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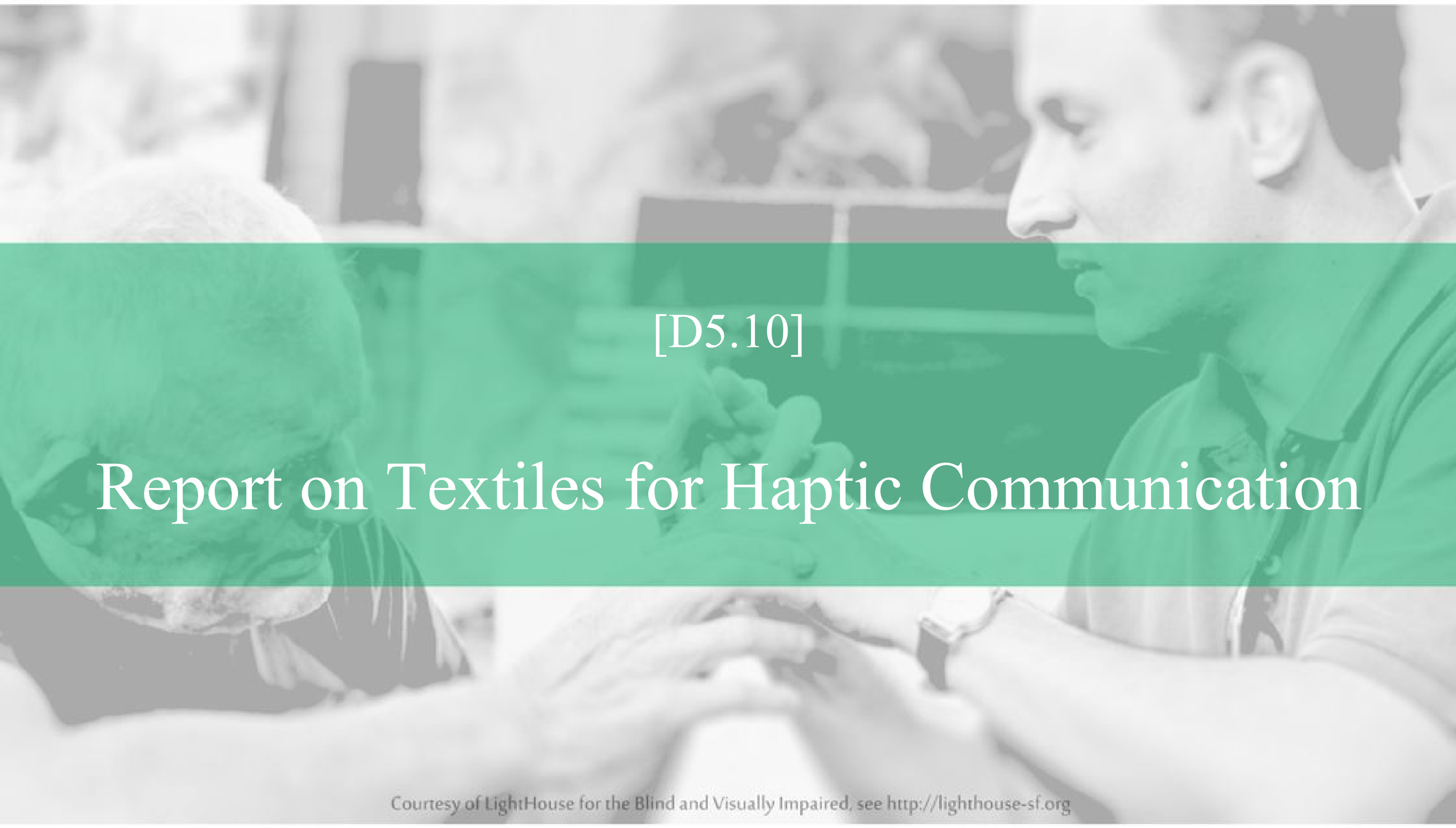
SUITCEYES

1 Jan 2018 - 31 Dec 2020

Smart, User-friendly, Interactive, Tactual, Cognition-Enhancer, that Yields Extended Sensosphere
Appropriating sensor technologies, machine learning, gamification and smart haptic interfaces



[D5.10]

Report on Textiles for Haptic Communication

Courtesy of LightHouse for the Blind and Visually Impaired, see http://lighthouse-sf.org

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Dissemination level		
PU	PUBLIC, fully open, e.g. web	PU
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R	Document, report (excluding the periodic and final reports)	R
DEM	Demonstrator, pilot, prototype, plan designs	
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OTHER	Software, technical diagram, etc.	

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Glossary	
Abbr./ Acronym	**Meaning**
HIPI	Haptic intelligent personalized interface
VR	Virtual reality
AR	Augmented reality
UX	User experience
NANV	Non audial, non-visual (communication)
ECG	electrocardiography, electrocardiogram
EMG	electromyography, electromyogram
EEG	electroencephalography, electroencephalogram
TFC	Total fat content
TBW	Total body water
NMES	Neuro muscular electrical stimulation
TENS	Transcutaneous electrical nerve stimulation

Table of contents

List of figures

List of tables

Executive Summary

Textiles, in the form of garments but also as bed linen, pillows etc. come naturally when used in contact with the human body. Furthermore, garments are covering a large part of the body. One could then establish a close, natural, fundamental connection between textiles and the skin, the organ for tactile (touch) experiences. No other technology and no other synthetic class of materials could match this. Textiles are then potentially an excellent vehicle for reaching humans through haptic communication. Haptic communication is a generic term for taking use of receptors both in the skin (cutaneous) and in the muscles and joints (kinaesthetic) informing the central nervous system (CNS) of stimulus present at the skin and body limbs and their velocity and acceleration, respectively. Vocabulary has been established but a more adequate term would be tactile communication referring to touch sensations which involve a subset of the cutaneous receptors.

We identify 13 benefits of textiles for haptic communication, few of which are matched by other hard technologies. They are formulated as axiom-like claims based on the essence of textile and merged with the essence of human tactile capabilities, in turn connected to what communication in general demands. They are meant to be a fundamental basis for future development of textile based devices and systems and practices for haptic communication, as well as a practical tool for constructors. When possible they are accompanied by examples of physical prototypes developed.

Introduction

The deliverable D5.10 is based on T5.6 stated as follows:

"Mapping the limits of textiles for haptic communication (M20-M36) [Lead HB]"

Exploring the challenges, limitations and possibilities of textiles as means for haptic communication involves taking into account, merge knowledge from and balance between, at first sight, highly disparate areas with their own historical development, way of formulating research questions, of finding the study object, of populating with experts, driving forces, and motivations. *Textile* factors such that drapability, inherent surface roughness, presence in everyday human tasks, producibility, wear and tear properties, comfort, hygiene have to be taken into account. *Psychophysical* factors such that human tactile resolution capability, difference between passive and active touch, glabrous versus non-glabrous sensitivity, the existence of haptic illusions, the further exploration and use of them add. Finally, *communicate* such as monologue, dialogue, feedback and loop closing, signal system versus full-fledged languages, digitalization of signals, semiotics; as well as psychological, sociological, societal and behavioural aspects developed within WP2, WP4, WP6 and WP7 all contribute.

That the endeavour is at all worth the effort is originally based on the following logic:

P_1 Communication is fundamental for every human being

P_2 There are people not having access to sight and hearing

P_3 These are then left with tactile communication

P_4 Tactile experiences are related to cutaneous receptors in the skin

P_5 Among artefacts textiles are always close to the skin.

I.e. (Hypothesis, H): textiles should have potential for haptic communication

Haptic communication is a generic term for taking use of receptors both in the skin (cutaneous) and in the muscles and joints (kinaesthetic) informing the central nervous system (CNS) of body limbs and their velocity and acceleration. Vocabulary has already been established but a more adequate term would be tactile communication referring to touch sensations which involve a subset of the cutaneous receptors. Scholars sometimes include thermal receptors, including them a term, tactual communication, could be used.

In Fig. 1 the aim and ground of the report is graphically illustrated.

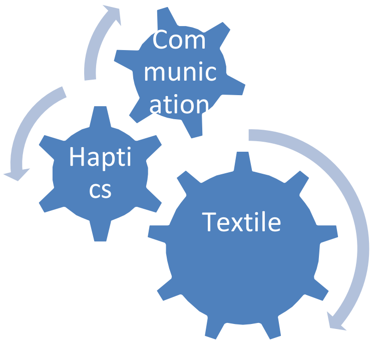

Figure 1. In the work the haptic, textile and the communication realms meet.

We first introduce some concepts and terminology. Then we discuss communication, one of the building blocks (Fig. 1) in the discussion of the present work. Haptics is the next theme, followed by a short mentioning on what the essence of textile is. This enables us to identify the benefits of textiles for haptic communication, as well as the problems that have to be solved.

Implicitly, we are addressing a certain group that could benefit enormously from textile haptic communication technologies as the work has been done in the context of the H2020 project SUITCEYES addressing the needs and variabilities of people having deafblindness. But the hope is that the content is valuable for an even wider field of application.

Of focus is the skin. But as an initial note on limitation it is the *overall* human skin of 1,8-2 m^2 area that is our interest. This large-area-approach is in contrast with much of the studies (and devices) that are devoted to hands and fingertips, only. As long as haptic communication devices are inferior to human interpreters and fellowmen it is important to keep hands free for any hand sign language, say, or managing a cane or, simply carrying a bag.

