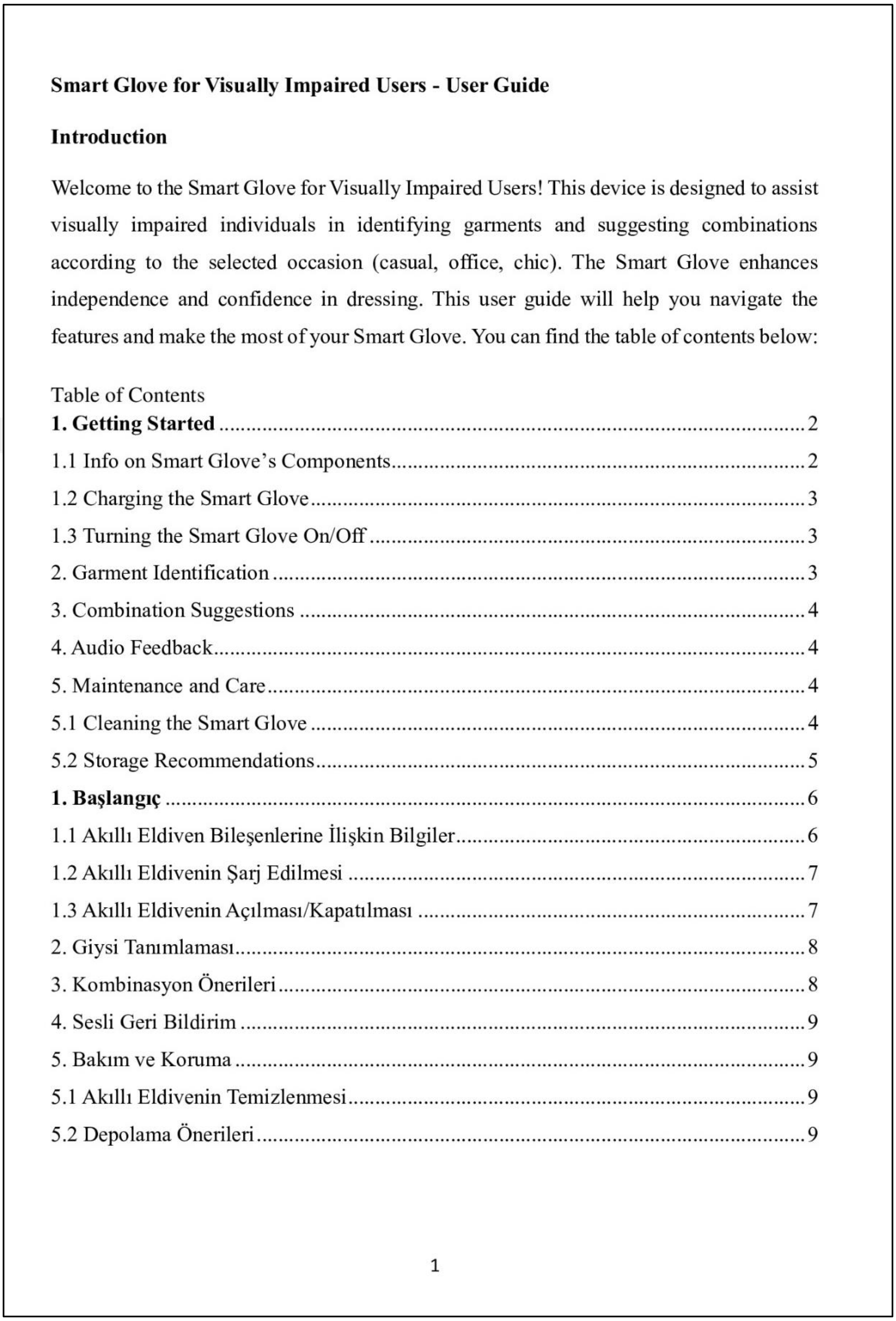
Etik Kurulumuz 28.02.2023 tarihinde sizin başvurunuzun da içinde bulunduğu bir gün- demle toplanmış ve Etik Kurul üyeleri projeleri incelemiştir.

