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ÚSTAV JAZYKŮ

SMART CLOTHING TECHNOLOGY AND APPLICATION

VÝROBA A VYUŽITÍ CHYTRÝCH TEXTILIÍ

BACHELOR THESIS

BAKALÁŘSKÁ PRÁCE

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VEDOUCÍ PRÁCE

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Vymezte koncepci chytrých textilií a jejich výroby a řešte jejich možné využití včetně výhod a nevýhod.

DOPORUČENÁ LITERATURA:

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Abstract

The main goal of this bachelor thesis is to acquaint the reader with the issue of smart clothes and frame their concept. The thesis provides a brief historical survey to outline the background for smart clothes including a few illustrative examples. The author classifies smart clothes according to their integration into garments, the position regarding the human body, and he lists the groups into which smart clothes can be further divided. Next, he deals with the design of smart clothes which depends on the end users' requirements. He also describes the possible construction of smart clothes, discusses the communication architecture which considers a smart garment as a system with an emphasis on the communication facet, and the importance of a layering system for smart clothes.

Key words

Smart clothes, wearable computing, clothing technologies, smart clothes design, end user, smart wearables

Abstrakt

Hlavní cíl této bakalářské práce je představit čtenáři problematiku chytrého oblečení a vymezit jeho koncepci. V práci je uveden stručný historický přehled, který utváří obraz o původu a kontextu chytrého oblečení, včetně několika názorných příkladů. Autor popisuje rozdělení chytrého oblečení vzhledem k jeho integraci v oděvech, pozici vůči lidskému tělu a uvádí skupiny, do kterých může chytré oblečení být klasifikováno. Dále se zabývá designem chytrého oblečení, který závisí na požadavcích koncových zákazníků. Také popisuje možnou konstrukci chytrého oblečení, diskutuje architekturu komunikací, která považuje oblečení jako systém s důrazem na komunikační aspekt, a upozorňuje na důležitost systému vrstev chytrého oblečení.

Klíčová slova

Chytré oblečení, přenosný počítač, technologie oblečení, design chytrého oblečení, koncový uživatel, chytrá nositelná elektronika

Rozšířený abstrakt

Inovace v oblasti senzorů, textilií a nositelné elektroniky umožnila rozvoj nového odvětví, tzv. chytrého oblečení, kterému se v poslední době dostává poměrně velké pozornosti. Tato bakalářská práce se zabývá koncepcí chytrého oblečení a seznamuje čtenáře s jeho výrobou a možným využitím. Hlavním cílem této práce je vymezit koncepci chytrého oblečení, a to za pomoci strukturovaného popisu jednotlivých aspektů, jenž zahrnují například design či využití v praxi. Práce také nastiňuje problematiku chytrého oblečení týkající se například designu či výzev, kterým musí čelit. Autor se snaží popsat model chytrého oděvu, a to nejen jeho „chytré“ stránky, ale i z pohledu oblečení samotného a zároveň poskytuje zhodnocení chytrých oděvů v tržním a sociálním kontextu. Tato teoretická studie má za úkol informovat a zvýšit povědomí v oblasti chytrého oblečení, které má potenciál stát se významným prvkem ve světě vzájemně propojených zařízení, které tvoří rozsáhlé prostředí internetu věcí (Internet of Things, zkratka IoT).

K vypracování práce je z velké části použitá doporučená literatura, která se zabývá chytrým oblečením a tématy s ním souvisejícími. Odbornou literaturu rovněž zahrnují monografie, časopisy, sborníky, kvalifikační práce a články, které byly nalezeny databázích Vysokého učení technického v Brně, a to zejména IEEE Xplore Digital Library, Sage, Springer Link, EBSCO a ACM Digital Library. Pilíř koncepce chytrého oblečení je tedy založen na rešerši zdrojů ze zmíněných databází. Vzhledem k tomu, že koncept chytrého oblečení je poměrně nový a neexistuje jedna všemi uznávaná definice či perspektiva, se autor snaží zachovat rozmanitost ve zdrojích, což se současně odráží i v jejich počtu. Jednotlivé kapitoly bakalářské práce dále čerpají ze serverů jako researchgate.com či sciencedirect.com a v neposlední řadě byly jako zdroje použity i internetové články, blogy či stránky produktů a firem. Z důvodů zachování aktuality bylo pro zmapování informací a vytvoření osnovy pro tuto práci bylo nutné zrealizovat průzkum za pomocí internetu vzhledem k ne příliš aktuálním datům vydání některých publikací. Po zvolení názvu jednotlivých kapitol, podkapitol, vymezení jejich cílů a obsahu se primárně čerpalo ze seznamu doporučené literatury, zdrojů citovaných v těchto pracích a druhotně z prací na internetu a článků nalezených v návaznosti na dané téma. Následně při ověřování témat a tvrzení, byly vybrány ty s největší prevalencí mezi zmíněnými zdroji. Pro lepší vizualizaci daných chytrých oděvů, jejich rozdělení apod. byl ve většině kapitol použit obrazový materiál.

Práce je rozdělena do čtyř hlavních kapitol: chytré oblečení, design, využití a jeho současný stav. První kapitola slouží jako úvod do chytrého oblečení, která specifikuje a vysvětluje pojem „chytrý oděv“ popsáním dvou jeho aspektů, tedy „oblečení“ a „technologie“. Pro zajímavost a nastínění kontextu se kapitola zabývá i stručným historickým vývojem chytrého oblečení, který líčí první průkopníky ve světe chytrých oděvů a okolnosti, jež vedly k jejich rozvoji. Je zde zahrnuta i klasifikace chytrých oděvů nahlížející na možnosti jejich rozdělení ze dvou pohledů: pozici vůči tělu a jejich úrovni integrace.

Druhá kapitola diskutuje design chytrých oděvů a vysvětluje dvě základní skupiny kritérií, formu a funkci, zahrnující například estetiku, kulturní pozadí či požadavky cílené aktivity, které je nutné zohlednit při procesu výroby chytrých oděvů. Následně pokračuje popisem konstrukce chytrého oblečení, která navazuje na úvodní rozdělení jeho aspektů; popisuje tedy model chytrého oděvu z perspektivy oblečení samotného a chytrého oblečení jakožto sítě propojených zařízení plnících funkce komunikace.

Navazující třetí kapitola řeší využití chytrého oblečení a uvádí příklady produktů, využívaných v soukromém sektoru i volně dostupných na trhu. Tyto produkty jsou stručně popsány a kategoricky rozděleny podle sféry, ve které jsou využívány. Rovněž se u každé sféry zmiňuje technologie, která v dané sféře převládá a která je obvykle přítomná u produktů spadající do tohoto okruhu.

Závěrem se autor snaží zhodnotit současný stav chytrého oblečení, a to z různých pohledů. Popisuje vývoj a aktuální stav chytrých oděvů na trhu, povědomí společnosti o chytrém oblečení, jeho technologické, praktické a sociální výzvy, a v neposlední řadě přijetí chytrého oblečení ve společnosti.

Chytré oblečení spojuje dvě vzdálené oblasti oděvního a elektronického průmyslu. Výhoda chytrých oděvů spočívá hlavně v jejich pokrytí těla, jenž je dělá mimořádně mobilní a také obzvlášť vhodné pro monitorování různých fyziologických funkcí. Z průzkumu trhu a popularity chytrých oděvů je zřejmé, že technologicky obohacené oblečení je teprve na počátku svého vývoje. Tento „sci-fi“ koncept si postupně začíná razit svou cestu k mainstreamu, avšak s rychlostí, kterou tento proces současně postupuje by to mohlo být i v řádu desítek let. Je potřeba adresovat překážky, které brání rozkvětu tohoto byznysu, zejména technologické a praktické výzvy chytrých oděvů, ale také mnohdy zanedbávané sociokulturní aspekty, jenž souvisí s vnímáním, povědomím a přijetím chytrých oděvů ve společnosti.

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Vedoucí bakalářské práce: Mgr. Ing. Eva Ellederová, Ph.D.

Prohlášení

Prohlašuji, že bakalářskou práci na téma *Výroba a využití chytrých textilií* jsem vypracoval samostatně pod vedením vedoucí bakalářské práce a s použitím odborné literatury a dalších informačních zdrojů, které jsou všechny citovány v práci a uvedeny v seznamu literatury na konci práce.

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V Brně dne 25.5. 2021 ....

Dan Popek

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1 Introduction

Along the ongoing development of technology, the proportions of electronics are diminishing, and multiple functions can now be performed by a single device. Such progress caused new and exciting areas of research to emerge, one of them being smart clothing, which can be referred to as a "smart system", capable of sensing and communicating with the environmental and wearer's conditions and stimuli (Cho, 2009). Over the past three decades the research on textile electronics has evolved tremendously from initial explorations into a promising new industrial field on the market that is estimated to be worth 5.3 billion dollars by 2024.

The ubiquity of clothes and their pervasiveness on our bodies are the two key qualities which could change the way we interact with computing systems. As the current interaction of mobile devices mainly involve the user's explicit inputs such as touch and speech, smart clothes provide an intimate body contact, which opens new possibilities for the interaction. Since smart clothes can track the movement, bio-signals and the ambient environment, they have a great number of applications, such as healthcare, sport, fashion, education, security, etc., and slowly barge their way into the mainstream. However, smart clothes will still have to overcome such issues as washability, bulkiness, or durability to become appealing to the everyday use. Despite these obstacles, smart clothes may be revolutionary in a way how we communicate with the world around us, possibly even replacing smartphones one day, as a demand for more practical, mobile and easy-to-use devices increases.