The text is no review of a specific field but rather a program for further investigations with the formulation of thirteen hypotheses elaborating, detailing and sharpening on hypothesis H above.

Concepts and terms

This section introduces and clarifies concepts and terms used throughout the report.

Actuator – are (here) components that actuate, giving some output *from* the textile point of view. For garments this is stimuli to the wearer. Examples are vibrotactile elements, simply called vibrators or tactors, heating elements, cooling elements and acoustic elements. Actuation is the opposite of sensing. Sensors are taking output from the surrounding (say a human being) *to* the textile. All actuators have some ramping up time before giving perceivable actuation. For many actuators this time is negligible as for vibrators, but it is considerable (minutes) for thermal elements. Terminology used here is that actuators are *light* (up) and turned *off*. Vibrators *actuate*, thus giving vibration of different frequencies or amplitudes, giving a certain temperature, pressure etc. Time questions of sensors are of importance for total latency in a communicative system. Time critical systems are imperative for security in navigation and object recognition during walking, somewhat similar as for autonomous cars orienting themselves in a dynamically changing surrounding.

Sensor – devices capturing information and/or measuring some input. Examples are cameras (photon flow and electromagnetic field wave of a certain frequency band as input), ultrasonic detectors (ultrasonic waves) and tilt sensor. Worth mentioning, even if self-evident, is that sensors are the opposite of actuators. For a long time in the smart textiles community focus has been to enrich textiles with sensor functionality rather than actuators

Haptics – is referring to different facets related to taking use of receptors both in the skin (cutaneous) for indicating different forms of mechanical stimuli and in the muscles and joints (kinaesthetic) informing the central nervous system (CNS) of body limbs and their velocity and acceleration. Haptics could then refer to a) the means of perceiving, b) the related (if any) process of communication, c) the science, and d) any technology, supporting and using, touch sense(s).

Tactile – phenomena and devices that have to do with the sense of touch. “Tactiles”* as a counterpart of haptic technology has not been established.

Receptor – are on one hand chemical complexes of protein molecules in biological systems that receive and transduce signals. On the other, receptors are also referring to cell(s) that are able to receive and transduce signals from stimulus. It is the latter meaning that is used in the present text.

Textile – a class of materials and a class of artefacts characterized by having long fibrous structures as a constituting part. This includes not only a) garments and clothing but also the categories of b) interior or interiors or interior textiles (bed linen, carpets, curtains, pillows) and c) technical or industrial textiles (filters, textiles for agricultural, automotive etc.)

Smart textile(s) – a textile where some further (textile also being a technological outcome) technology has been added. Includes clothing equipped with actuators and sensor and in the former case garments with tactile elements such as vibro-tactile devices.

- ception - has become a suffix[1] used in a sensorial context, for different senses and groups of senses or sensorial aspects. Etymology is *cept* a Latin root word, meaning taken or seized, and *ion* a suffix meaning action or condition, possibly*capio*, *capere*, to take or grasp

[1] There is also a (originally) slang suffix – *ception* meaning “ multi-layered, nested” or referring to something being inside of something else; cake-ception: “a cake inside the a cake inside a cake” or “*Russian Stacking Doll-ception: A stacking doll inside of a stacking doll inside a stacking doll etc..”* etc.

Perception – from Latin *perceptio*, meaning gathering or receiving is the ability to become aware of something through the senses i.e. humans (or other living organisms) recognition and interpretation of sensory information. It includes such activities as recognizing, observing, and discriminating, organizing, identifying, interpreting.

Exteroception – from Latin root *ex* and *extero* meaning outside, is the awareness of environmental stimuli acting on the body. It is due to the activation of exteroceptors, and is including vision, hearing, touch or pressure, heat, cold, pain, smell, and taste.

Introception – is the experience of sensations coming from inside the body. That is sensations coming from the gastrointestinal, urinary, reproductive tracts, circulatory or respiratory systems. It comprises digestion, breath regulation, tense muscles or heart racingetc. It is intimately coupled to essential emotions such as hunger, thirst, pain, need for the bathroom, sexual arousal, relaxation, anxiety, sadness, frustration and safety.

Proprioception – is from Latin *proprius*, meaning "one's own", "individual", is the conscious or unconscious awareness of joint positionand movement of our body, including our sense of equilibrium and balance. More or less used synonymously with kinaesthesia(such as(Taylor, 2009)sometimes differentiated so that proprioception is related to static positioning of body parts and kinaesthesia, is the sense that lets one perceive movement, and action of parts of the body. Proprioceptionarises from signals derived from sensory receptors in the muscles, skin, and joints, and from central signals related to motor output.

Kinaesthesia – from Greek; *kinein* "to set in motion; to move" (from Indo-European root **keie-* "to set in motion") + *aisthesis* "perception, feeling"a modern medical term meaning movement senseor muscular sense. Sometimes also denoted kinæsthesia or kinesthetic sense. It is more or less synonymous with proprioception.

Nociception – from Latin *nocere* 'to harm or hurt') is the detection of painful stimuli. Specialized neurons in the root ganglia systemdetect extremes of heat, cold, mechanical and chemical signals, and alert the body of danger(Rosenberg and Pascual, 2020).

Communication

General communication

Communication, from classical Lat communis where it meant "common" and "to share with," "to share out," or "to make generally accessible", is an extremely widely used term, concept and phenomenon. It is spanning from an utterly general meaning of "transmitting something that can be regarded as information (for and by someone)", which for humans is synonymous with "talking" to a very specific meaning as in mathematical theories for telecommunication where quantification is possible. It includes such diverse phenomena as language, signs, television, radio, telecommunication, cell phones, internet, as well as fashion, make up, architecture, music, and authoring. It is a fundamental part of existing as a human being at all. It involves enabling information, exchanging thoughts, ideas, facts, warnings and emotions, all fundamental for survival. Communication is something that makes connections between entities in the world.

A vast number of explicit(Hauser, 1996) and implicit definitions of communication has been presented, both in the scientific literature and in literature for laymen. Today, one talks not only of human communication, nowadays only a subset of all kind of communication, but of biotic (related to living organisms) and abiotic communication, thing-thing communication, hybrid thing-man communication (often used terms are machine-machine and man-machine communication), one way (from a sender to a receiver in a monological manner) and two way (a dialogue between two agents), linear and circular, business-to-business communication, interpersonal, intercultural, classical (following classical, Newtonian physics) versus quantum communication (following the physics of quantum mechanics).

Even if not as many as for definitions, also several models of communication have been proposed, so also for full-fledged theories of communication2. The development and widespread use of computer and computer networks since the end of World War II, and the emergence of information science as an independent discipline in the 1950s has accelerated the efforts.

[2]Theories of communication have been developed since the 1940s, roughly in four stages. First, communication was regarded as a problem of transport, enabling transmission from a sender to a receiver without loss of information. Such theories built on the metaphoric similarity between human-human and telephone mediated communication. In a second stage, starting in the 1950s, theories of information storage and retrieval were developed. In the third stage, starting in the 1960s, theoretical development was inspired by psychology. In the fourth stage, starting in the 1990s, there was "a social turn" which led to two separate theoretical approaches. One expanded the psychological viewpoint to understand social aspects. The other was inspired by sociology.

Defining communication

It is notable that Fiske (Fiske, 2002) states early in his classical book "Introduction to Communication Studies" that "Communication is one of those human activities that everyone recognizes but few can define satisfactorily".

Definitions of communication most often involve terms such as *meaning, knowledge, belief,* or *intention*. This means then that these concepts in turn have to be defined for a consistent description. This creates a large conceptual apparatus. This is not the purpose of the present work. Some simple observations are that

1. communication has something to do with presentation, transfer or enabling the extraction of *information*,

2. some "sender" is involved, as is some "receiver"

3. communication often involves means of different kinds[3]

3. communication is appearing in so many contexts and need to be allowed to be of many different qualities

4. some processing of what is communicated take place, meaning both that there is some time impact (delay) and potentially some distortion of what is communicated

5. communication connects entities in the world in some way

Then for our purposes we could say;

> Communication is (here) defined as a process by which an entity (intentional agent, human, animal, AI, humanoid, plant) transmits in order to modify the behavior of one or several other entities (intentional agent, human, animal, AI, humanoid, plant) and these are indeed impacted due to this.

To be noted is that we are not referring to "information" in the definition, a notoriously difficult concept. We are not limiting ourselves to humans only. Neither are we explicitlyincluding "symbols" (but potentially allowing for the hypernym of signs) as what is transmitted. We are not saying that communication is an "action", that is; an event triggered by intention and therefore based upon the presence of an intentional agent such as a human being. One could communicate that one is nervous without intending to do so i.e. passing through an event without will behind. On the other hand, concluding what an observed changed behavior is due to, is difficult.It is involving the complexity of causality chains, outside the scope of the present text.

In the definition, "in order to" is necessary to include. It alludes to some flavor of "purpose". Without it any event when a branch of a tree hits you would be regarded as communication. We leave it open to what degree variation is necessary for communication in this general meaning or if only one constant "message" is enough for transmittance.

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[3]Such as telephone or turning own body toward or not toward ones antagonist as for animals, or historically having beacons for signalling that the enemy fleet is approaching

Shannon Weaver model:

In order to get a vocabulary, identifying key entities in a communication act and establishing at least a rudimentary relation between some of these entities the intuitive appealing Shannon-Weaver model (denoted Shannon-Weaver or SW from here on) is taken use of. The intention is to have Shannon-Weaver to help putting any type of communication (biotic as well as abiotic) on equal footing. To some degree this is indeed possible but we should also state immediately that SW is too simplified and failure to capture a number of significant features of communication.