Sonuçta 28.02.2023 tarihinde **“Görme Engelliler İçin Yardımcı Teknolojilerin Kullanımı: Giyim Alanında Akıllı Eldiven Tasarımı”** konulu projenizin etik açıdan uygun olduğuna oy birliğiyle karar verilmiştir.

Gereği için bilgilerinize sunarım.
Saygılarımla,

**Prof. Dr. Murat**
**Bengisu Etik**
**Kurul Başkanı**

# APPENDIX B: Smart Glove for Visually Impaired Users- User Guide (Word)

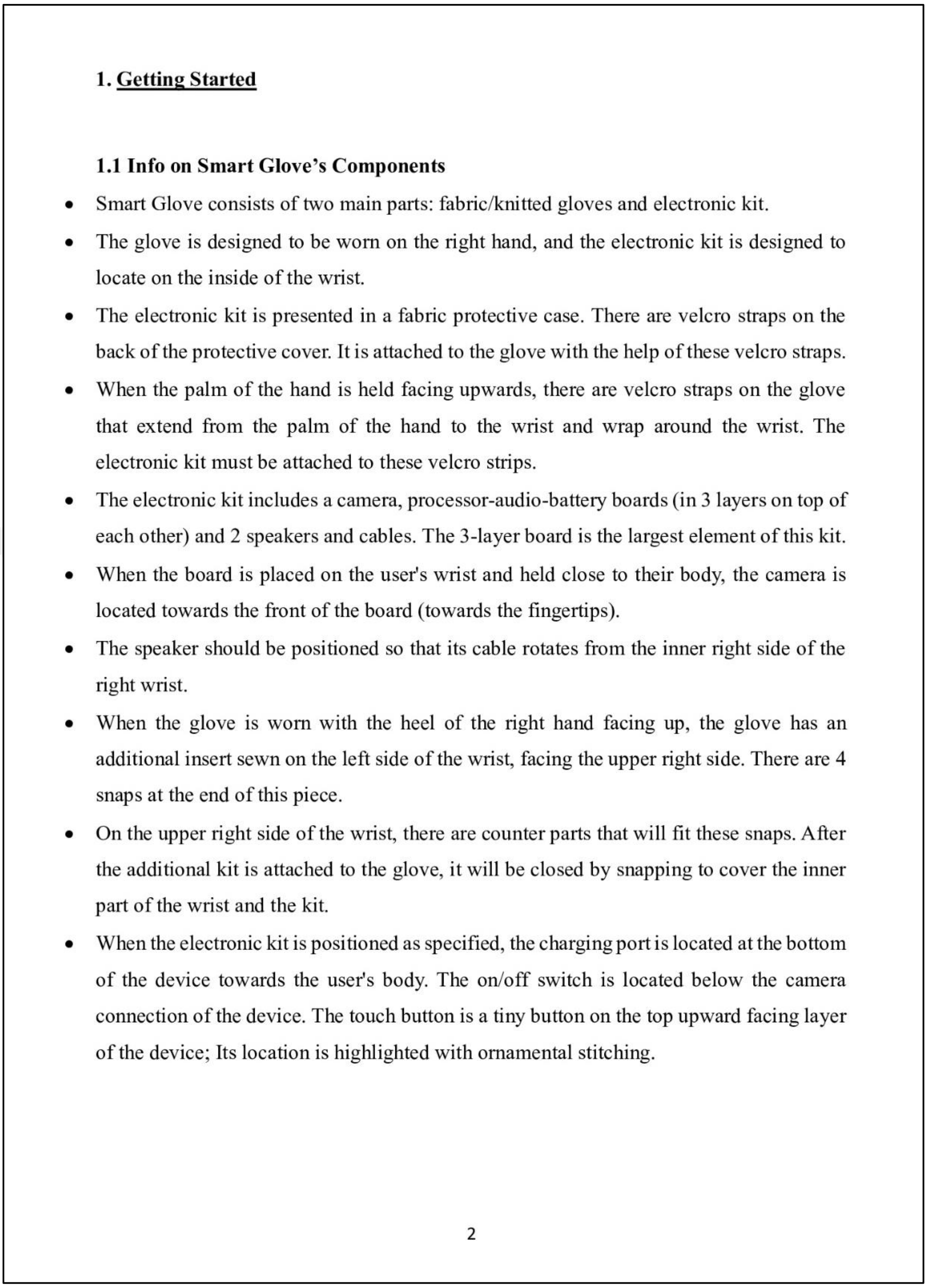


## Smart Glove for Visually Impaired Users - User Guide

### Introduction

Welcome to the Smart Glove for Visually Impaired Users! This device is designed to assist visually impaired individuals in identifying garments and suggesting combinations according to the selected occasion (casual, office, chic). The Smart Glove enhances independence and confidence in dressing. This user guide will help you navigate the features and make the most of your Smart Glove. You can find the table of contents below:

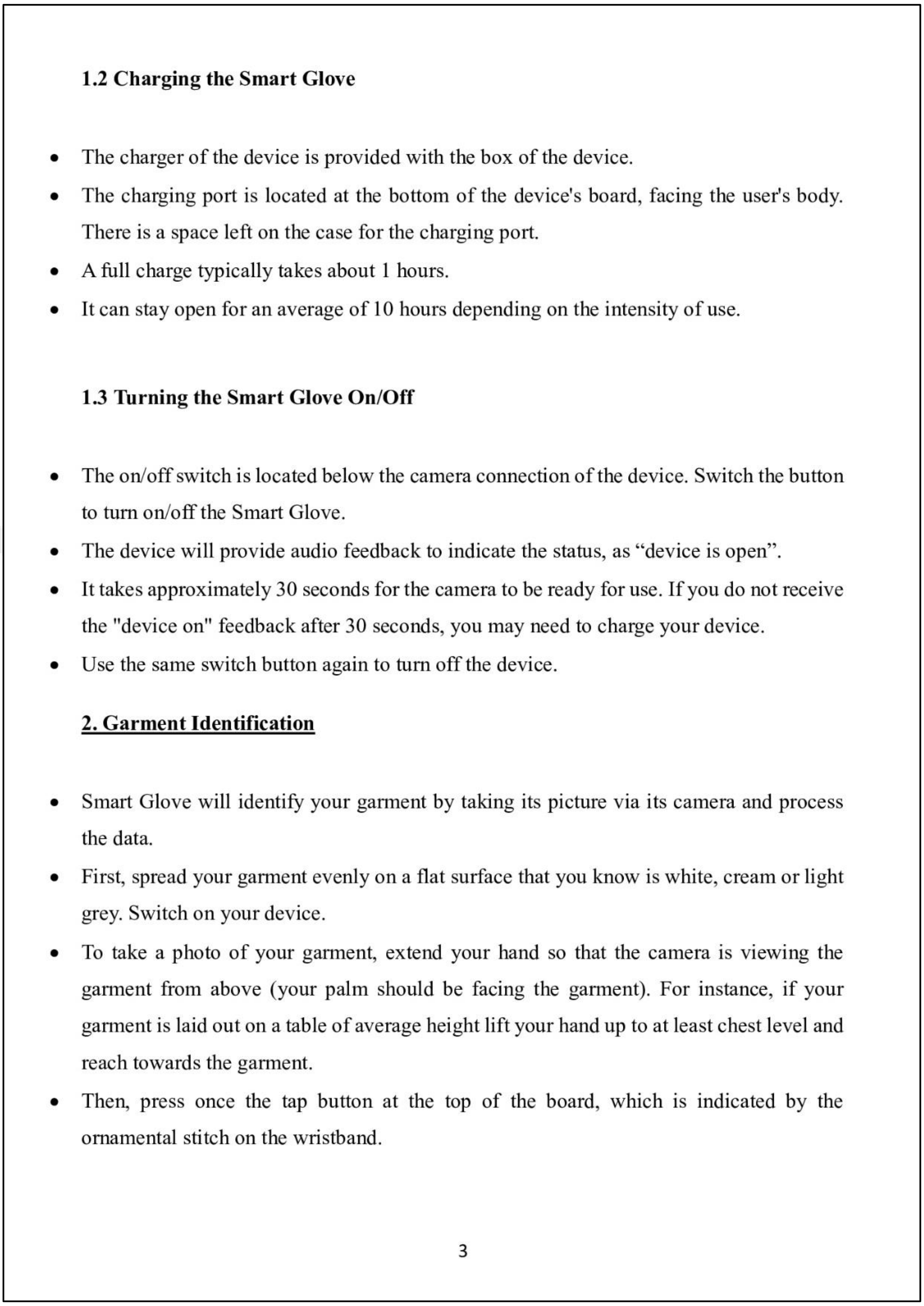
Table of Contents



# 1. Getting Started

## 1.1 Info on Smart Glove’s Components

- Smart Glove consists of two main parts: fabric/knitted gloves and electronic kit.
- The glove is designed to be worn on the right hand, and the electronic kit is designed to locate on the inside of the wrist.
- The electronic kit is presented in a fabric protective case. There are velcro straps on the back of the protective cover. It is attached to the glove with the help of these velcro straps.
- When the palm of the hand is held facing upwards, there are velcro straps on the glove that extend from the palm of the hand to the wrist and wrap around the wrist. The electronic kit must be attached to these velcro strips.
- The electronic kit includes a camera, processor-audio-battery boards (in 3 layers on top of each other) and 2 speakers and cables. The 3-layer board is the largest element of this kit.
- When the board is placed on the user's wrist and held close to their body, the camera is located towards the front of the board (towards the fingertips).
- The speaker should be positioned so that its cable rotates from the inner right side of the right wrist.
- When the glove is worn with the heel of the right hand facing up, the glove has an additional insert sewn on the left side of the wrist, facing the upper right side. There are 4 snaps at the end of this piece.
- On the upper right side of the wrist, there are counter parts that will fit these snaps. After the additional kit is attached to the glove, it will be closed by snapping to cover the inner part of the wrist and the kit.
- When the electronic kit is positioned as specified, the charging port is located at the bottom of the device towards the user's body. The on/off switch is located below the camera connection of the device. The touch button is a tiny button on the top upward facing layer of the device; Its location is highlighted with ornamental stitching.