The main goal of this thesis is to frame the concept of smart clothing and describe it to the readers. This is done by systematic division into the sections concerned with various facets of smart clothing. The thesis is divided into four main chapters: smart clothing, its design, applications and current state. The first chapter, which serves as an introduction to smart clothing, describes and specifies such a concept by addressing both the "smart" and "clothing" aspects. To outline a background for smart clothing, its historical context is provided as well as possible classifications of smart clothing. In the following chapter, specific criteria, such as aesthetics or end-use activity, are discussed. Besides, a construction model of smart clothing is proposed, approaching the topic from two perspectives: apparel construction and communication architecture within the smart clothing system. For more practicality, the next chapter gives real-life examples of smart clothing from three major active areas: healthcare, military and sport; and typical technologies within each field are presented. The last chapter discusses the current state of smart clothing, which involves its market situation, awareness and acceptance in society, or challenges it must face.

The reason why I chose to write this thesis is that I believe that smart clothing may become a new interface between humans and the digital world in the future, since technology always progresses, and people will always try to find new ways to make their life easier. Smart clothing, in my opinion, is now at the state similar to the beginning of smart phones in the 90s when they were too expensive, large and unwieldy. Unlike smart phones, smart clothing benefits from the direct contact with the user's body, which allows a whole new spectrum of capabilities to emerge. It is, therefore, in my interest to raise the awareness of smart clothes and possibly provide a steppingstone for the people who may want to further study this topic.

2 Smart clothing

Clothes have evolved rapidly over time – from just a thin layer of fabric separating the body from the outside world to protect and warm us due to our lack of hair to a whole spectrum of multipurpose garments being able to withstand extreme temperatures or carry advanced gadgets and electronics, allowing the user to adapt to almost every situation imaginable, often called as smart clothes. Uhlig (2012) suggests that "smart clothing can be roughly defined as clothing enhanced with electronic functionality" (p. 6). These electronic devices often provide intelligent services that can form a larger smart system based on a use of communication interfaces (Fernandés-Caramés & Fraga-Lamas, 2018).

Uhlig (2012) mentions that smart clothing can range from a jacket with integrated LEDs, which keeps bicyclists visible at night, to a snow suit that transmit weather reports to its wearer or sends an emergency signal in case of emergency or an undershirt that monitors a soldier's body for bullet wounds and transmits them to the base. To be able to carry out most of these functions, there is a need for smart clothes to be aware both of its surroundings or environment and the wearer itself. This is affirmed by Tao (2001) who notes that smart clothing is de facto a smart system capable of sensing and communicating with the environmental and wearer's stimuli. Both the stimuli and the responses can be electrical, thermal, mechanical, chemical and magnetic.

When defining the concept of smart clothing, it is important to bear in mind that this type of clothing is still clothing even though it is most technologically advanced. Therefore, smart clothing should be regarded as casual wear. Fashion is a critical ingredient in the process of designing smart clothes because the outcome is still a piece of clothing. For this reason, smart clothing must be designed with fashion considerations in mind and designers of smart clothing need to stay updated about fashion trends. Like normal clothing, smart clothing must fulfil emotional requirements (Ariyatum et al., 2005).

Considering the previous descriptions, the definition of smart clothes could be characterised by two aspects. First, it is a garment or, to a certain degree, accessory which includes some type of technological equipment with a specific function that allows the user to extend their capabilities in certain ways. Second, it performs the functions of casual wear, such as being fashionable and comfortable at the same time.

2.1 Historical overview

Many innovations we use in everyday life, such as Teflon, Gore-Tex and the World Wide Web, have their origins in military technology. During the latter part of the Cold War, military expenditure on both sides of the Atlantic grew and some developments ended up as commercial products. As the wearable technology was part of the military research programs, it was the first step in this field.

However, it was the rapid growth of electronics and computing in the second half of the 20th century, especially in the 1980s and 1990s, that benefited most. For example, the invention of the World Wide Web allowed people interested in this area to share information, which caused the research to progress in a faster pace. Next, it was the availability of computers which greatly facilitated teaching and learning electronics engineering and computer science thanks to lowering costs and accessibility of their parts (McCann & Bryson, 2009). Also, the penetration of electronics and computing in jobs, homes and everyday life brought up new areas of electronics or computer crossover research with physiology, medicine, cognitive psychology, culture, as well as wearables leading to the emergence of new technologies and strategies.

Malmivaara (2009) notes that "the cradle of wearable computing was where research resources could be expended in new technology and where the slightly unusual pursuits of science were not weeded out" (p. 7). As you could expect these places were predominantly technology-oriented universities and institutes, amongst the most progressing ones were Carnegie Mellon University in Pittsburgh (CMU), the Georgia Institute of Technology in Atlanta (Georgia Tech) and the Massachusetts Institute of Technology (MIT). The universities and institutes ran research programs in areas such as computer technology, computer science, virtual reality, user interfaces and new media, starting in the 1960s. By providing such areas of research, first cyborgs[1] emerged, many of which were students at the MIT Media Lab whose research and publications are considered by many as a foundation of the wearable computing today.

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1 Manfred Clynes and co-author Nathan labeled the word "cyborg" in a story called "Cyborgs and Space" as a human augmented with technological "attachments", published in *Astronautics*, September issue, 1960. In literature focused on smart clothing the term "cyborg" is sometimes used to describe people who researched this field, contributed to it or were part of the wearable community.

One of these students was Steve Mann known for his work in augmented and altered reality. Apart from running multiple wearable computing projects such as a wearable radar system for the blind, audio wearables or mediated reality wearables such as AR[2] systems, Mann (1997) describes his design of the first general-purpose wearable system called WearComp with graphics, text, multimedia and video capabilities in 1981 (as illustrated in Figure 1) and Wearable Wireless Webcam in 1994, which he used to become the first person in history to successfully live-stream, thus enabling viewers to see a live view on his website directly from his portable webcam.

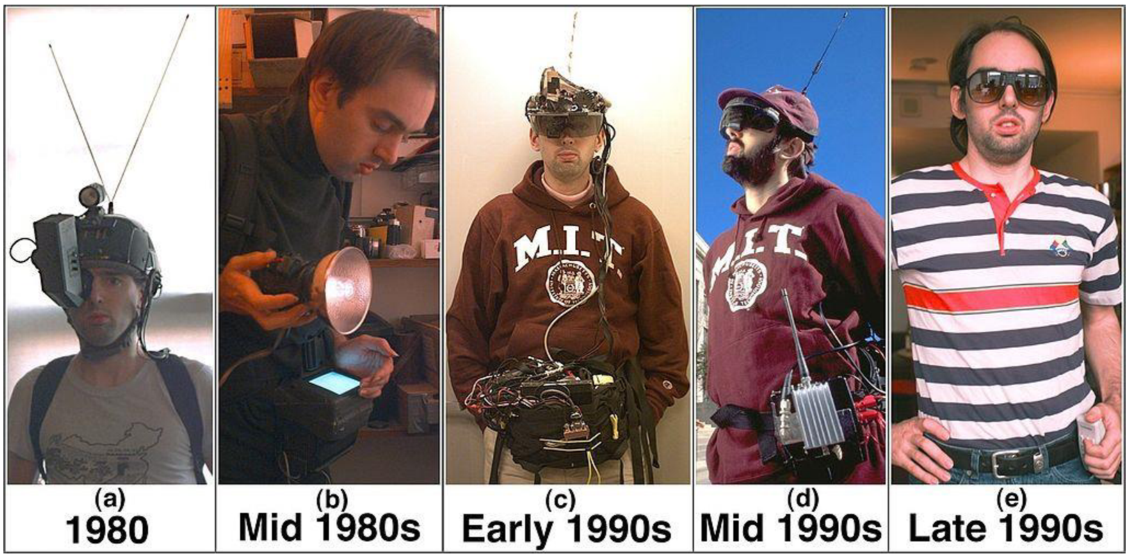

Figure 1. Evolution of Steve Mann's WearComp wearable computer.
Reprinted from https://www.wikiwand.com/en/Wearable_computer

The very first wearable computer, however, is often attributed to Edward O. Thorp and Claude Shannon who in 1961 created a cigarette pack-sized device with only 12 transistors that was used to beat Las Vegas casinos at the roulette wheel where it would time the revolutions of the ball on the wheel and estimate where it would end up. The computing device was worn on the waist and its output consisted of a speaker behind the ear, while the input was provided by a toe-switch. Thorp (1998) reports +44% gain, but the process required many tactics and skills to avoid suspicion and due to the reoccurring hardware problems, they never risked major bets.

2 Alkhamisi and Monowar (2013) define augmented reality or AR as able to deal with the new information immediately direct or indirect therefore influence the physical real-world environment has been enhanced/augmented were by adding virtual computer-generated information to it.