The communication model and the communication theory due to Claude Shannon and Warren Weaver is one of the earliest (1948 and onward[4]). The model, often presented graphically, is almost instantly clear. The wider theory framing and underlying it, is based on mathematical rigor. It opens up for further theoretical elaboration, including both quantification, simulation and prediction at least within certain realms as telecommunication. In any case, Shannon-Weaver has become widely spread and applied in a wealth of different discipline, far beyond where it started in a military signaling context, choosing between radio or telephone communication with the purpose to describe signal transmissions with maximum capacity and minimal distortions. Shannon-Weaver has also had a tremendous impact on further models and theories developed along the same track - or developed in opposition to it. Scientific disciplines such as telecommunication or even the area of information science itself count Shannon as a founding father.

The basic principle is very simple. A *message* is sent by a *sender* through a communication *channel* to a *receiver*, or to multiple receivers. *Noise* of different kinds could negatively impact the message. That's it. It is specially designed to find hindrance to optimal communication between sender and receiver. As seen, Shannon-Weaver is *linear*. The message goes *from* the sender *to* the receiver. A terminology is developed with concepts such as *source, transmitter, noise, channel, message, receiver, channel, information destination, encoding and decoding* that we now go into some detail with, see Fig 2.

[4]Shannon Weaver A Mathematical Theory of Communication Bell System Technical Journal

Shannon Weaver Model and its *sender /source* concept:

Sender or information source is the originator of the message (the message is the idea or concept with a distinct meaning). A sender could be a person, but also several, a group or an organization, say a TV news channel or a company wanting to communicate its business or a municipality that wants to inform the citizens about a dangerous disease in the population.

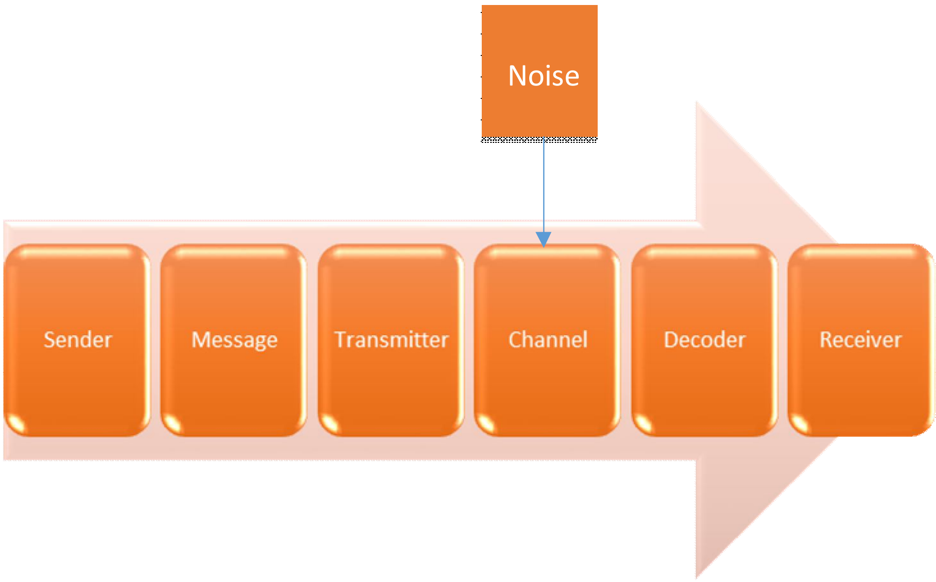


Figure 2. The Shannon Weaver model for communication (Shannon, 1948)(Shannon, 1949). The overall motion is from sender to receiver i.e. linear. There were versions early on including feedback..

Here we adopt to the generalization that the sender could also be a computer with some algorithm or even some device or artefact that could send out something, say a flow of photons. Central in the Shannon-Weaver theory is that the sender is *selecting* the messages out of potentially many. The sender is "formulating itself" as for a newspaper or simply sending out some information as for a sensor. In any case there is an abstract message around from the very beginning.

Shannon Weaver Model and its *message* concept:

The message is the idea or concept with a distinct meaning and as such mental in the cases of humans and only abstract in terms of abiotic communication. A message is a "signal or combination of signals that serves as a stimulus for a receiver"(Shannon, 1948). The message floats and is conveyed spatially and temporally somewhere between the sender and the receiver.

The message concept is further elaborated in for example (Capurro, 2011).

Shannon Weaver Model and its *encoding* concept:

The sender must itself or let someone (a special media department at the municipality) or something (using some machine such as Morse key, digitizing converter, computer key board (and accompanying technical devices) *encode* the message into a form that is appropriate to the communication channel. It is meaningless to write a paper letter and try to put that on a telephone transmission cable or talk Spanish to someone who cannot Spanish. Channels need their format. For telecommunication, binary data is central - and has been that since the formulation of Shannon-Weaver.

Encoder or *transmitter* is then any mean which converts the message into (proper) signals.

So, the sender‘s messages could be converted into signals like electromagnetic or acoustic waves or binary data compatible with transmitting the messages through cables or via satellites. In telephone (=encoder) the voice is converted into wave signals and then further transmitted through cables.

Shannon Weaver Model and its *channel* concept:

Originally, the term communication channel was used as denoting the mean to convey the message from the sender to the receiver using either radio or telephone electrical wire (Shannon, 1948). A channel is the "vehicle or medium through which signals are sent" (Shannon, 1948) (p. 52). It is the way in which we communicate. It is the method(s) and mechanisms used to transmit a message to a recipient, or to receive a message from someone else.There are multiple communication channels available to us today. These include face-to-face conversations, wired telephone, cell phone telephone, text messages, email, the Internet (including social media such as Facebook and Twitter), blogs, vlogs, public and commercial radio and television, written letters, printed brochures and books. Thus, the channel is the route the message is sent by. It is obvious that **c**hoosing an appropriate communication channel is vital for effective communication. Each communication channel has different strengths and weaknesses.

Shannon Weaver Model and its *noise* concept:

No channel is ideal. What is encoded in is not necessarily what is decoded by the receiver. Static electricity on the telephone line or obscure medical terminology used by health-care professionals to laypersons may contribute to the message being misinterpreted by the receiver. There are thus *error producing processes*.

Noise is defined to be "[a]nything that distorts the message intended by the source, anything that interferes with the receiver's receiving the message as the source intended the message to be received" (Shannon, 1948). Both for humans, animals and machines there are fuzzy limits between when the message is still understood and when it makes absolutely no sense.

It has been suggested (Shannon, 1948)that there are different type of noise. They could be classified as three types: *physical* noise, *psychological* noise, and *semantic* noise.

The first type of noise interferes with the physical transmission of the signal or message. Examples include air conditioners humming, a blunt pencil, and sunglasses.

The second, psychological noise, includes biases and prejudices, in both the sender and receiver, leading to distortions in receiving and processing information: closed mindedness and ongoing emotional arousal (due to something external of the message), for example.

The third, semantic noise, "the interference is due to the receiver failing to grasp the meanings intended by the sender." (Shannon, 1948). Jargon, technical, or complex terms are examples.

Shannon Weaver Model and its *decoding* concept:

Once received, the recipient is to *decode* the message. Decoder is any mean to convert the signal to message. It is the reverse process of encoding.

People will of course decode and understand messages in different ways. This communication will depend on their experience and understanding of the context of the message, how well they know the sender, the senders' psychological state, and the time and place of receipt. Thus, there are a wide range of factors that will affect decoding and understanding.

Shannon Weaver Model and its *decoder* concept:

The receiver is the agent, machine, AI, human being, animal etc. who should have the message and is able to get impacted by it.

Feedback

SW also opens up for feedback. With a feedback loop from the receiver to the sender added to the model it better describes for example, interpersonal communication.

Criticism of Shannon-Weaver model of communication:

The model fails to include any concept of environment which shapes the sender's and receiver's meanings of messages. The sender plays the primary role and receiver plays the secondary role, merely receiving the information in a passive way. This is an apprehension that is too simplified.

A highly problematic use of information (information as something prima facie flowing between a sender and a receiver and concerning possible selections from a repertoire of physical symbols.) is lurking behind the surface. This is not the place for going into that issue just to note that SW information is used for uncertainty reduction which is a narrow use of the term and does not correspond to every day us. Information is outside SW contextnot something identical for both sender and receiver, but it has to be constituted through the communication process (Luhmann, 1992)

Semantics not included. For humans meaning is extremely important both for engaging in any communication at all and encoding and decoding.

The message concept in SW is not compatible with message in inter-personal communication (Gozzi, 2004)where interpretation is involved.

Neither is semiology included. Communication is most often related to the use of symbols, such as words. A symbol exists as a consequence of human convention. An index on the other hand, is a natural, universally understood phenomena such as thunder (which follows the occurrence of lightning) and smoke (which suggests that a fire is also present). An icon is an entity resembling something else such as a painting or a photo. SW does not involve any of these signs.

Human communication

Based on these general aspects we go on and focus on what is of interest for us; human communication.

Simple typology for human communication

There are in principle an infinite number of ways to make typologies of human communication. Useful for the coming is the much-used classification of human communication into

i. Spoken or verbal communication
ii. Written communication
iii. Non-verbal communication
iv. Visual communication

Spoken or verbal communication

Spoken or verbal communication is the use of language to transfer information through speaking. Spoken or verbal communication embrace face-to-face communication as well as taking use of any tools, like a megaphone, telephone, cell phone, radio, television, movie, video conference, Skype, vlog etc. In focus is the sound producing capability as well as the audial perception. These are two phenomena that have accompanied humans since the down of humankind and even sharpen what humans are at all.