### 1.2 Charging the Smart Glove

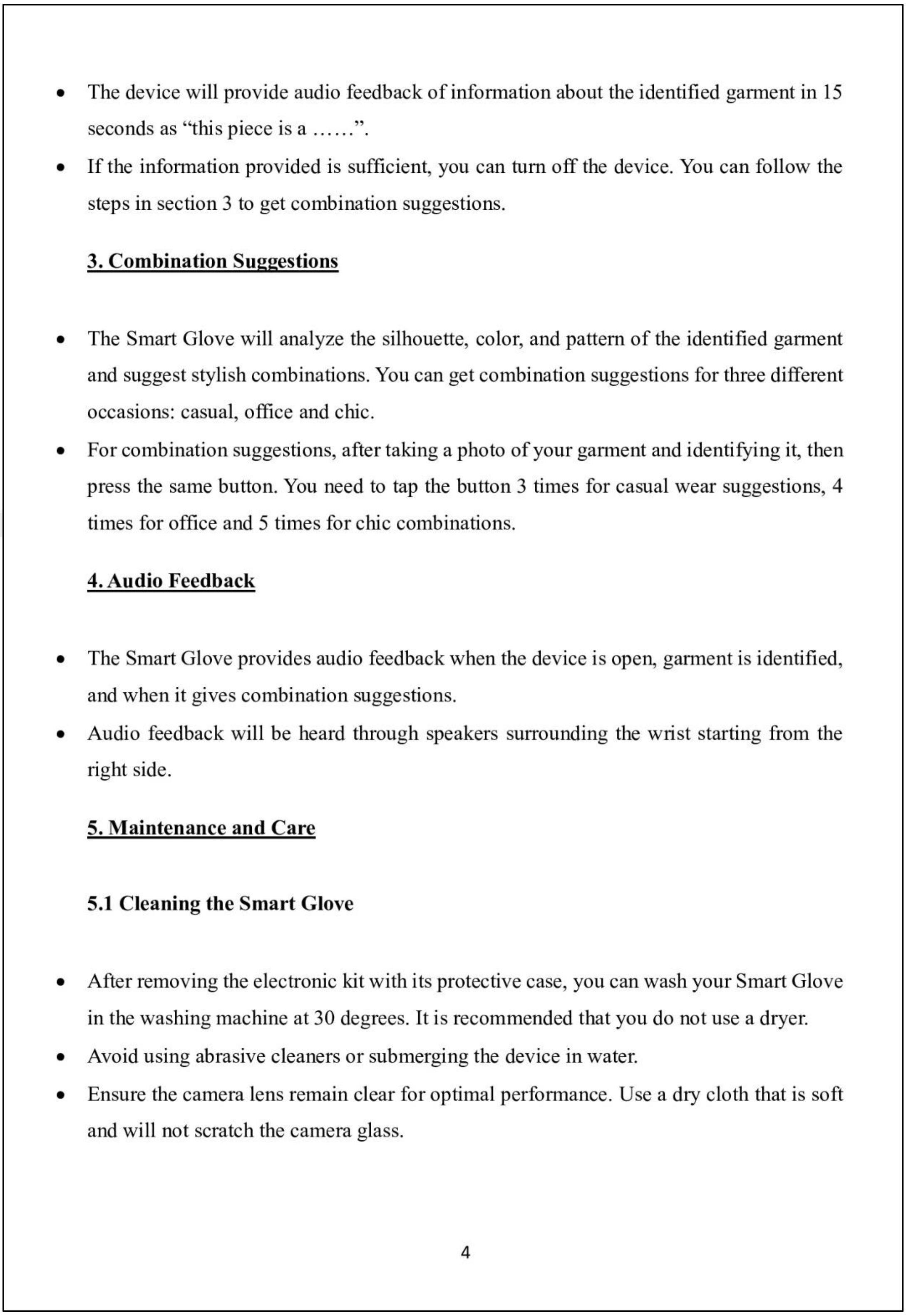
- The charger of the device is provided with the box of the device.
- The charging port is located at the bottom of the device's board, facing the user's body. There is a space left on the case for the charging port.
- A full charge typically takes about 1 hours.
- It can stay open for an average of 10 hours depending on the intensity of use.

### 1.3 Turning the Smart Glove On/Off

- The on/off switch is located below the camera connection of the device. Switch the button to turn on/off the Smart Glove.
- The device will provide audio feedback to indicate the status, as “device is open”.
- It takes approximately 30 seconds for the camera to be ready for use. If you do not receive the "device on" feedback after 30 seconds, you may need to charge your device.
- Use the same switch button again to turn off the device.

## 2. Garment Identification

- Smart Glove will identify your garment by taking its picture via its camera and process the data.
- First, spread your garment evenly on a flat surface that you know is white, cream or light grey. Switch on your device.
- To take a photo of your garment, extend your hand so that the camera is viewing the garment from above (your palm should be facing the garment). For instance, if your garment is laid out on a table of average height lift your hand up to at least chest level and reach towards the garment.
- Then, press once the tap button at the top of the board, which is indicated by the ornamental stitch on the wristband.



- The device will provide audio feedback of information about the identified garment in 15 seconds as "this piece is a ……".
- If the information provided is sufficient, you can turn off the device. You can follow the steps in section 3 to get combination suggestions.

## 3. Combination Suggestions

- The Smart Glove will analyze the silhouette, color, and pattern of the identified garment and suggest stylish combinations. You can get combination suggestions for three different occasions: casual, office and chic.
- For combination suggestions, after taking a photo of your garment and identifying it, then press the same button. You need to tap the button 3 times for casual wear suggestions, 4 times for office and 5 times for chic combinations.

## 4. Audio Feedback

- The Smart Glove provides audio feedback when the device is open, garment is identified, and when it gives combination suggestions.
- Audio feedback will be heard through speakers surrounding the wrist starting from the right side.