2.2 Classification

There are various approaches and parameters to classify smart clothes; therefore, to provide a general classification is challenging. According to the TC 124 of the IEC (2019), which actively tries to standardize the field of wearable electronic devices and technologies, one way is to categorize smart wearables which are integrated into smart clothes. To understand this classification, we need to distinguish between smart wearables and smart clothes. Fernandés-Caramés and Fraga-Lamas (2018) define smart wearables as electronic devices intended to be located near, on or in the body to provide intelligent services that can be part of a larger smart system, using communication interfaces, in the context of their integration within smart clothes, which can be created by embedding the smart wearables into garments. The classification of the European Committee for Standardization (2019) for smart wearables then read as follows:

- Accessory wearables – a low-power devices that are adapted to the human body in order to be worn as accessories like smart watches, smart glasses or fitness trackers.
- Textile/Fabric wearables – integrate electronics into textiles through flexible fabrics. In 2011, the European Center for Standardization categorized this kind of wearables, defining them as functional textile systems that interact with its environment (i.e., they adapt or respond to changes in the environment).
- Patchable wearables – skin-patchable devices that are flexible and very thin.
- Implantable wearables – lightweight self-powered wearables that are implanted into the human body without any health concerns.

IEC (2018) suggests that the previously mentioned types of wearables can be further classified, based on their location near, on or in a human body, into:

- Near-body wearables – intended to be located near the body but they do not need to contact it directly.
- On-body wearables – located on the body, in direct contact with the skin.
- In-body wearables – they are implanted inside the body.
- Electronic textiles – they make use of fabric or textile-based electronics and components.

In addition, Prahl (2015) explains that there are many methods of attaching electronics onto textiles, which differ mainly by their level of integration into clothing. To give some examples, such e-textiles, ordered from the lowest to the highest level of integration, can be (a) attached with clips or to belts, (b) magnet or velcro-attached, (c) based on flexible electronics, (d) sewn-in e-textiles and smart clothing (see Figure 1).

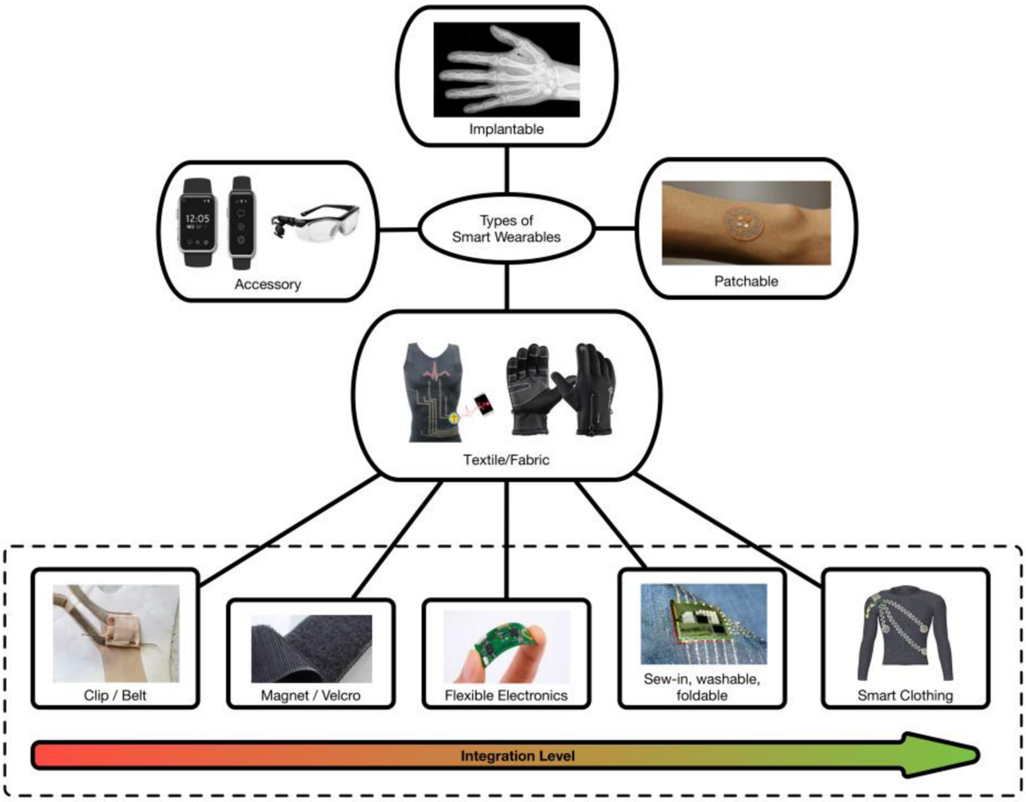

Figure 2. Main types of smart wearables and textile/fabric wearable.
Reprinted from Fernandés-Caramés and Fraga-Lamas (2018, p. 4).

More general classification was described in 1998 when the Tampere University of Technology and the University of Lapland and Reima Ltd. set out to explore wearable technology as a shared project. In the project, the different kinds of prototypes, concepts and a few commercial products needed to be organized into groups for inspection (Malmivaara, 2009). These groups were defined as *wearable computers, wearable electronics* and *intelligent clothing.*

A *wearable computer* is a computing device constructed in a way which allows it to be worn or carried on the body, while still having the user interface ready for use at all times. Such device would have both input, which can be keypads, joystick or buttons, and graphic interfaces such as LCD-displays as an output. The critical feature of wearable computer is its ability to be reprogrammed or reconfigured for another task, which may include adding or changing hardware.

Wearable electronics should be simpler than wearable computers. They are designed to execute set tasks to fulfil needs of a specific target group. Fundamentally, they are designed to be worn on the body, which should be also a premise for it to function i.e., there should be a conceptual link to the wearer's body. A chest belt or a heart-rate monitor is given as an example.

Intelligent clothing is defined as a garment which is enhanced with something un-clothing like, without taking away or compromising traditional characteristics such as washability or wearability. It adds a non-traditional function of the garment such as health monitoring or improve traditional function e.g., protecting the body. For instance, it could collect data and transfer it wirelessly or process the data itself, responding to the result, without any user interface.

In this chapter, two different approaches for classification of smart clothes were adopted. However, there are more classifications which use different aspects of smart clothes as a base to categorize them, for example Singh (2004) considers a functional activity which measures how well smart clothes can interact with their environment. Since most studies on smart clothes focus on specific area within the field, which might make the classifications misleading, a rather general approach is used here to provide a simple illustration of the classification.

3 Smart clothes design

3.1 End-user requirements

When designing smart clothes and wearable technology, it is important to consider various aspects which influence the way how the product will develop. The major element that dictates the design, apart from rather more general criteria such as washability or price, is the end-user requirements. According to McCann (2009, p. 45), “to be acceptable and comfortable, as a vehicle for self-expression, products must look stylish and attractive and function reliably in relation to the technical and aesthetic concerns of the wearer, as well as from social, cultural and health perspectives.” Utilizing this approach, he then suggests two main areas under which main topics of the end-user requirements can been organized, *form* and *function*, which are depicted together with the corresponding subareas in Figure 3.

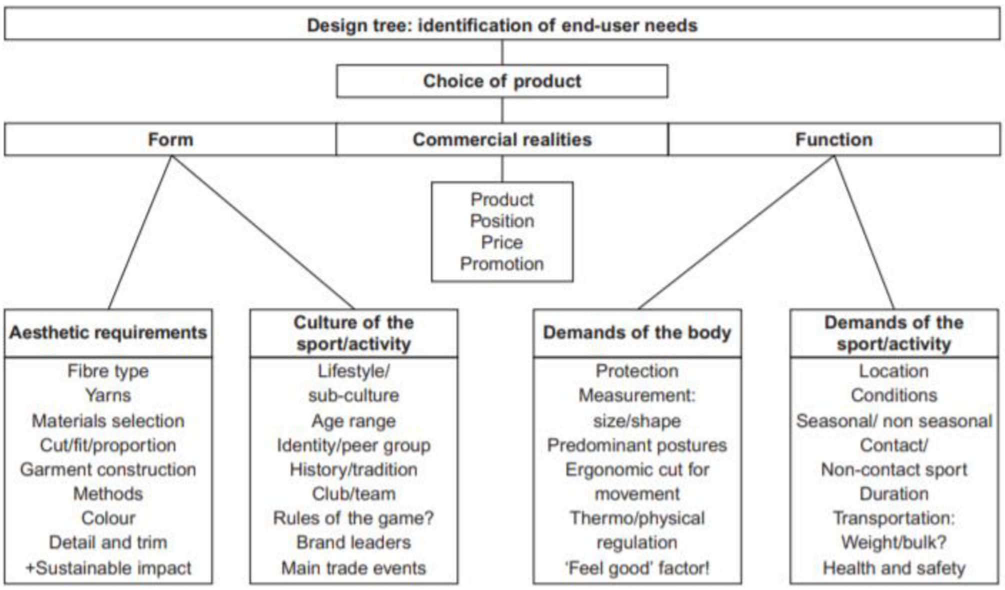

Figure 3. End-user requirements tree for clothes design process.
Reprinted from Bougourd and McCann (2018, p. 309).

3.1.1 Form

Form expresses aesthetic concerns and the importance of respecting the culture of the end-user. Simply put, it is the stylistic aspect of a garment and it is often considered as a key element in terms of acceptability and wearability of the final product, which is affirmed by Sonderegger (2013) who points out the strong correlation between the usability ratings and ratings of the attractiveness of the product, indicating that more attractive products are also considered to be more usable. When considering the 'style' of a garment, an appropriate balance of aesthetic concerns such as colour, fabrication, cut, proportion and detail will contribute to the users' psychological 'feel good' factor. For example, colour selection for components that constitute the individual item of clothing may be influenced by designer fashion, peer group trends, codes of culture and tradition, and individual preference as well as by corporate image or health and safety requirements (McCann, 2000). I will now describe some of those influences as they are essential during the process of designing smart clothes.