Even if there is no perfect exactness of words meaning in a language each word in a language has a rather well-defined and agreed, conventionalized, meaning. This also goes for synonyms and homonyms. There is no language having jokers, words that can be put in hap-hazardously in a speech act, meaning whatever. Meaning everything is meaning nothing. And for spoken and verbal communication cognitive capabilities are activated. Concomitantly spoken and verbal communication could be denoted "word communication" or " symbolic-cognitive communication" (this also includes - to an even stronger degree - written language).

Spoken or verbal communication is the arrangement of words in a structured and meaningful manner, adhering to the rules of grammar and syntax, again conventionalized. It has a sequentionalized nature; not all words can be produced simultaneously, nor could the words be perceived and understood simultaneously, nor is it necessarily the case that a set of words could be transferred simultaneously.

As there is a relative definite meaning both to words and to any syntactic compositions thereof verbal communication is regarded as efficient and important.

Written communication

Written communication embraces letters, reports, newspaper, books, written orders, e-mails, social media, magazines, calculations, homepages on the Internet and other media. It focus on the written, typed, printed and graphically presented word and as such the central sense is vision. To a part, some haptic aspects are involved during production. It is difficult to judge how important that is. Written communication is not only one of the most important innovations ever. It also defines mankind being intimate coupled to man's cognitive abilities. The production of written artifacts has exploded during a relatively recent period of humankind development with Egyptian hieroglyphs, Babylonian wedge language, Chinese signs, Norse runes. The importance of being able to perform calculations with numbers written down cannot be overestimated for the development of societies and, in the continuation, welfare.

Written communication is based on symbolic language and words, expressed like graphemes. As also for the spoken and verbal communication, where there has been a conventionalization process. Together with spoken and verbal communication, written communication, could be denoted "word communication "or " symbolic-cognitive communication".

Written communication enables decoupling of any sender and any receiver, both spatially and temporally. We can receive a blog post from the other side of the globe as well as reading legal, religious or scientific texts from hundreds or thousands of years back. Recording information and conveying information to a later generation has been fundamental for the development of both humans and human society.

Written communication is an efficient way of communicating not least for complicated, complex arguments.

Non-verbal communication

Non-verbal communication is of another character than both the previous types. It embraces body language, facial expressions, gestures (that could be parallel to any spoken communication), the tone of voice (also parallel to any spoken communication, giving clues to the emotional state beyond the spoken words). Furthermore, non-verbal communication is how we dress, how we act in a given situation or in general, where we stand among people, how we move, and what hair cut do we have, our scent. It is sometimes intentional, sometimes unintentional. In short, non-verbal communication is an umbrella term that includes all communication, which is not carried out purely through the use of words - or other symbols.

In one way, it is a primitive form of communication but perhaps a more proper notion is that non-verbal communication is subtle. Highly important clues of our surrounding are transferred. Not least are emotions expressed and concluded. By non-verbal communication humans interfere with thrust, respect, anger, dislike, attractiveness, sexual interest, unpleasantness, social status etc.

From a textile point-of-view it is interesting that dressing, but also hair style, worn jewelry and make-up are part of communication. This kind of non-verbal communication gives us cues (or are interpreted by us) about personality, role, occupation, Zeitgeist period, historical epoch, class, wealth and status. Characters in television or advertisements or theater or movie are dressed to make them easy to identify. The funny guy is given colourful or ugly clothes, whereas the hero is contrasting with sober and slick costume. An extrovert type could have wild and colourful hair. This is partly a cliché. Even if you are rich and powerful it is not necessarily the case that you always have the most expensive branded clothes on you. But for sure, sub-communities most often both identify themselves by certain clothes (punkers- hard rockers – hip-hoppers) and these signals are caught by the surrounding Further on, uniforms are used as a societal instrument to identify certain groups and are to be there so that they are easy to identify; police, military staff (also signaling different ranks), medical personnel etc.

Interacting with a person on a cell phone also involves informatics cues such as dialect, talking speed, emphasize. This belongs to the group of non-verbal communication though.

However, non-verbal communication has limitations. Non-verbal communication is not as structured compared as to verbal counterpart and is sometimes rather spontaneous. Exceptions include dressing style, hair style, perfumes used etc. But as it is not (perceived as) planned, it is sometimes considered more reliable than verbal communication, as it is assumed to reflect the true core of the communicator.

A classification of non-verbal communication or behaviour has been suggested by Ekman and Friesen(Ekman and Friesen, 1969)In their typology they introduced five classes:

translatable,(also called "emblem") is non-verbal behaviour consisting of specific actions with known, conventionalized, meanings, such as some gestures

illustrative, is demonstrating something, say by drawing a figure in the air, or as a trainer showing how an athlete should perform a movement required to perform a task which is under discussion.

affect-display, is to include others to see the (visible) effects of especially emotions, and by this to deduce the nature of those emotions

*regulator*is conscious and designed to direct, control and guide the behaviour of one or several other persons present, such as holding up ones hand to stop someone talking

*adapter*is to improve or maintain the comfort or security or confidence of the person showing the behaviour. Examples include changing position in a chair, or smiling.

These are not necessarily disjoint classes.

In conclusion, everything which can be noticed by another person or any machine may communicate something – whether a person knows it or not, and whether the person likes it or not.

Visual communication

Visual communication is to use photographs, drawings, paintings, sketches, charts and graphs to convey information. This could be made on paper or other physical surfaces or on digital media.

Visiocentrism

To be noted is that the list i,..,iv above mirrors the bias of humans and human society towards the two senses of vision and hearing. This is called visiocentrism, which thus includes not only vision but also hearing.

NANV definition

To counteract visiocentrism a concept, non-audial and nonvisual communication (NANV) modalities, has been introduced(Stöhr et al., 2019). These include haptic and tactile channels such as vibration, heating, pressure, cooling etc.

What functions have human communication:

Humans use communication in different ways and for a vast number of reasons, such as;

1. to satisfy *existential*, personal needs, that is to feel that one is wanted and valued by other people
2. in order to *co-work* with others (e.g. four persons together lifting and moving a table from one room to the next).

3. to *survive*, to urge and get access to basic physical and physiological needs of warmth, food, water and shelter. Included here is to communicate in order to order home delivery food on internet or rent a flat (i.e. getting shelter).
4. to be *rescued*. If we feel ourselves in physical danger, we would try to communicate with others to try to get help (e.g. during a robbery attempt)
5. to keep a *social group together* (e. g spectators singing together at a football match). In the extension of that - keep a society together (e.g. authorities informing about a new law).
6. to *warn* others (e.g. road safety signs or a warning shout as above)
7. to *inform* others (e.g. health care unit having phono numbers on their home page)
8. to *educate* others (at school, training, universities)
9. to *explain* something (e.g. a manual for using a haptic device)
10. to *entertain* (e.g. telling jokes or watching a movie, including gamification)
11. to *describe* (e.g. a TV documentary or telling someone about a holiday)
12. to *persuade* (e.g. a trailer for a radio program or a phone call from a charity organization). We communicate to persuade other people to think in the way that we do or to act in the way that we do. The most obvious example of this is advertising
13. To *express*an opinion (e.g. arguing in a newspaper for a political standpoint)
14. To *advise* others (e.g. talking to a teenager about life, coaching a CEO before a negation)
15. To *span time* i.e. to convey experiences and knowledge from previous generations.

It is common to consider easy communication as a basic condition for economic development together with capital, labor, and raw material.

By communication technologies humankind has developed for itself it is possible to transcend both of the fundamental ontological dimensions of space and time. Spatially, by means such as semaphores or beacons or fires or Morse code and telegraph sender and receiver has successively moved further away from each other. Temporally written signs could sustain erosion by time and the Rosetta stone made it possible to read hieroglyphs thousands of years old. It made it possible to have cultural transmission between generations.

Haptic physiology

Lederman and Klatzky explain haptics as a ‘perceptual system’ that consists of two different subsystems: the *cutaneous* and the *kinaesthetic*. (Lederman and Klatzky, 2009)

Cutaneous system embraces receptors in the skin. The kinaesthetic receptors in muscles and joints.

Tactile(from L. *tactus, tangĕre, tactum*, to touch) refers to cutaneous receptors for”touch”in a *passive* sense i.e. when the person is unprepared for any mechanical stimulus. This is in contrast to *active touch* which is when a person is actively approaching an object perhaps accompanied by vision and hearing and including cognitive expectations. The person is then also informed by the positions of the body and the limbs (that is having the kinaesthetic system activated) simultaneously as the skin and the stimulus object are encounter each other.

Even if perhaps *tactual* is a more proper term *haptics* has become much used as an umbrella term for technologies exploring, supporting and using, touch senses whether this is passive or active.

The skin organ

The skin, the largest organ(Tortora, 2010) of the body of about 2 m^2, a mass of 4 kg and typically keeping a pH of 5, is the ultimate physical interface between humans and the outside environment. It offers a wealth of physiological functions such as body temperature regulation, protection, thermal insulation, cutaneous sensation, excretion and absorption and synthesis of vitamin D. It has advanced physical properties such as elasticity, self-repair capability and membrane functionality.