## 5. Maintenance and Care

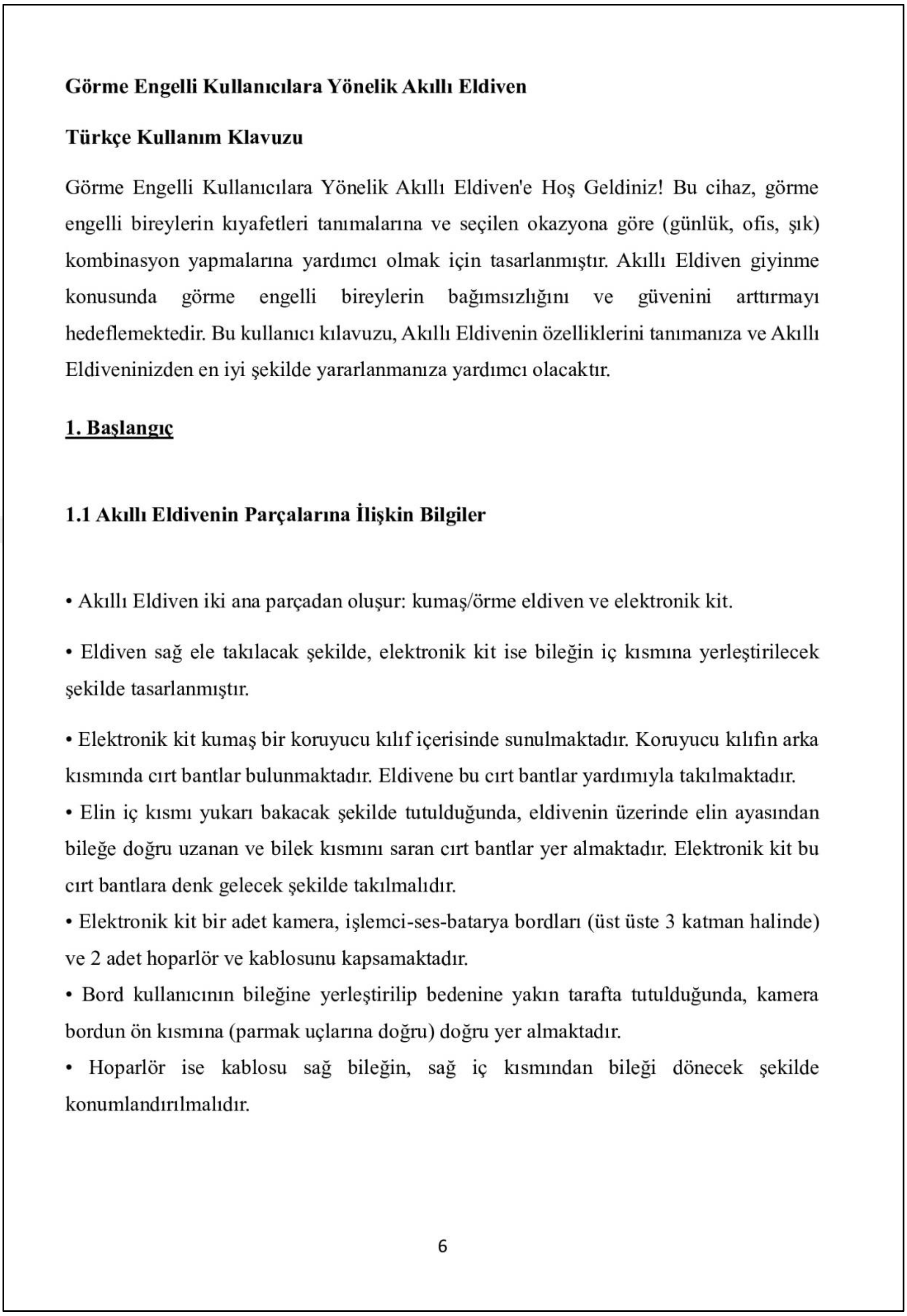
### 5.1 Cleaning the Smart Glove

- After removing the electronic kit with its protective case, you can wash your Smart Glove in the washing machine at 30 degrees. It is recommended that you do not use a dryer.
- Avoid using abrasive cleaners or submerging the device in water.
- Ensure the camera lens remain clear for optimal performance. Use a dry cloth that is soft and will not scratch the camera glass.