Component positioning

Wagar, Wang and John (2015) stress that appearance of garments is highly affected by the placement of the components. Certain areas in the human body are ideal for placement of additional components. Usually, such places are inert parts with large surface areas. However, it often depends on the type of the component, its design and the way it is integrated into the garment. For example, Martin (2002) mentions wrists as a perfect spot to place hearth beat sensors, unlike the neck or inside an elbow, as it is less movement-limiting and more comfortable and aesthetically acceptable for the wearer.

Culture of end-user

Today many business organizations are striving to move beyond their geographical boundaries by expanding into international markets (Ugur, 2017). This expansion requires knowledge of foreign countries with regard to their different social and cultural backgrounds. Certain cultures and their traditions may directly influence the code of wearables. What is perceived trendy by a younger generation will surely not be appreciated by elderly users in the same manner. Concerning smart clothes design, (McCann, 2009) highlights the import of cultural aspects as it is needed to foster awareness of both clothing requirements and the application of emerging wearable technologies that have appropriate functionality and true usability for the identified user. Such aspects may concern the lifestyle demands of the wearer in terms of behaviour, environment and peer group pressure.

Selection of material

Choice of fabric is essential since material qualities are an integral part of the overall experience. Ishii and Ullmer (2014) note that tangible user interfaces can make use of the human senses in a rich and multidimensional way. Factors such as breathability, elasticity, stretchability or thermoregulation need to be taken into consideration during the process of designing smart clothes. Modern smart wearables are often manufactured, using synthetic fabrics that offer more functionality and generally better qualities for technology integration. Properties of natural materials, however, cannot be neglected in the context of end-user requirements. Häkkilä, He and Colley (2015) present a study which compares user experiences when interacting with different natural materials. The user experience research findings regarding using natural material reflect the curiosity, aesthetics and playful nature of the interaction, and they provoke many associations and memories.

3.1.2 Function

Function follows standard demands of the human body and particular demands of the end use or activity. McCann (2009) states that the comfort of clothing is affected by appropriate styling in relation to measurement, shape and fit, predominant posture and the ergonomics of movement for a particular community or target market. Sizing comes as an important criterion, since small, medium or large sizes cannot be definitively set for all ranges of end-use activities and ages. Clothing should, ideally, enhance support for the body where needed without restricting movement and be adjusted with relation to the use or activity it is intended for.

Body demands

Many authors associate the demands of the human body with the comfortability of a garment. Various aspects can be observed in this context. According to Kaplan and Okur (2011), the five most important fabric/garment attributes that influence comfort are garment fit, sweat removal, thermal insulation, allergic problems and design. These attributes are confirmed by McCann (2009) who highlights the thermal regulation and moisture management as key aspects of the maintenance of comfort. Nayak, Wang and Padhye (2015) report that the thickness or type of material tend to retain body heat and perspiration inside the garment, which can all lead to heat and moisture build-up and subsequently compromise the body’s ability to maintain thermal balance, resulting in discomfort and fatigue. Turner (2000) states that wearers will not be comfortable and may be at risk in relation to cold exposure if a high level of moisture is absorbed within the garment base layer; for example, cotton instead of fibres that wick away moisture. Any special requirement such as the case where the user interacts with an extreme environment must be kept in mind when designing such apparel (Hännikäinen, 2006). In addition, electronic components generate heat. All the above factors can lead to thermal discomfort.

End-use purpose

Together with the human body needs, we must consider demands of the activities for which smart clothes are designated. It is necessary for designers to identify the main activities or sequence of events, look at any relevant training manuals or videos as well as primary research in observing and obtaining feedback to identify with the end-user needs (McCann, Hurford and Martin, 2005). Related questions may be presented in the process: Is the activity permanent or of medium or long duration? Is it a uniform for daily use, leisure wear worn once a week or wear for travelling worn for a couple of weeks per year? Understanding the impact of the environment in which the activity takes place is required. Is the activity seasonal? Can it be practised indoors in a stable environment or outdoors in unknown terrain? Is it a contact or non-contact activity? Are there extreme conditions or a range of temperatures and degrees of humidity? Mentioned criteria highlight the need for the communication between the designer and the user, which again promotes the idea of collaborative design with the users as an efficient approach for smart clothes design. Nevertheless, Uhlig (2012) proposes that the whole process should not be solemnly steered by the users.

3.2 Construction

Generalization of the construction of smart clothes is not an easy task. Rich diversity of garments exists within clothes, varying in shape, cuts, purpose and other aspects. However, we can approach this issue by using *layering principle*, which recognizes layers within an apparel that smart clothes can follow in general. Intuitively, we should consider the technological factor of smart clothes. De Acutis and De Rossi (2017) claim that e-textiles will eventually enter the environment of the Internet of Things (hereinafter referred to as IoT), therefore I will focus on the communication system of a smart garment to illustrate the structure of such a system and provide a general idea of how it can function.

3.2.1 Layering principle

The functional *layering system,* originally tested and later used in military combat wear and now adopted in performance sportswear, embraces an inter-dependent base-layer, a mid-insulation layer and an outer protective layer (see Figure 4). Each layer of the garment system can be used as a potential location for the embedding of wearable technologies such as vital-signs monitoring in underwear and base layers, thermal regulation together with impact protection in mid-layer garments, and textile-based electronic user interfaces in the outer layer. McCann, Morsky and Dong (2009) add that "the effective functioning of the layering system provides a focus for design innovation in the cutting and placing of an appropriate mix of technical textile structures and assemblies around the body (p. 236)."

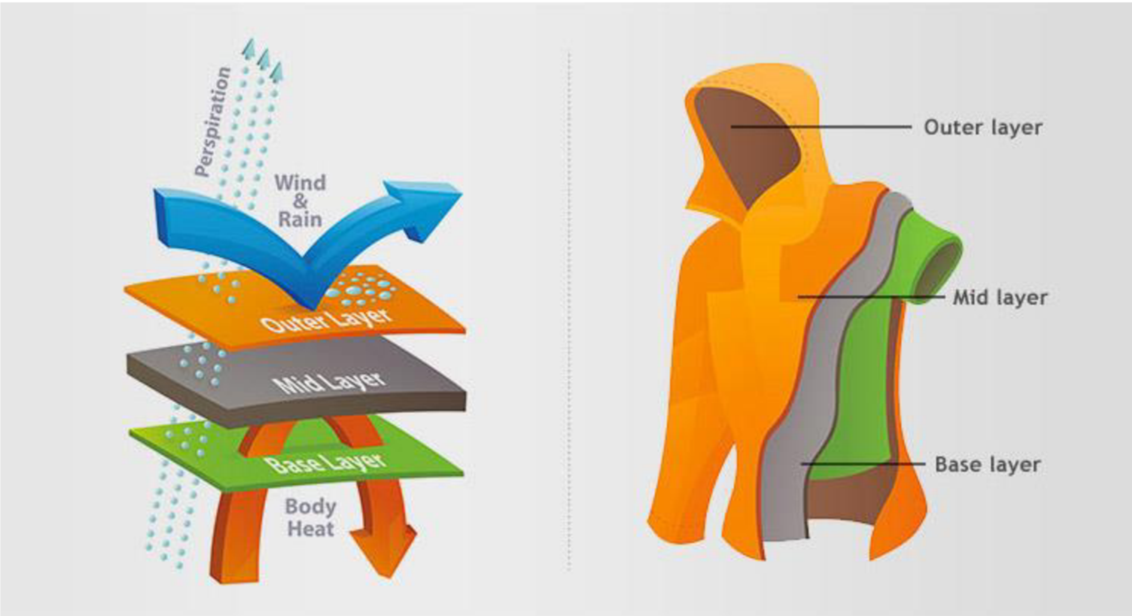

Figure 4. Layering system.
Reprinted from https://www.blacks.co.uk/blog/the-layering-system-a16

Base layer

A base layer is one of the most integral pieces of clothing, forming the key foundation of the layering system and enabling users to stay warm and dry. It is the wicking layer which transports away moisture from the skin and helps regulate body temperature. Sweat goes through the next layer of clothing so the base stays dry. Light-weight warp and weft[3] knitted structures are usually selected for easy movement, providing stretch in their stitch construction to fit like a 'second skin', enhanced through the integration of elastomeric fibres (McCann, Morsky and Dong, 2009).

As for fabric, synthetic materials are used more often than natural ones. For example, standard cotton holds perspiration and cause you to feel cold and clammy when resting unlike fabrics made of materials such as polyester or polypropylene which wick the perspiration away from the skin and prevent chilling especially when stationary or in extremely cold conditions (Baker, 2016, September 8). However, there is still use for fabrics of natural origin. Merino wool, for example, is a great insulator keeping body warm in colder, exposed conditions and is a natural anti-microbial. Added value may be provided through a range of fibres and finishes that offer anti-microbial, antiseptic and anti-UV protection as well as through the micro-encapsulation of vitamins and natural healing materials (Hibbert, 2004). Such qualities can find use, for example, in custom-made garments for the treatment of burn victims. The fit and shape of the body for a range of figure types is an obvious consideration for the design development of base-layer garments with embedded wearable technologies.

A sublayer of the base layer is often recognized as intimate apparel which include bras, briefs, shorts, corsets, swimwear etc. Design is mainly focused on comfort since it is directly in contact with skin which is convenient for monitoring health or performance. This can be utilized particularly in smart sport underwear, which became a popular branch as there is a high demand for monitoring performance when exercising (Cadenius & Gartvall, 2018).