The skin can be separated into two main parts: the outer most layer of the *epidermis*(epi-, from Greek “over” etc.) and the deeper layer of the *dermis*. The epidermis is the thinnest layer and consists of four principal types of cells: keratocytes, melanocytes, Langerhans cells and Merkel cells. Together with nerve cells, the Merkel cells detect touch sensations. The dermis is the deeper connective layer of the skin containing collagen and elastic fibres. The ‘top layer’of the dermis is called *dermal papillae* where we find both the Meissner corpuscles (sensing touch) and "free nerve endings" that can mediate the sense of warmth, coolness, pain, tickling and itching (Tortora, 2010).

To distinguish the free nerve endings mediating warmth, coolness, pain etc. we may categorise them functionally based on what stimuli they detect. "Most stimuli are in the form of mechanical energy, such as sound waves and pressure changes; electromagnetic energy, such as light or heat; or chemical energy, such as a molecule of glucose" (Tortora, 2010). The receptors relevant to haptics is the *mechanoreceptors* detecting mechanical stimuli, *thermoreceptors,* for heat and *nociceptors* detecting painful stimuli(Tortora, 2010). The actual transduction of physical stimuli takes place in a specific part of the receptors membrane where a change in electrical conduction takes place (Møller, 2014).

The cutaneous system and sensation

McGlone and Reilly(McGlone, 2010) state that the classical cutaneous senses consist of four submodalities: tactile, thermal, painful and pruritic (itch). The tactile submodality subserves the perception of pressure, vibration and texture, and rely upon *four different receptors:*

- Pacinian corpuscles: transmits a sense of vibration in the frequency range of 40-500 Hz for vibration stimulus
- Meissner's corpuscles: transmits a sense of "flutter" in the frequency range of 2-40 Hz for vibration stimulus
- Merkel's disks: transmits a sense of pressure in the frequency range of 0.4-2.0 Hz
- Ruffini endings: transmits a sense of "buzzing" in the frequency range of 100-500 Hz(McGlone, 2010)

Neurological, one differentiates between afferent and efferent nerves. Afferent(from Lat “af”/”ad” *to* and “ferre”*carry*) nerves are conducting signals from the body, such as receptors, *to* the central nervous system(CNS), which is spinal cord and brain. Efferent nerves (from Lat “ef”/”ex” *out from*and “ferre”*carry*) are conducting motoric signals *from* CNS to the body – muscles and glands.[5]

Afferent nerves innervate the skin and the receptors.

Sensory receptors convert physical stimuli into the pattern of electrical action potentials in the afferent nerves. The properties of the receptor cells determine the sensitivity and the sensory threshold to which the afferent nerve responds" (Møller, 2014). Hipp and Gerhardtstein makes a definition of ‘sensory judgement’ ‘a decision made by a human or nonhuman animal on the basis of incoming sense data processed by perceptual/cognitive systems of the brain’ (Hipp and Gerhardstein, 2017)

In relation to the Shannon-Weaver model, in the human body Tortora and Derrickson states the four conditions that must be satisfied for a *sensation* to occur:

1. A *stimulus*, or change in the environment, capable of activating one or several receptors must occur.
2. A *sensory receptor* must transduce the stimulus to an electrical potential signal, which ultimately produces one or more nerve impulses if it is above some threshold.
3. The nerve impulses must be *conveyed* along an afferent nerve, from the sensory receptor to the spinal cord and eventually to the brain

[5]There are also mixed nerves with both afferent axons and efferent axons.

4. A region of the brain must be able to receive and *integrate* the nerve impulse to a sensation, possible together with other impulses.(Tortora, 2010)

Skin as a receiver in haptic communication

As the skin is sensitive to external mechanical stimulus it opens up for use it as a receiver in a communication act. Where to activate is important both to do and to describe. We differentiate between *location* which is the geometrical position on *the body and the skin* i.e. an anatomical measure and placement. If wanted to be extra clear the terms "anatomical location" could be used. *Placement* is the positioning of some actuator (or sensor) on *the textile*.

Location is important both as a target for focused stimulation for example due to the high density of receptors but also for having triangulation points in zones on the body where there is a lack of location marks. Accuracy is in any case important. Locations can be more or less pointwise or more extended. There are different levels of accuracy, for example:

1. **Points.** Locations where parts of the skeleton are shaping the skin contour are often to be regarded as pointwise. Example is acromion on the shoulder.
2. **Joints:** are more extended locations still relatively well-defined.
3. **Muscles:** muscles are of many different sizes but are in any case showing a location that is extended and no longer a point. For example the triceps, as long as one is on the correct side of the upper arm one will, more or less, always hit the triceps.

What parts of the body are appropriate to use for haptic displays? To take into consideration for this are the following:

- The character of the stimulus, what modality i.e. what channel is to be used. Here vibration, thermal and pressure are some broad alternatives.
- Sensitivity in the skin for this stimulus
  - Resolution in spatial as well as temporal meaning
  - Threshold
- If the location already is occupied (for example: hands, mouth). It is of interest to use parts of the body that are not utilised.
- If the location is flexing or fixed
- The character of the location including
  - Exposure to friction body-parts to body parts such as for the thighs.
  - Exposure to sweat which might be positive (lower impedance for electrodes) as well as negative (corrosion)
  - If any device could generate heat and if the location is such that discomfort could be critical

Pathology

It is extremely rare to lose the general sense of touch, hypoesthesia, except for short periods of time and for certain locations as due to neurological trauma. Cases have been described in scholar as well as popular literature[6]. People witness of a situation as being effectively paralyzed. In cases of acquired impairment it takes years for these patients to learn how to manipulate objects depending solely on their sense of sight.

Illusions

Given that haptics could be in some way compared to hearing and seeing, there is also what is called 'haptics illusions' (Lederman, 2011). There are many of them. The interesting thing is that they can be utilized(Ali and Ivan, 2011)

. For example pressing in a sequence two different skin locations – typically the forearm is used - results in the perception that there was also a pressure in-between. This is called sensory saltation. Thus, it might be challenging to illustrate lines on the skin not by stroking, which might be difficult to arrange technically in a wearable say, but by two pressure generating actuators, a much more simple technical solution.

Haptics, haptic technology

Haptics definitions

Haptics is the a) class of haptic phenomena, the mode of perceiving, and b) the human systematic knowledge of such phenomena, *haptics as a science*, as well as c) (in more specific meaning) the use, exploration and practical application of such phenomena, including haptics for communication and d) *haptics as technology* that can be related to communication or not.

That is, there are haptics_a,haptics_b , haptics_c , haptics_d

Addressing haptics_c, it includes medical use of haptic knowledge and praxis for handling a variety of disorders, somatic or mental, as well as making technology and engineering, using and/or initiating haptics_a. Modern technology and among that haptics_d is of course building upon science and haptics_b.

So acknowledging the broader scope of the term haptics, haptic technology and haptics could and is used synonymously. Haptic technology is part of a larger field of *sense technology* or *sense science* (Persson forthcoming)where sense science could be seen as the hypernym in

[6] Ian Waterman described in BBC documentary, popular science articles and theatrical portrayals.

the same way as, say life science, is to specialized scientific sub-disciplines like bioorganic electronics.

Presently there is growing interest for haptic technology both for real-world contexts and cyber dittos.

The core question of haptics$_d$ is what is possible in haptics$_a$ and haptics$_c$ to be shaped into products and technical processes. This is *technification*which also includes digitalization of physical technologies

Vocabulary has been established but a more adequate term would be tactile communication and "tactiles" referring to touch sensations but that has not been established.

Why haptics

There are many reasons to engage into haptic interactions, see Figure 3.

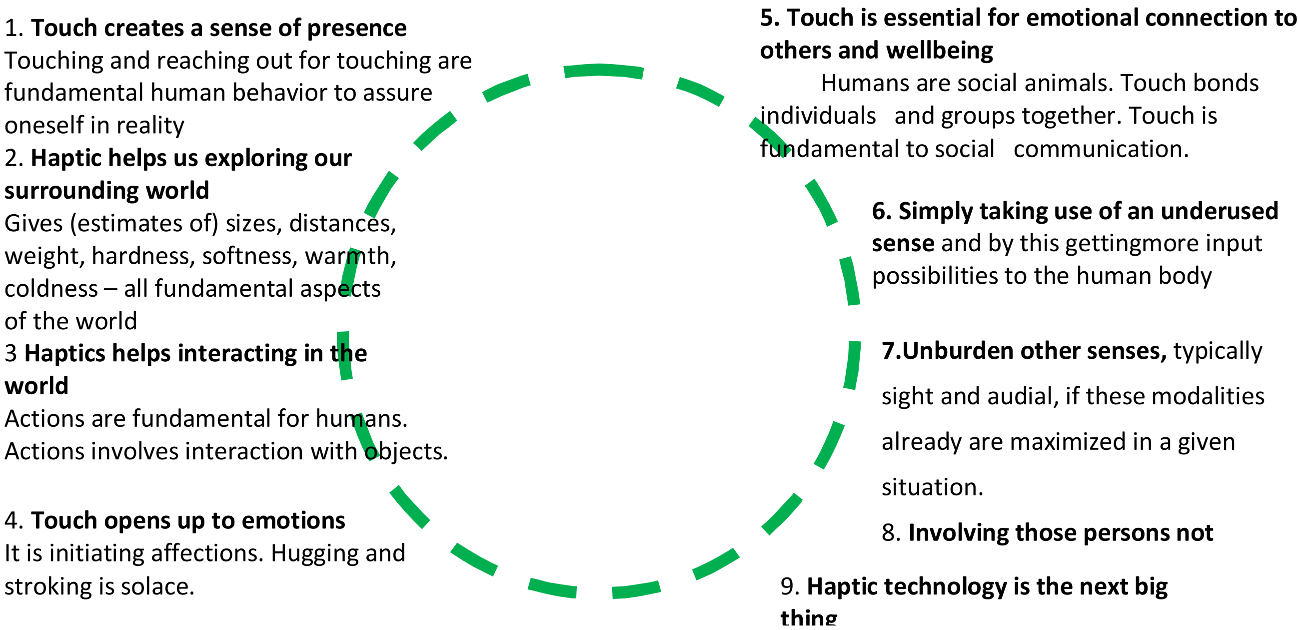


Figure 3. Why haptic communication, some answers, sorted on different aspects.