### 5.2 Storage Recommendations

- Store the Smart Glove in a protective case when not in use. Avoid exposing it to extreme temperatures, direct sunlight, or moisture.

Congratulations! You are now ready to fully utilize your Smart Glove for identifying garments and receiving stylish combination suggestions. Enjoy the enhanced independence and confidence in your daily dressing routine!



**Görme Engelli Kullanıcılara Yönelik Akıllı Eldiven**

**Türkçe Kullanım Klavuzu**

Görme Engelli Kullanıcılara Yönelik Akıllı Eldiven'e Hoş Geldiniz! Bu cihaz, görme engelli bireylerin kıyafetleri tanımalarına ve seçilen okazyona göre (günlük, ofis, şık) kombinasyon yapmalarına yardımcı olmak için tasarlanmıştır. Akıllı Eldiven giyinme konusunda görme engelli bireylerin bağımsızlığını ve güvenini arttırmayı hedeflemektedir. Bu kullanıcı kılavuzu, Akıllı Eldivenin özelliklerini tanımanıza ve Akıllı Eldiveninizden en iyi şekilde yararlanmanıza yardımcı olacaktır.

## 1. Başlangıç

### 1.1 Akıllı Eldivenin Parçalarına İlişkin Bilgiler

- Akıllı Eldiven iki ana parçadan oluşur: kumaş/örme eldiven ve elektronik kit.
- Eldiven sağ ele takılacak şekilde, elektronik kit ise bileğin iç kısmına yerleştirilecek şekilde tasarlanmıştır.
- Elektronik kit kumaş bir koruyucu kılıf içerisinde sunulmaktadır. Koruyucu kılıfın arka kısmında cırt bantlar bulunmaktadır. Eldivene bu cırt bantlar yardımıyla takılmaktadır.
- Elin iç kısmı yukarı bakacak şekilde tutulduğunda, eldivenin üzerinde elin ayasından bileğe doğru uzanan ve bilek kısmını saran cırt bantlar yer almaktadır. Elektronik kit bu cırt bantlara denk gelecek şekilde takılmalıdır.
- Elektronik kit bir adet kamera, işlemci-ses-batarya bordları (üst üste 3 katman halinde) ve 2 adet hoparlör ve kablosunu kapsamaktadır.
- Bord kullanıcının bileğine yerleştirilip bedenine yakın tarafta tutulduğunda, kamera bordun ön kısmına (parmak uçlarına doğru) doğru yer almaktadır.
- Hoparlör ise kablosu sağ bileğin, sağ iç kısmından bileği dönecek şekilde konumlandırılmalıdır.

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- Eldiven sağ elin içi yukarı bakacak şekilde giyildiğinde, eldivenin bileğin sol yanında dikili, sağ üst yanına gelecek şekilde ek bir ek parçası yer almaktadır. Bu parçanın ucunda 4 adet çıt çıt bulunmaktadır.

- Bileğin sağ üst kısmında ise bu çıt çıtlara denk gelecek karşı parçaları yer almaktadır. Ek parça kit eldivene takıldıktan sonra buradan bileğin iç kısmını ve kiti saracak şekilde çıt çıtlanarak kapatılacaktır.

- Elektronik kitin belirtilen şekilde konumlandırması yapıldığında, şarj girişi cihazın kullanıcının bedenine doğru olan alt kısmında yer almaktadır. Açma/ kapama tuşu cihazın kamera ara bağlantısının altında kalacak şekilde yer almaktadır. Dokunma butonu ise cihazın en üst yukarı bakan katmanında minik bir tuş halindedir; süs dikişi ile yeri belirginleştirilmiştir.

### 1.2 Akıllı Eldivenin Şarj Edilmesi

- Cihazın şarj aleti cihazın kutusuyla birlikte verilmektedir.

- Şarj girişi cihazın bord kısmında, kullanıcının bedenine bakan yönde, en altta yer almaktadır. Şarj girişi için kılıf üzerinde boşluk bırakılmıştır.

- Tam şarj genellikle yaklaşık 1 saat sürmektedir.

- Kullanım yoğunluğuna bağlı olarak ortalama 10 saat açık kalabilir.