Mid layer

The main purpose of the mid layer is to serve as insulation to trap and return excess body heat from the base layer. However, Lyko (2014, October 21) points out that a high-quality mid layer will also be breathable. The layer also wicks moisture away from the body, so any trapped liquid is transported out to be evaporated. The mid insulation layer is usually lightweight, thin and windproof, designed to maintain a pleasurable temperature and capable of transferring heat before overheating occurs, e.g., via a full zip or sleeves wide

[3] Warp and weft – technical names for long continuous lengths of interlocked fibres e.g. yarns. The yarn which lies parallel to the fabric edge is called the warp and the yarn which lies perpendicular to the fabric edges is called weft yarn (Sarkar, 2020, February 5).

enough to be pulled to the elbows. McCann, Morsky and Dong (2009) identify two varying components of the mid insulation layer. It is the ability to trap still air, i.e., to maintain the stable microclimate in between the wearer and the garment and the thickness of the layer. The fibres of the insulation layer require higher volume to be able to efficiently trap the air, which is achieved by using 3D space knit, woven and non-woven assemblies. In addition to this, mid layers are often designed to fit loosely on the body so that there would be more space for the trapped air (Devold, n.d.). The thickness varies according to the weather for which the garment is intended where logically thicker layers are more suitable for colder environments. Common mid layers can be fleeces, soft shells, or sweatshirts.

Wearable electronics may be embedded in the mid layer garments to provide enhanced thermal regulation, for example the Venture Heat Softshell ~~or~~ and the North Face heated fleece.

Outer layer

The primary role of the outer layer is to protect the preceding layers from water, wind or snow and at the same time to allow perspiration to escape, i.e., to be breathable. Fabrics of the layer are normally made of lightweight nylon or polyester, which are exceptionally strong fibres, and they may also have areas of more abrasion-resistant fabrics. Outer layer garments are normally made of woven constructions and may be referred to as ‘hard shells’ with coatings or laminates incorporated in two- or three-layer assemblies (McCann, Morsky and Dong, 2009).

Lister (1963) and Mierzinski (1903) write that the most common way to achieve waterproofness is by coating the fabric with a solid polymeric coating such as neoprene, polyurethane, or polyvinyl chloride. However, such solid nonporous continuous layers are impermeable to the passage of both air and water vapour, which makes them fully waterproof but not breathable (Holme, 2003). Breathability of garments and fabrics is crucial regarding garment comfort and, more importantly, the maintenance of a stable body temperature. On the other hand, the absence of water repellent finishes, which increase the breathability, is expected to result in soiling or staining, which, in turn, requires the fabric to be laundered more often. Therefore, to find the golden mean, the characteristics of a waterproof shell should be adjusted to allow the transmission of water vapour to make it breathable as well as waterproof (see Figure 5), for the usage of waterproof breathable fabrics is enormous (Özek, 2018).

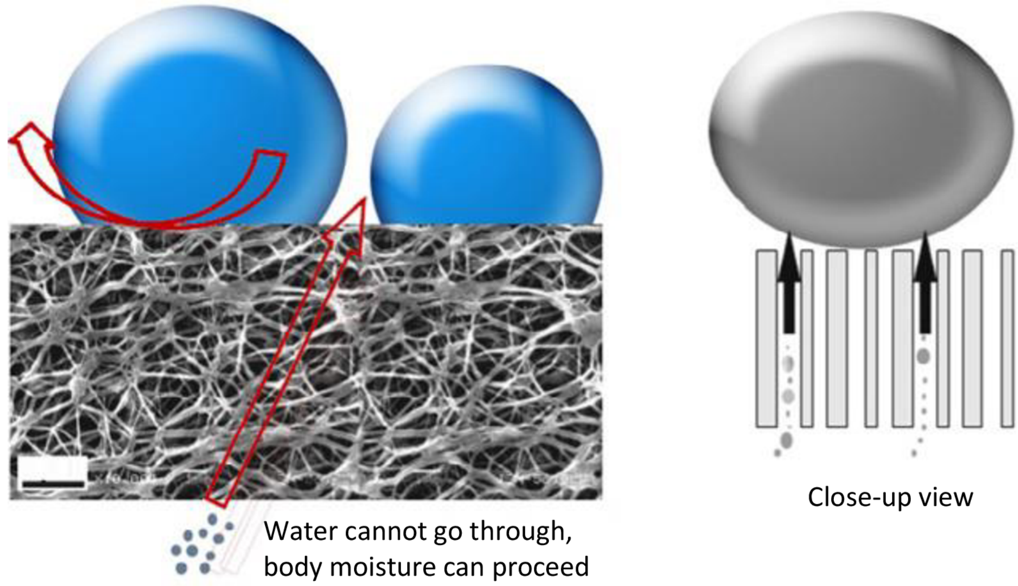

Figure 5. The functions of 'waterproof' and 'breathable' character.
Reprinted from Özek (2018, p. 30)

3.2.2 Communication architecture

Smart wearables are becoming increasingly pervasive, which is propelled by the continuous miniaturisation of electronics, advances in sensor technology, computing power, connectivity and improving capability to embed intelligence in electronic components and systems. Together with the rapid development of the IoT, cloud computing and big data, smart clothes improve their communication, storage and control capabilities, which makes them an ideal candidate to become the new interface between humans and the digital world (EC, 2016). Having a reliable and functioning communication network with devices communicating within and outside the garment may be an essential feature in the process of integrating smart clothes in the IoT.

Fernandés-Caramés and Fraga-Lamas (2018) seek to provide a diagram (see Figure 6.), which shows subsystems of such a network and illustrates how the segments are connected. The different subsystems may communicate by using either wireless communication or by using conductive fabrics.

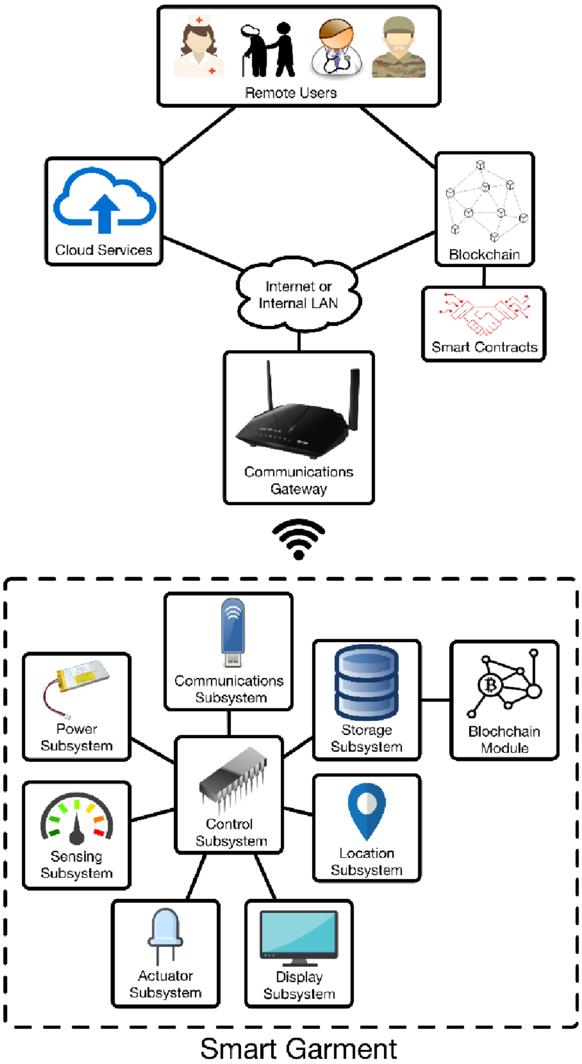

Figure 6. Generic architecture of communication smart garment system. Reprinted from Fernandés-Caramés and Fraga-Lamas (2018, p. 6).

The part of the communication architecture which supports collecting smart clothing data consists of a communication gateway, a cloud server and a blockchain.

The communication gateway exchanges information with the smart garments in order to send it through the Internet or an internal LAN to remote services provided, for instance, by cloud servers or a blockchain (Fernandés-Caramés and Fraga-Lamas, 2018). Bonomi et al. (2012) state that the gateway acts as a medium between the end device, i.e., a smart garment and the cloud services, enabling the users to place resources and providing swift responses to the smart garments.

Cloud servers provide us with a facility of sharing, accessing and interoperating the resources between different users and the systems being owned by the organizations (Palivela et al., 2011). Blockchains are able to track, coordinate, carry out transactions and store information from a large number of devices, enabling the creation of applications that require no centralized cloud. These components are then divided into three layers, according to the range: BAN, PAN, LAN and WAN.

A Body Area Network, or BAN, is a short-range network, where devices are distributed around the body, i.e., the devices are embedded in garments, therefore it is called a Wearable BAN (WBAN). Anwar et al. (2018) comment that since smart garments mostly rely on batteries, there is a need for WBANS to be energy efficient.

A Personal Area Network (PAN), e.g., Bluetooth and a Local Area Network (LAN), e.g., Wi-Fi, collects data from smart garments and send them to a cloud or remote server.

A Wide Area Network (WAN) is created when many smaller local area networks are connected together to form a larger group, spanning a large geographic area such as a city, a state or a country (Mitchell, 2020, August 14). It is similar to the Internet and essential for many IoT applications.