1. Touch creates a sense of presence. This has deep existential couplings. By being touched upon and by actively reaching out for touching, humans are assuring themselves that they are in reality. Tactile sensations, together with vision and proprioception, the sense of the

position of the body in space,combine to achieve the sense of body ownership. When this is not present, we become disorientated, losing our sense of what is our body and what is not, what is inside and what is outside. There is a quote fromDescartes; “Of all our senses, touch is the one considered least deceptive and the most secure.” Haptic experience is perceived as not lying to us.

2. Haptic helps us to explore our immediate surrounding world. Together with the sense of sight it gives estimates of sizes, distances and weights. Hardness and softness are qualities included in a haptic encountering. This enables identification and classification, in turn basis for cognitive decisions on further contact or the opposite. Tactile sensations warn us or invite us. Unlike vision it provide a 360° field of perception around the body.

3 Haptics helps to interact in the world. Not just exploring but interacting with the physical external world is fundamental for humans. Without haptic feedback, it is impossible to carry out even the simplest actions and actions are inevitably associated to humans. A person reaching for a cup of tea is directed by sight moving the hand towards the cup, estimating the size of it, the assumed friction based on a glaze. But it is haptic feedback i.e. both tactile sensations when the porcelain of the cup is in contact with the fingers and proprioception of the arm, hand and also torso that allows a grip around the cup and to pick it up. This is done without having to think about it, it is completely intuitive and automatized.

If these items are of ontological-philosophical character we now turn to psychological and psychosocial reasons;

4. Touch opens up to emotions. Illustrative enough many languages have the same word(stem) that are close in meaning, such as English *touch* (in the tactile sense) and *touched* (emotionally impacted) given that there seems to be a clear connection. Hugging and stroking is solace, i.e. emotionally impacting-A crying kid could stop becoming cradled. Touch could startemotions and stop emotions.

5. Touch is essential for emotional connection to others and wellbeing which is central for social aspects but in the prolongation to family aspects and societal aspects. It is known ref that touch is essentialto early childhood development.

6. Simply taking use of an underused sense and by this gettingmore input possibilities to the human.

7. Unburden other senses, typically sight and audial, if these modalities already are maximized in a given situation. This could occur for say combat vehicle staff of a first responder.

8. Involving those persons not having access to (full) sight and hearing. This inclusion aspect is central for the SUITCEYS project having deafblindness (DB) as study object but also divers, and certain kind of first responders such as fire fighters. This is *sense switching*. Sense switching is extracting information within a stimulus coupled to a certain sense and remake this to another stimulus, typically then of a perceivable sense for certain impairments.

9. Haptic technology is the next big thing in augmented reality (AR), virtual reality (VR), and user experience (UX). Haptic technology integrates touch into computer interfaces and virtual worlds. Haptics is still missing in many such systems so is to create user experiences that truly deliver immersion, a sense of agency, and meaningful social connections.

Haptics and haptic communication

Haptic technology can be many different things with many different purposes;

- for wellbeing stimulating psycho-somatic sensations, including what is called tactile massage (ref) used for example in terminal care at hospices (ref)

- manipulating and controlling objects at a distance such as remote driving, telepresence, and surgery at a distance

- interacting with digitalized objects in AR and gaming contexts

- using haptic for communication purposes for symbolic-cognitive communication as discussed above.

The last item relates to take use of haptic practices, $haptics_a$ already around, and *technify* them to $haptics_d$. It is therefore valuable to shortly discuss some communicative systems using touch.

Different sign systems and languages using haptics

Several sign languages in the hand (hand-by-hand, tactile fingerspelling etc.) by a present interpreter to a person incapable to communicate in another fashion, have been developed. Embracing as much of the aspects of human communication as discussed above is a general goal.

Such persons include people with deafblindness, where it is important to notice that people have individually different abilities for cognition, learning, levels of hearing and seeing and spanning a wide spectrum in language development, communication abilities and therefore independence levels. (Guthrie D., 2009).

> **Tadoma** (from the names of the first two children to whom it was taught), is sometimes referred to as "tactile lip-reading". The individual with deafblindness places their thumb on the speaker's lips and their fingers along the jawline. The middle three fingers often fall along the speaker's cheeks with the little finger picking up the vibrations of the speaker's throat. It is then characterize as calling for a high degree of intimacy between sender and receiver and the occupation of the hands of the receiver. So it is truly one-to-one communication. It is unpractical for a mobile situation, The Tadoma

method was invented by the American teacher Sophie Alcorn and developed at the Perkins School for the Blind in Massachusetts. It is regarded as difficult to learn and use, and is rarely used nowadays.

Lorm (from Hieronymus Lorm or Heinrich Landesmann 1821-1902 who invented it) is built upon a Lorm alphabet, which is different for different countries as it is coupled to the (ordinary) alphabet in the language of that country. The inside hand is divided into zones – the five fingertips, the heart of the palm etc. The speaker is tapping or stroking different zones on the receivers hand and to the combination of zone and action a letter (A, B, ..) or other meaning is allocated. Thus hands are taken use of, intimacy is lowered. It is one-to one communication. It is mainly used in continental Europa and its German-speaking countries.

Braille (from Louis Braille 1809-1852, the inventor) is perhaps the best known tactile based language for the general public. Developed for people having blindness it is based on blocks of (normally) six dots that can either be raised or not (typically on paper that can be embossed). Thus such a block gives 2^6 =64 possible signs. These are used for numbers and letters. Occasionally it is used by people having deafblindness. Braille signs are also used in tactile mode on the body by mimicking the signs by the finger of the sender. As it is on paper it is possible with one-to-many communication further and separating sender and receiver, supported by different kind of braille displays developed.

TASL - Tactile-(American) Sign Language, Tactile ASL (TASL) is a variety of American Sign Language ASL used throughout the United States by and with the deaf-blind. Likewise there are tactile versions of other sign languages even if TASL is perhaps the most used. It is widespread among those with Usher's syndromeTASL and ASL are both visually based and much focused on using hands and for one-to-one communication. Intimacy is moderate. TASL differs from ASL in that signs are produced by touching the palms.

PTASL - Protactile-(American) Sign Language used throughout the United States developed by and with the deaf-blind community differs from TASL in that signs are directly rooted in touch rather than visually signs. It is also the case that it is practiced not only on hands but on other body parts as well. It is also so that it is possible to communicate in small groups i.e. departure from the paradigm of one-to-one communication.

Social haptic communication or language (SHL) as developed by Riitta Lahtinen (Riitta M, 2008)is based on having an interpreter (sender) giving haptic stimulus on the back, or the shoulders (also other body locations can be used). So in this case the hands of the receiver are not used, fig 4. Intimacy could be regarded as higher than for systems where just the hands are used. One-to-one communication is what is practiced. SHL has developed its own vocabulary. *Haptice*, plural *haptices* is “single messages shared by touch on the body”(Riitta M, 2008). To be noted is that both skin reception is involved as well as movement of body parts or even the whole body. Instances include verbs (come, dance, stop, walk), nouns (drink, sugar, door), adjective (tired, cold), particle (in front, behind). *Hapteme* = plural haptemes are "variables of touch"[7] (Riitta M, 2008)and so that "haptice consist of variables of touch". It is said to be "a grammatical variable related to touch, an element for building and identifying haptices and of separating them from each other".

Figure4. Social haptic communication. The woman in yellow is tactually by her fingers and arms "writing" on the back of the man in blue, who has deafblindness.

Thus there are many different tactile sign systems. They are different in terms of intimacy, use of hands of the receiver, being for one-to-one or one-to-many and demanding sender and receiver(s) being close to each other.

The term hapteme might be useful also outside of SHL. As stated it is not an optimal term, as in communication and linguistics there are the well-established "phonemes" and "morphemes" whereas the analogy with haptemes is missing. Putting haptem as least a meaningful unit of touch (pressure, stroke, itch, vibration, nod, tap,…) stimulus so that it cannot be divided further and getting meaning. As being meaningful it is conceivable, perceivable and understood by the receiver. Connects to phonemes (least meaningful sound) and morphemes (least meaningful syntactical unit).

Except for the Braille case not that many technical devices have been developed for these languages, but haptic technologies used for enriching sight, hearing or in VR are plentiful.

[7] p 147

Haptic devices and haptic wearables

Haptic communication is one out of many types of haptic devices. An overview is given in Figure 5.