### 1.3 Akıllı Eldiveni Açılma/Kapama

- Açma/kapama tuşu kamera - bord bağlantısının altında, en alt bordta bulunmaktadır. Akıllı Eldiveni açmak/kapatmak için tuşu yana kaydırın.

- Cihaz, durumu "cihaz açık" olarak belirtmek için sesli geri bildirim sağlayacaktır.

- Kameranın kullanıma hazır hale gelmesi yaklaşık 30 saniye sürer. 30 saniye sonunda "cihaz açık" geri bildirimini almazsanız cihazınızı şarj etmeniz gerekebilir.

- Cihazı kapatmak için tekrar aynı tuşu kullanın.

## 2. Giysi Tanımlaması

- Smart Glove, kamerasıyla giysinizin fotoğrafını çekerek giysinizi tanımlayacak ve verileri işleyecektir.

- Öncelikle giysinizi beyaz, krem veya açık gri olarak bildiğiniz düz bir yüzeye düzgün şekilde yayın. Cihazınızı açın.

- Giysinizin fotoğrafını çekmek için, kamera giysiyi yukarıdan görecek şekilde elinizi uzatın (avuç içi giysiye dönük olmalıdır). Örneğin, giysiniz ortalama yükseklikte bir masanın üzerine seriliyorsa elinizi en az göğüs hizasına kadar kaldırın ve giysiye doğru uzatın.

- Daha sonra bordun üst kısmında bulunan, bileklikteki süs dikişiyle gösterilen dokunma düğmesine bir kez basın.

- Cihaz, tanımlanan giysiye ilişkin bilgileri "bu parça bir ……" şeklinde 15 saniye içerisinde sesli geri bildirim olarak verecektir.

- Verilen bilgiler yeterli ise cihazı kapatabilirsiniz. Kombinasyon önerileri almak için 3. bölümdeki adımları takip edebilirsiniz.

## 3. Kombinasyon Önerileri

- Akıllı Eldiven, belirlenen giysinin silüetini, rengini ve desenini analiz ederek kombinasyonlar önerecektir. Günlük, ofis ve şık olmak üzere üç farklı ortama uygun kombin önerileri alabilirsiniz.

- Kombin önerileri için giysinizin fotoğrafını çekip tanımladıktan sonra aynı tuşa basın. Gündelik kıyafet önerileri için 3 kez, ofis için 4 kez, şık kombinler için ise 5 kez düğmeye basmanız gerekmektedir.

## 4. Sesli Geri Bildirim

- Akıllı Eldiven, cihaz açıldığında, giysi tanımlandığında ve kombinasyon önerilerinde bulunduğunda sesli geri bildirim sağlar.
- Sesli geri bildirim sağ taraftan başlayarak bileği çevreleyen hoparlörler aracılığıyla duyulacaktır.

## 5. Bakım ve Koruma

### 5.1 Akıllı Eldivenin Temizlenmesi

- Elektronik kiti koruyucu kılıfıyla birlikte çıkardıktan sonra Akıllı Eldiveninizi çamaşır makinesinde 30 derecede yıkayabilirsiniz. Kurutma makinesi kullanmamanız tavsiye edilir.
- Aşındırıcı temizleyiciler kullanmaktan veya cihazı suya daldırmaktan kaçının.
- Optimum performans için kamera merceğinin temiz kaldığından emin olun. Yumuşak ve kamera camını çizmeyecek kuru bir bez kullanın.

### 5.2 Depolama Önerileri

- Akıllı Eldiveni kullanılmadığı zaman koruyucu bir kutuda saklayın. Aşırı sıcaklıklara, doğrudan güneş ışığına veya neme maruz bırakmaktan kaçının.

Tebrikler! Giysileri tanımlamak ve şık kombin önerileri almak için artık Akıllı Eldiveninizi tam olarak kullanmaya hazırsınız. Günlük giyinme rutininizde bağımsızlığın ve güvenin tadını çıkarın!

# APPENDIX C: Smart Glove for Visually Impaired Users- User Guide (Braille)

This appendix contains the braille printed user manual of the Smart Glove for visually impaired individuals. Since a special paper is used for Braille printing, it starts from the next page.

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