As discussed previously, smart clothes are often aware of their environment so they can react to the stimuli. This function is performed by the sensing subsystem that monitors diverse phenomena or events, such as temperature, vital sign rates, motion, altitude, location or objects, from the surrounding environment via sensors and detectors (Stoppa & Chiolerio, 2014). Assuming that most smart garment systems are comprised of multiple components, a control subsystem is required to coordinate and control their functions. Fernandés-Caramés and Fraga-Lamas (2018) mention such devices as CPUs, microcontrollers, or ASICs. Although Control Processing Units are computationally efficient, they consume too much power, which is inconvenient for smart clothes, since they are usually powered by small batteries. Microcontrollers, however, require less power and have sufficient computational power to carry out most tasks. Thanks to their sufficient on-board memory, they are readily usable without additional computing components and can directly interface with sensors and other components (Rouse, 2019). Application-Specific Integrated Circuits are designated explicitly for specific applications. Sinclair (2011) states that ASICs are high performance devices with low energy demands but more expensive and complex to manufacture.

Sharma (2011) explains that when a system performs a function, a control subsystem acquires information from the process through process inputs, i.e., event or information that triggers the process, or from the human interface subsystem. An interface between the user and the smart garment may be implemented in the form of displays, but they generally require a lot of energy and have other problems, such as resistivity to high or low temperatures, drops or external impacts, especially with regards to smart clothes. Nonetheless, they might be easier and more comfortable when interacting with a smart garment rather than using external devices to do so. For example, electronic-ink displays consume power only during the process of updating the shown information, which saves a tremendous amount of energy (Siegenthaler et al., 2012).

A subsystem responsible for communication itself may be a key for integration of smart clothes into the IoT as the connection to the Internet opens up a wide variety of use cases and applications that utilize large databases and remote processing power. Fernandés-Caramés and Fraga-Lamas (2018) propose two main functions of this subsystem: mutual transportation of data between a smart garment and a communications gateway and identification mechanism for the wearer, e.g., to identify through MAC address or IP and a port. Popular technologies which can provide both the identification and communications channels include Bluetooth, Wi-Fi, 3G/4G,5G, infrared or ultrasound. However, a technology for identification alone can be used as well. In this case, a well-known identification system, such as RFID or NFC, may be used. In simple terms, they are non-contact systems, usually comprising a reader and a tag, which can exchange information on short distances (Chandler, 2012, March 7). RFID is usually used for asset tracking and NFC can enable contactless payments. They have many advantages, although the most relevant is that line-of-sight is not required between a tag and a reader and their small size, therefore they can be embedded into garments or accessories easily.

Lemey et. al (2016) state that data collected by other subsystems of a smart garment are initially processed by the control subsystem, which reduces the amount of the data to be transmitted, and then stored locally in static memories, e.g., SD cards. However, if we speak about smart clothes in an IoT context, Bishop (2019, November 5) suggests storing the data on external servers, as it is less expensive and complex. In addition, with regards to smart wearables, there might be other disadvantages to local storage subsystems in smart clothes due to their wearable nature, e.g., external impacts. Chen et. al (2017) and Fernandés-Caramés et. al (2018) propose uploading information to a cloud server or fog computing gateway[4] as a way of external data storage, where the data are processed, stored, and eventually presented to the user through a graphical interface, e.g., via a web application.

Lastly, a smart garment system needs a power source. For example, Fernandés-Caramés and Fraga-Lamas (2018) claim that batteries are the most important and efficient ways of establishing energy networks in smart garments. Nevertheless, Jung et. al (2014) suggest supercapacitors for same purpose since they offer a high-power density, a fast charging and discharging speed and a long lifespan. Min (2009) divides the power requirements of portable devices into three categories:

- Low end: These are small electronics able to last even for years and can readily be embedded into smart textiles without much trouble or causing inconvenience to wearers.
- Mid-range: These are usually devices with wireless communications which are powered by classic batteries, e.g., AA batteries.
- High end: Such devices make use of Li-on batteries, e.g., laptops or smartphones.

All the above-mentioned subsystems should provide a skeleton, showing the main components which perform various functions and together form a smart clothing system with an emphasis on the communication aspect of smart clothes, which is an essential part of integration of smart garment systems into the IoT. Additionally, EC (2016) consider IoT and wireless communication standards as necessary to enable interoperability between wearables and their environment, e.g., smart homes, smart buildings, since most wearables will have communication capabilities.

[4] Omnisci (2020) defines fog computing as a decentralized computing structure located between the cloud and devices that produce data.

4 Applications

Chunyan and Yue (2015) state that "intelligent garment design is a multidisciplinary subject". To design a smart garment, there, indeed, are different disciplines involved in the process. Usually, it is a combination of fashion and different branches of technology. Such a combination might sound rather narrow at first glance, but reality is that when you merge already a vast field of technology with wearable designs, you get a great number of emerging subbranches with considerable potential. A significant role in smart clothes is ascribed to IoT due to which smart clothes are allowed to thrive even better, allowing users to interact effortlessly, e.g., via a smartphone. Applications for smart clothing are still rather specific, regarding usage, although a Survey by World Economic Forum (WEF) predicts that 10% of people would wear Internet-connected garments by 2025, which may suggest that smart clothing will potentially find its way into mainstream, which it has been striving towards for years. There are many applications for smart clothing, but in this chapter, the three main areas and their products are discussed, because of a large amount of information.

4.1 Healthcare

Smart clothes in healthcare are primarily concerned with monitoring of body signals through sensors and diagnosis as clothes and textiles are in direct contact with about 90% of the skin surface, therefore, smart sensors and smart clothes with non-invasive sensors offer an attractive solution for home-based and ambulatory health monitoring (Leutheuser et al., 2017). Monitoring vital signs normally involves recording a heart rate, body temperature, a respiratory rate and blood pressure but it may also include other measurements such as posture and motion, pulse oximetry and electrocardiography (ECG). Nevertheless, to provide personalized healthcare and non-invasive monitoring through user-friendly wearable interfaces between devices and humans more than just sensors is required. Textile-based wearable body sensor networks (WBSN) are close interdisciplinary collaboration between biomedical sensors, electronic textiles and advanced wireless network technology (Kim & Wang, 2015). For instance, VitalPatch® is a health monitoring device for home and hospital use which monitors eight vital signs and can be remotely connected via a mobile app.

InfoBionic's MoMe System continuously streams ECG and motion data for real-time review to allow physicians to accurately diagnose and treat patients remotely. Socks^{TM} by Siren company is a foot monitoring system that tracks foot temperature and other information for people with diabetes to prevent amputations (see Figure 7).

Figure 7. Siren Socks.
Reprinted from https://siren.care/.

Apart from sensor technology, GPS technology found an application in medicine as well. GPS is used to track and communicate with elderly people suffering from dementia or Alzheimer's. A study by Pot, Willemse and Horjus (2012) shows that both carers and dementia patients were less worried when being alone, were more often outside independently, and received more freedom from their caregivers when being tracked, using GPS.

Yamakhoshi (2011) states that WBSN for non-invasive healthcare monitoring will be the most desirable development required for preventive medicine, early diagnosis and timely treatment of chronic diseases. As the population is getting progressively older and the quality of life improves, a demand for less expensive and higher quality healthcare increases. Together with the fact that patients, in general, prefer treatment at home with minimum pain and discomfort, integration of non-invasive sensors into clothing can enhance home healthcare (Axisa et al., 2005). Thus, the cost of healthcare could be reduced, while the quality of healthcare would remain the same. Still, WBSN have to face many challenges, such as miniaturization of components, energy consumption, wireless communication, or data privacy.

4.2 Military

The current and potential applications of smart clothes in military are miscellaneous. They range from health monitoring body suits to performance enhancing powered exoskeletons. Smart clothing also has a long history in military application. In fact, the first idea to put embedded sensors into garments was given birth thanks to Dr. Sundaresan Jayaraman's research team at Georgia Institute of Technology whose smart T-shirt project funded by the US Department of Navy won the best invention of millennium in 1998 (Georgia Tech Wearable Motherboard™, n.d.). Scataglini, Andreoni and Gallant (2015) identify the current main applications of smart clothing in military as health monitoring, environmental safety monitoring, stress management and empowering human function. The most prevalent function seems to be health monitoring, i.e., monitoring of vital signs (heart rate, temperature, etc.). A typical example of health monitoring smart clothing could be WPSM (Warfighter Physiological Status Monitoring) system which measures and monitors a heart rate, a respiration rate, body motion and body position, fluid intake, sleep, etc., and transmits the collected data to the wearer or the paramedic during the combat (Tharion & Kaushik, 2006). But monitoring does not always have to concern vital signs. For instance, a uniform model called Teleintimation Garment developed by Ashok Kumar is able to track bullet penetration in addition to viral signs measurements (Kumar, 2015).

Apart from clothes, accessories seem to be another point of interest in the research field on smart wearables. For example, IVAS (Integrated Visual Augmentation System) high-tech tactical glasses are being developed by Microsoft for the U.S Army. Apart from having many other functions, the most significant capability of these glasses should be aided target recognition, allowing to recognize difference between a civilian and an enemy (Cox, 2019, November 20). Progress has also been made in research on exoskeletons, which can improve the current physical capabilities of a soldier, allowing them to run faster, lift heavier objects and relieve strain on the body during physical operations, e.g., Lockheed Martin's Onyx (see Figure 8), which is a performance enhancing system which combines mechanical knee actuators with multiple sensors and artificial intelligence software to improve strength and endurance (Husseini, 2020, May 15).