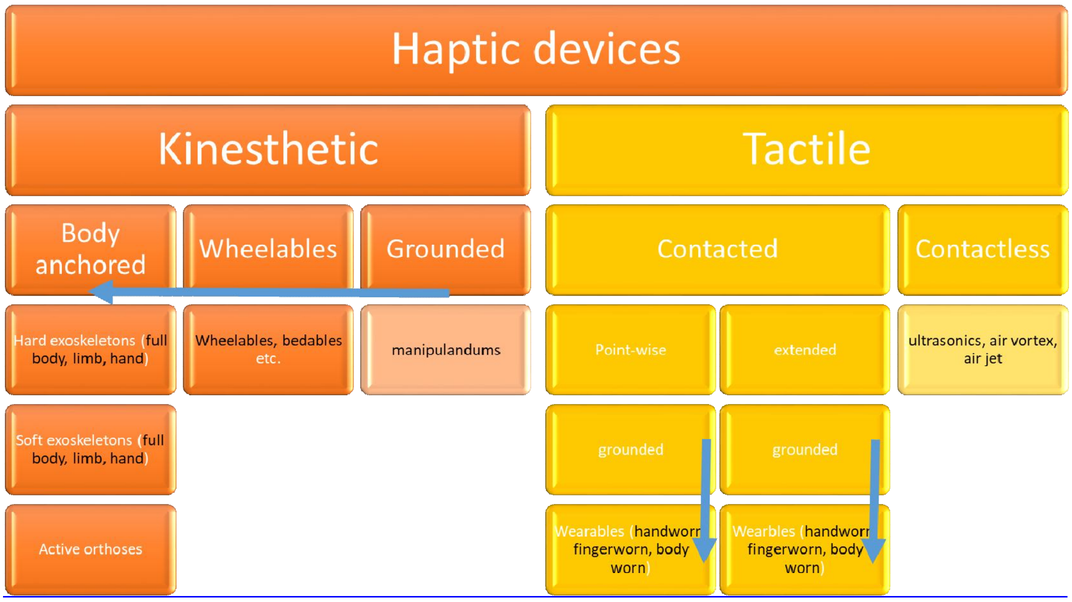


Figure 5. Hierarchy of haptic devices. One grouping could be according to what sensory system is involved. Then the kinaesthetic devices could be divided into table grounded, such as haptic devices for remote surgery, more portable devices connected to wheelchairs or beds and wearables, hard and soft. Kinaesthetic devices are close to motoric devices and exoskeletons are indeed included.Tactile devices could be divided according if the mechanism is such as mechanical contact is needed, most common, or emerging contactless technologies. Contacted (vibro-tactile elements, etc.) could be point-wise (called zero dimensional later in the text) or extended (having so-operating tactors in matrices). Blue arrows indicate increasing degree of portability for some sub-groups.

Textiles

Textiles and humans

The first shielding humans used for covering their skin was animal skin. But for approximately 6000 years humans have replaced this with manufactured textiles (Kumar, 2016), making textiles closely intertwined with human progress and development.

One definition of the term textile and fabric is given by Hatch as

"manufactured assemblages of fibers and/or yarns that have a substantial surface area in relation to thickness and sufficient mechanical strength to give the assembly inherent cohesion"(Hatch, 1993)

A simple but important observation is that textiles are hierarchical; textile yarns consist of filaments, filaments of polymer chains, polymer chains of monomers (Fig.6). And yarns are put together in weft and warp systems, knitwear and braiding; fabrics thereof are sewn, laminated and pressed together to textile products. Hierarchy increases the degree of freedom for how to create functions because enabling technologies could be added on polymer level, on filament, fibre, yarn, fabric or levels above. A similar example is dying which could be carried out in many ways; spin colouring, yarn dying, fabric or garment colour treatments, each connected to a specific level.

To be emphasised is that textiles are embracing three large classes;

- Clothing, garments
- Interiors including bedlinen, pillows, carpets, curtains, table cloths, furniture fabric
- Technical textiles

Then, garments are important but not the only type. By textiles it is today possible (McQuaid and Beesley, 2005)to solve a wide spectrum of technical problems so that textile big-bags can lift a weight of 12 tons; gloves are protecting from cut from knives and even razor wire;airbags that protect a space rover when landing on the surface of a foreign planet(McQuaid and Beesley, 2005).

The skin is an elastic material, hence clothing, that is placed closed to the skin, must also provide this elasticity in order to feel natural and comfortable for a person to wear. Like the skin, a fabric has the ability to elongate with movement and then to recover to original state(Hatch, 1993). A peculiar property of textile is drapability i.e. that a fabric can be draped around a physical object with complicated geometry. This is impossible for wood, say, but also paper or standard plastic foils, that are bendable but not conformal.

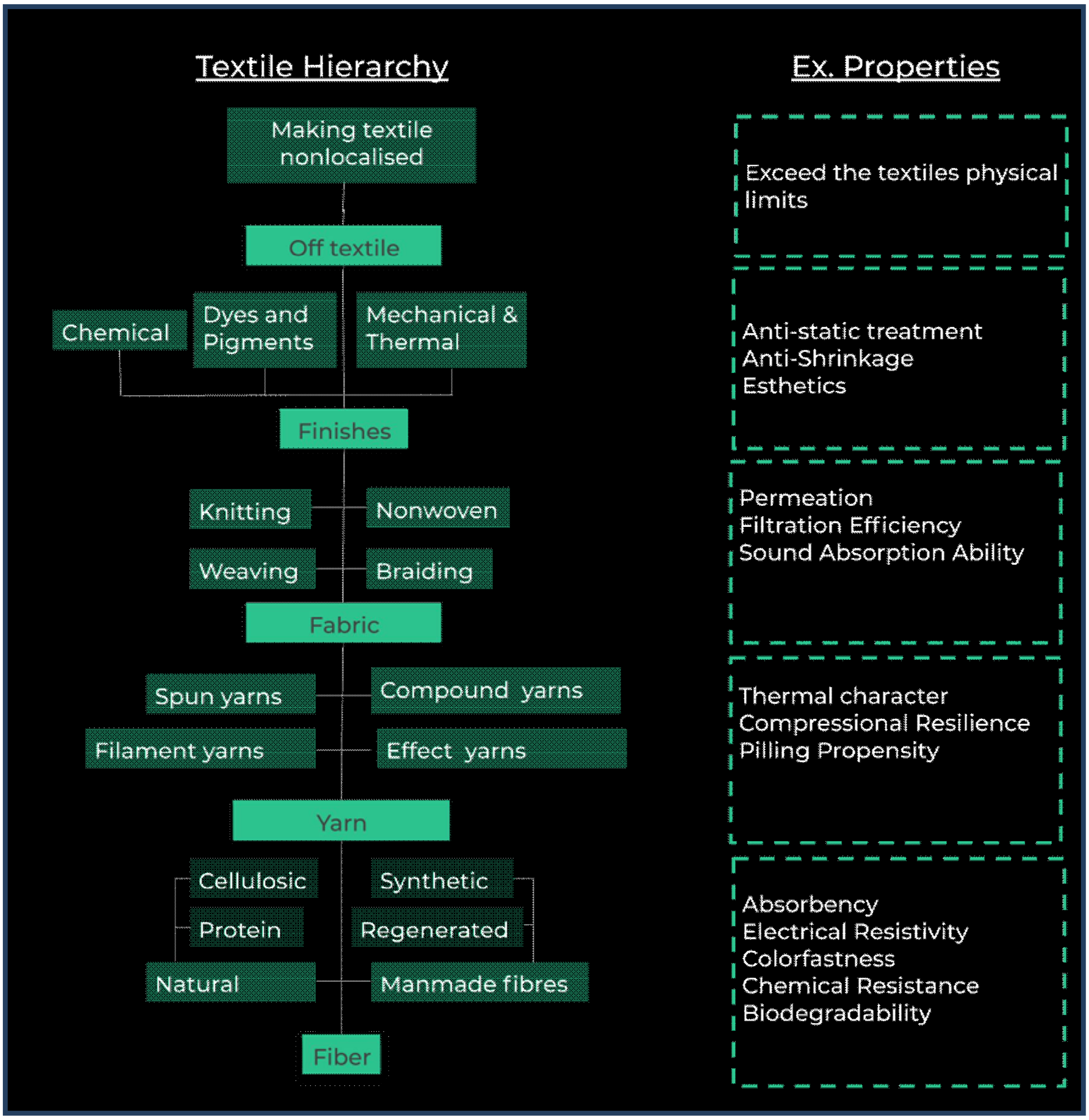


Figure 6. Definition of textile - fabric – garment hierarchy. What is referred to as fibre –property relationship is that characteristics on a lower level is both impacting the layer(s) above but also controlled from there. From our Lindell et al Connecting the world to garments

Given this, textiles haveunique benefits when it comes to haptic wearables, compared to other devices such as steel and plastic based smart watches, activity bracelets, rings etc. and even leather and many other polymer based materials.

Table 1 is summarizing what can be done by textiles and examples. In fig 7 the aspects of producing garments are noted.

Characteristics of what textiles provide textiles	Examples
Create 2D surfaces - cheap and with precision	weaving
Obtain lightweight structures	Gaze weave
Cover large and small objects from $(mm)^2$ to $(km)^2$	Agricultural geotextiles
Acting as interfaces	Clothing vs the surrounding
Drape	Mummification
Pliability	Training tight
Create distance	Gloves towards a fire
Create porous layers	Air and water filtration
Create high efficient area	Scaffolds, catalytic surfaces
Create dense layer	Air bag weave comparting gas under pressure
Express aesthetics, status, power	Formal and informal clothing
Patterns - periodic	In weaves, creating antennas
Create high tensile strength 1D	Ropes and wires
Keep moisture in	Sanitary products
Keep moisture away	Water proof fabrics
Substrate	Hydroponic agriculture
Vehicle for reaching human body	Haptic textile devices
Recyclable	Quality in yarn, fabric, design
Degradable	Using protein fibres

Table 1. Textile characteristics and examples thereof answering the question what textiles are and what textiles can do.