Figure 8. Lockheed Martin's Onyx.
Reprinted from https://www.lockheedmartin.com/en-us/products/exoskeleton-technologies/military.html

One great issue with such robust exoskeletons and electronic wearables in general is power. The power sources are often too invasive and often have to be recharged, which is not suitable for soldiers who have to be mobile, especially on the battlefield, since every excess weight is undesirable. Therefore, power systems for energy harvesting are developed. For example, E-uniform proposed by Srivastava et al. (2020), which collect solar energy thought an integrated solar panel or the PowerWalk® by BionicPower (2021), which is a bionic power product composed of a knee brace. With a device on each leg, a walking soldier can generate enough power to charge up to four smart phones over the course of an hour, walking at a comfortable pace.

There also have been attempts to create full body suit systems which would combine all of the functions imaginable, for instance, TALOS (Tactical Assault Light Operator Suit) exosuit which was supposed to include embedded sensors for monitoring body temperature, a heart rate, hydration levels and body position, heaters and coolers to regulate the temperature inside the suit, full-body bulletproof armour, 360° cameras with built-in night vision and a powered exoskeleton (Scataglini, Andreoni, & Gallant, 2015). The project was launched in 2013 and despite the 80 million dollars budget, it was abandoned in 2018 due to insufficient technological advancements in the various fields, which created challenges yet unable to be overcame by the current technology (Shehzad, 2020, May 10). However, there are ongoing projects on smart clothing in military and it has been anticipated that smart clothing, equipped with sensors to optimize/enhance the soldier's performance and protection, will be available to the US army's combatants by 2025 (Scheftick, 2014, September 12).

4.3 Sports

Today's smart wearables are usually compact, light and mobile, which makes them a great possible target for applications in sports. Especially for sports, it was the recent advancements in sensors and wireless communications together with the miniaturization of electronics, which allowed smart clothes for sports to bloom. Not long time ago the traditional methods for studying athletes were restricted by the need of the systems to either be connected to power, or for the sensors to be directly tethered to the processors, which kept many studies limited to laboratories rather than performing experiments in the field of play (Scataglini, Moorhead and Feletti, 2020). In addition, the systems were often bulky, which restricted the athletes to perform as they would normally do, therefore the data received would be rather inaccurate. Now, electronics are embedded into garments seamlessly, which resulted in more comfort and lower restraint of movement for the user. A typical example of smart clothing in sports could be the Smart Shirt by Ambiotex. Smart Shirt as illustrated in Figure 9. The Smart Shirt contains integrated sensors, along with the clip-on box, which record vital sign data such as heart rate variability, anaerobic threshold, as well as fitness and stress levels (Ambiotex, 2021). The collected data are then sent to an app which visualizes, analyses and stores the data in real time.

Another instance of advanced body monitoring could be AIO Smart Sleeve by Komodo, which uses ECG technology to monitor heart rate activity, sleep and workout intensity. The sleeve also has sensors for measurement of body temperature, air quality and UV rays (Komodotec, 2020). The products that have been stated so far are targeted at rather casual fitness and sport enthusiasts, though there are items of smart clothing intended for professional athletes as well. For example, Athlete Recovery is Under Armour's absorbs heat from the body and then reflects it back onto the wearer's skin. The way it is done is achieved by incorporating bio-ceramic technology into a patterned lining of the garment. The pattern includes special bio-ceramic particles that absorb infrared wavelengths emitted by the body and reflect back far-infrared energy, which is a completely safe type of radiation that promotes cell regrowth within the body, helping the body recover faster while promoting better sleep (Ismael, 2021). The next example of smart clothing for professional athletes can be Smart Sock by Sensoria. These socks are made from high-tech running friendly fabric, with One Sensoria Core microelectronics that snaps into the dock attached to one of the socks. Apart from monitoring various body signs, they track cadence, foot landing technique and the impact score generated as you walk and run, helping you identify injury-prone running styles (Sensoria, 2021).

Figure 9. Smart Shirt by Ambiotex.
Reprinted from https://www.trendhunter.com/trends/ambiotex

Overall, it was noticeable that the utilization of smart clothes in various fields usually resides in implementation of sensors for monitoring predominantly vital body signs data, which is then usually further processed through a smart phone app for analysis, comparison, etc., depending on the product functionality. However, there are many instances of smart clothing which perform different functions than simply monitoring. Needless to say, smart clothing has various applications across a large variety of fields with new products appearing on the market’s horizon.

5 Current status of smart clothing

The current status of smart clothes offers a perspective essential to the overall assessment of smart clothes. Smart clothes are a relatively new and exciting field attracting the interest of many people from different areas. As mentioned earlier, the potential of smart clothes is enormous, but this fact alone cannot bring success to smart clothes on the global level. If smart clothes want to succeed in the already competitive market environment, many challenges will have to be addressed before doing so.

5.1 Market

Smart clothing has been on a market for quite a short time. The first prototypes presented for consumers could be seen emerging in the early 2000s. It was at this time when the awareness of smart clothes, particularly their vast application potential, grew and new ideas were introduced. Langenhove (2015) describes smart clothes as an example of “hype” because of the initial excitement they invoked. This excitement caught an interest of many stakeholders, and smart clothes became not only a popular theme at conferences and workshops but also inspiration for various research projects. Smart clothes created many high expectations and even brought hope for the textile industry which was on the downfall at that time. As a result, several initiatives were set up to map the potential of smart textiles, e.g., the project SYSTEX. After a considerable amount of information was collected, it turned out that despite all the investments and market potential, no commercial breakthrough has been achieved yet due to several reasons concerned with standardization, market approach or insufficiency in the development of certain complementary technologies, e.g., smart material and data processing tools. Such results led to a gradual loss of interest. Nevertheless, smart clothes market estimated value was 2.16 billion USD in 2019 (see Figure 10). Although in 2018 it was 1.8 billion USD, which is not a great difference, a slight uptrend for the market is still present. As you can see in the chart in Figure 10, predictions for smart clothing still remain fairly positive. The source for the potential might not only come from the variety of applications but also from the market perspective. When we consider the size, growth and pervasiveness of the enormous apparel market and wearable technology, the merger of wearable technology with clothing might be a direction for possible market expansion (Hanuska et al., 2016). A recent smart clothing market report by the Insight Partners (2020) shows some interesting data, e.g.:

- In 2019, North America led the global smart clothing market, followed by Europe and Asia.
- The driving factor in the market seems to be rooted in healthcare and fitness, more specifically in vital signs monitoring.

Smart clothes are still present on the market and their market share gradually grows. From the market evolution and forecasts, one could conclude that estimated market potential is growing, but the reality shows that the real propagation of the market is usually lower than it is forecasted.

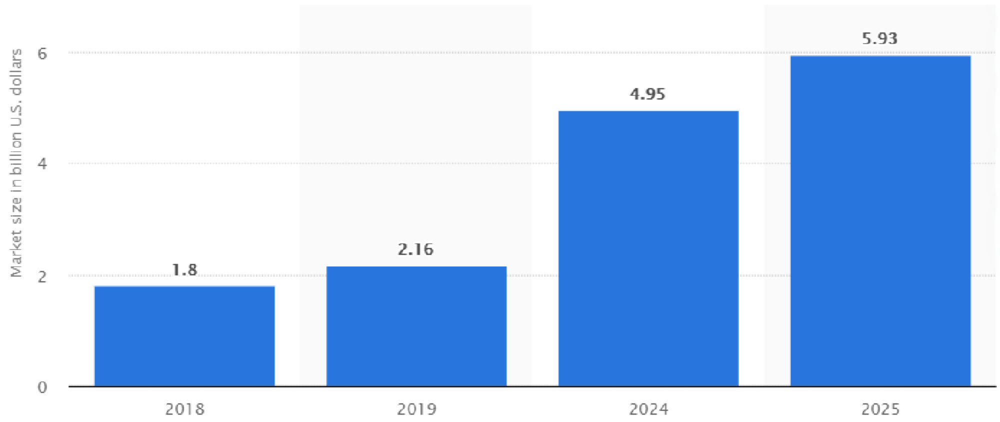

Figure 10. Smart clothing market size (in billion USD). Reprinted from https://www.statista.com/statistics/302735/smart-clothing-fabrics-shipments-worldwide/

5.2 Awareness

As illustrated in Figure 11, after the initial “hype” era, the searches for smart clothing settled around 25% of 2004’s peak period. From this chart, one might assume that popularity of smart clothes is not on the rise compared to wearables which reached over 32 billion USD on the market in 2019 as well as more Google searches.

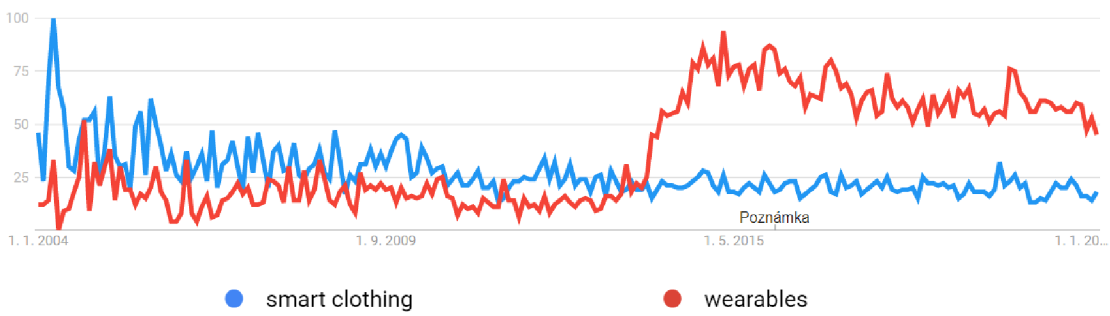

Figure 11. Google search trends for smart clothing and wearables.
Reprinted from https://trends.google.com/trends/?geo=US

A similar conclusion can be drawn from GMI APAC Wearable Technology Survey of 2015 (see Figure 12) which compares awareness of different wearable tech products.

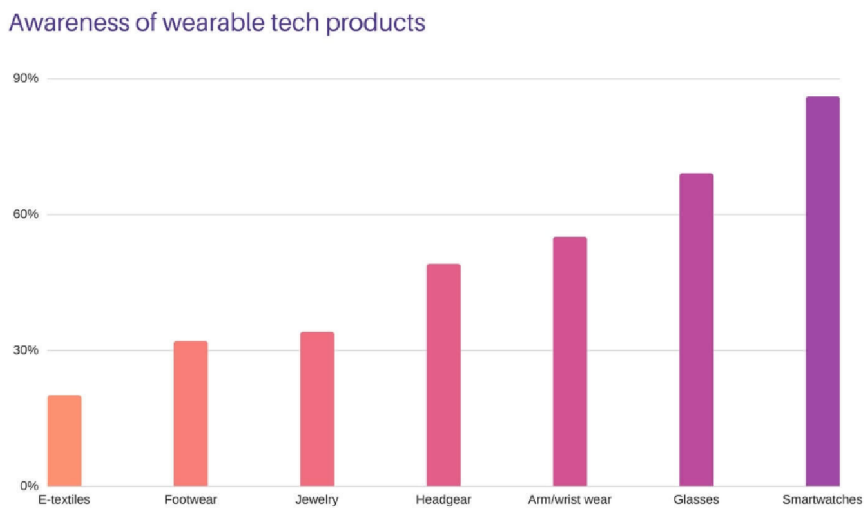

Figure 12. Awareness of wearable tech products in 2015.
Reprinted from https://teslasuit.io/blog/smart-clothing-market-challenges/

Only about 20% of the respondents are aware of smart clothing. One of the reasons for this lack of awareness could be the fact that smart clothing is not yet produced by major companies but rather by kickstart projects (Fernandés-Caramés, 2018).

5.3 Challenges

In order to create smart clothing more appealing both to the customers and companies, many obstacles must be overcome. Schneegass and Amft (2017), for example suggest:

- Fabrication – in order to realize smart textiles for various applications, one generic textile technology should be used as a basis and then altered and enhanced for the specific application.
- Integration – essentially integration of smart textiles into IoT; making smart clothes part of the "microcosm" of devices, i.e., smartwatches, smartphones etc.
- Privacy and control – security and protection of the data will determine the acceptance of smart textiles.
- User-centered evaluations – during the design process of smart clothes the user should play a crucial role in evaluation.

Joshi (2020, September 22) expands on these user-centred evaluations and mentions:

- Price – smart clothes still sit in a price range, rather unappealing for general population. Most items of smart clothing include embedded electronics and unique textile materials, which increases the price.
- Washability – consumers want a smart garment which will be reliable and usable for as long as possible. Therefore, washability presents a major concern as the integration of electronics makes the process almost impossible.
- Durability – since the majority of smart clothes includes electronics, e.g., sensors, antennas, etc., they become more susceptible to physical damage, which is supported by the fact of being a permanent part of the human body.
- Battery issues – powering of smart clothes is usually realized by external charging rather than batteries. Joshi claims that battery powered smart clothes are the future as smart clothes which need to be charged are quite impractical. Nevertheless, such implementation is a difficult task since integration of batteries increases undesired attributes, e.g., bulkiness, fragility and weight.

It should be noted that high-performance products do not always result in commercial success of a smart garment as the technological advancement is not the only criterion which determines the appeal for customers (Langenhove, 2015). De Acutis and De Rosi (2017, p. 395) state: "First of all, clothes are perceived and selected according to fashion criteria, user experience and individual personality, such as means of emotional and psychological communication, while electronic devices are chosen above all for their practical functionalities." Smart clothes are clothes and devices merged, and they have their own requirements, therefore smart clothing should consider both of these aspects to achieve greater success on the market. Such attributes, which take both of these perspectives into consideration, include reliability, sufficient safety levels, great design, comfort, simplicity, quality, added value and also an easy-to-use application interface to interact with the IoT environment.

5.4 Acceptance

The phenomenon of smart clothing from a consumer perspective is not well understood and a very limited number of researchers have examined how consumers perceive smart clothing (Macguire, 2011, December 23). As mentioned earlier, smart clothing is relatively new on the market, therefore there was not enough time to increase public awareness of its applications and advantages. Usually, when new innovations emerge on the market they are met with a certain amount of resistance. Smart clothes seem to be no exception and particular reasons for the resistance could be worth to inspect. For example, a study by Ju and Lee (2020) offers an insight into the reasons for consumer resistance to smart clothing. In their research, they interviewed 30 consumers who were resistant to buy innovative products such as smart clothing, though they were aware of the concept. It was revealed that the respondents did not want to immediately accept smart clothing, because they thought it was still in the development and they expected the function and design of smart clothing continue to improve. Others stated that the reason for their resistance to smart clothing was not simply because of their resistance to a change of their current status, as they felt satisfied with what they had or did not feel that they needed to make any changes. It was also observed that consumers would not buy smart clothing unless a trustable brand produced it with appropriate functions and lower prices or particular qualities, such as washability, would be improved. One of the reasons was also dissatisfaction with the aesthetic aspect, despite the improved quality and performance. A previous similar study by Hwang, Chung and Sanders (2016) examines the attitudes and purchase intentions for smart clothing, with a much larger spectrum of people. Here, the perceived usefulness, i.e., whether the user considers the clothing to be useful or not, was the strongest predictor of attitude. It was also confirmed that perceived performance risks, i.e., when a user thinks that the product will not function as expected, negatively influence consumers' attitudes, and indirectly influence their purchase intention, which represents a significant obstacle preventing consumers from selecting the technology-integrated product.

From these two studies, it can be observed that the acceptance of smart clothes is dependent on many variables which concern both the technical and aesthetic aspect of clothes, as well as socio-cultural acceptance. Also, users' expectations play a significant role as people do not want to be disappointed with the product's functionality and usefulness.

6 Conclusion

The aim of this bachelor's thesis was to frame the concept of smart clothes and introduce it to the readers. The objective was also to raise the awareness of smart clothing, as the products have the potential to become part of our everyday life with the increasingly more advancing and miniaturizing technologies.

Such a goal was set to be achieved by the logical chapter division of the thesis where various aspects and factors of smart clothing are discussed. To establish a common premise about the definition of smart clothing, which would serve as a pivot point for the whole thesis, a characterization of smart clothes was provided in the beginning. Also, to further outline the concept, the thesis provides a historical context of smart clothes as well as their possible classification. Next, the reader was presented with the requirements for the design of smart clothes and their general construction with regards to both "smart" and "clothing" aspects, which further helped them to learn about the topic and partially reveal the issues the smart clothes have to deal with in terms of their design. Several smart clothes products and their brief descriptions were provided to introduce the reader with some real-life examples. These smart clothing products are sorted by the field in which they operate, i.e., healthcare, military, sports, and the text mentions technologies prevalent in those particular spheres. Lastly, the reader was acquainted with the current situation of smart clothes in relation to their market status and social perspective, which alongside with the previous chapters provided a better picture of smart garments and their status in today's world.

The source of information for this thesis was mainly the recommended literature as well as other books, articles and texts found throughout the process of writing. There sometimes were constrains in terms of the same definition of smart clothing across different works; however, this thesis tried to approach the topic from a general perspective, which allowed those slight deviations to be neglected.

To conclude, smart clothes, as a hybrid between fashion and technology, have to consider both aesthetic and practical aspects, especially from the end-user's point of view, which for example includes cultural context, body ergonomics or a feel-good factor. The main advantage of smart clothing proved to be their mobility and lasting presence on the human body, which enables a whole spectrum of applications, especially monitoring the body signals through sensors. Smart clothing is mostly now used in more specific areas rather than in the mainstream, which seems to be due to several reasons connected both to the awareness and acceptance of the public as well as performance and design of the products.

The futuristic conception of smart clothes, where humans would be able to interacts with their environment through technologies embedded into clothing items, is still far from reality. The potential for smart clothing is clearly visible, however, to use this potential many issues still have to be addressed. It seems like today's technology nor society is ready yet for smart clothing, but we can still see that this industry persists, and many new products, research and initiations are emerging every year, so it might be just a matter of time when smart clothing will make its way into the mainstream. Smart clothes may become a part of our everyday life in the future. As technology inevitably progresses, smart clothes may be an exciting new area which, I believe, is worth researching in order to make our lives easier and more comfortable considering the potential advantages it conceals.

7 List of references

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8 List of figures

9 List of abbreviations

TC	Technical Commission
IEC	International Electrotechnical Commission
SG	Standardization Group
3D	Three dimensional
EC	European Commission
ECG	Electrocardiography
IoT	Internet of Things
RFID	Radio Frequency Identification
NFC	Near Field Communication
WBSN	Wearable Body Sensor Networks
WPSM	Warfighter Physiological Status Monitoring
IVAS	Integrated Visual Augmentation System
TALOS	Tactical Assault Light Operator Suit