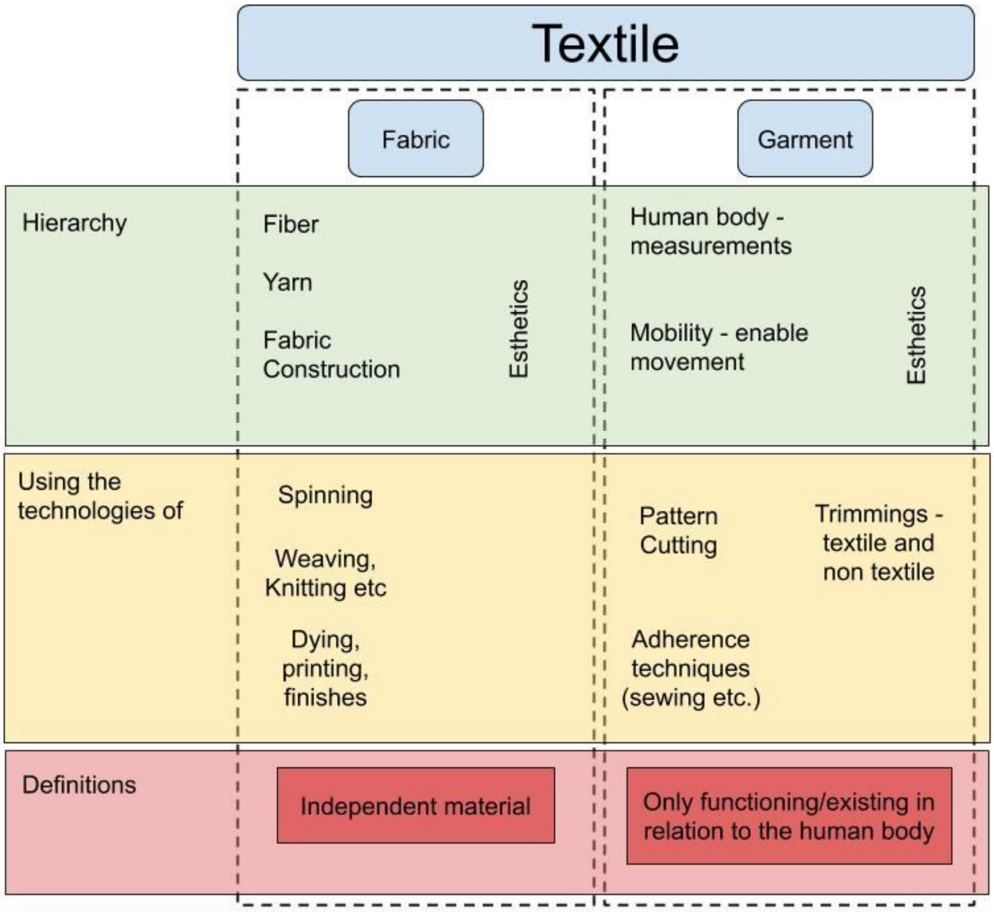


Figure 7. For producing garments, function is different in the form of fabric that is a material entity and the function(s) of garment that is related to the human body.

Textile - Fabric

The traditional way of organizing fabric structures are in *woven fabrics* - two or more sets of yarns are interlaced, *knitted fabrics* - loops of yarn are intermeshing, *twisted and knotted fabrics* - intertwined yarn, *nonwoven fabrics* - entangled webs(Hatch, 1993).

Textile - Garment

The given definition of a textile system from ISO 16298 is "an assemblage of textile and non-textile components integrated into a product that still retains textile properties, e.g. a garment, a carpet or a mattress" (ISO, 2011). The technologies needed for assembling of a garment (production factors put aside, this is addressed in D5.9) are pattern construction, cutting and assembling techniques.

The pattern construction sets the shape, ease, style and mobility ability of the garment. Assembly techniques entail whit sewing, gluing, melting or other techniques to put pattern pieces together.

Textile is then a platform. Its enrichment with sensors and actuators, including haptic devices, is often referred to as smart textiles.

Smart textiles

Smart textiles is a *class of artefacts that incorporates technologies from many different disciplines, besides textiles, by this offering many functionalities*(Persson et al., 2018)

In the figure below, fig 8, different functions are given taken another common approach namely smart textiles as interactive entities. Often this is interpreted as having sensor and actuator capabilities.

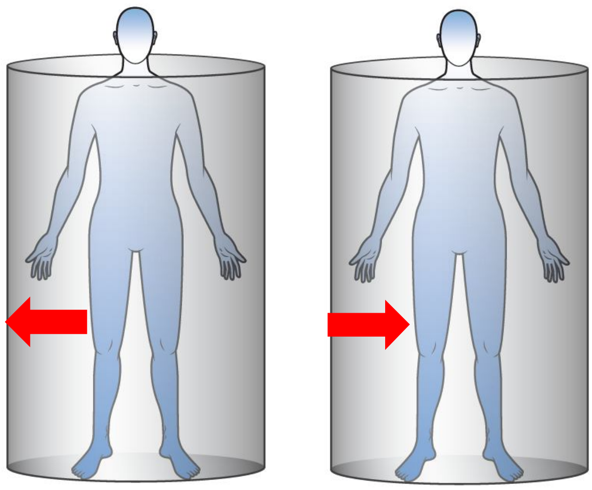


Figure8. Image the human being as embraced in a membrane of textile, symbolizing whatever of garments, causal, workwear, smart textiles. Then there are three entities; the human, the textile and the environment outside of the human+ garment system. Just looking at interaction between the human and the garment there are two directions, the outward, sensing direction and the inward (relative to the human) actuating direction. A vast number of phenomena and type of technologies that van be incorporated in textiles can be summarized under these:

a) Sensor side embrace ECG, electrocardiography, EMG, electromyography, EEG, electroencephalography, bioimpedance (TFC, TBW), accelerometry, pulse, breathing (say for neonatal, Sudden Infant Death Syndrome, SIDS),gait analysis, step analysis, cutaneous stress, sweat, biosensors

b) Actuation side embrace, active heating, active cooling, TENS, NMES, drug release, textile cosmetics, hepatitis photonic treatment, active orthosis, exoskeletons

Integration strategies

From a manufacturing point of view adding of enabling technologies to textiles could be described in terms of *integration on*, *integration in* and *integration off*. This is a conceptual framework developed by us (Guo et al., 2016) (E. Lindell, 2019)

Integration on (i-on) means here that the enabling technology in its physical manifestation is placed on the surface of the textile. Techniques embrace sewing, laminating, gluing using pockets, poaches, zippers, Velcro, magnetic, straps clips, buttons. Examples are sensor boxes in sewn on pockets and glued-on vibrotactile elements on the back part of a T-shirt. Thus, here “smartness” and ”textileness” are relatively separated. In many cases in fact easily spatially detachable. The textile is more or less only a carrier.

Integration in (i-in) means that the fact that textiles are around is taken in account. Textile manufacturing processes are used for creating the physical manifestation of the enabling technology. Textile properties are used for enabling the smartness functions. Structure and function are not separable. Examples are textile fibres that are electrically conductive. Knitted together they form a stretchable, foldable electrode. Smartness and textile-ness are intertwined and not easily spatially detachable. What is structure and what is function merge. The textile is far from working just as a carrier.

Integration off (i-off) The function is processed outside the physical limitations of the textile. Integration off is the IoT related integration, with part of the ‘smartness’ of the textile being located outside the physical domain of the textile.

In Figure 9 examples are show

Figure 9. Examples illustrating different integration strategies a) integration *onby using a back plane and screws enabling stability for a sensor (black) that is to be in a certain angle b) integration in using conductive tread knitted together with ordinary polyester; c) integration off by using a communicative (Raspberry Pi unit) for which the garment becomes connected to the outside for both outward and inward communication.*

Each of these has benefits and drawbacks. Brittle electronics can be detached before washing in the case of integration *on*. Good as hard electronics does not need to be redesigned or compromised or modified only moderately. Capacities of devices could be maintained. Also, i-on is a factor for less e-waste when the gear is worn out as any different types of materials, plastics versus metals say, are easier to separate. Maintenance is also simpler.

I-ons are good for modular systems including military rucksacks and workwear for different missions.

Integration *in*is taking use of the D=M property of textile. Fabric forming processes are additive i.e. tread by tread is added to each other in knitting and weaving. By this the structural properties are created; stiffness, mechanical strength, pliability drape, hand. But by this it is also simultaneously possible to add fibres having properties advantageous for generating certain functionalities. Inclusion of an electrically conducting tread is the starting point of an electrical circuit. Introduction of a piezoelectrical tread is the starting point to make a stretch sensor. It could also be that it is the very textile process that creates functions such as twisting creating Joule an driven string shaped actuators or weaving creating an addressable x-y system. A device (D) is formed simultaneously as the structure is built, functional parts are taking part in the structure and many of the structural, material (M) elements are adding to functions, D=M.

Integration *in* is valuable as by it, it is much easier, given treads are suitable, to maintain fabric properties such as drape and pliability. It could be problematic from a waste management point of view as functionalizing treads are part of the material and not easy to separate. Integration in have to handle washability, of concern for many, but not all, textile applications (compare underwear and curtains with highly different washing needs).

Integration *in* might also be inadequate for FashionTech. It might not be possible to include the same functionality in all garment a person is using. But not all garments fulfil the same purpose either. A party suit is not useful for going out jogging. Including batteries might create new types of danger.

Integration off makes the smart textile dependent on external data processing. The autonomy of the gear decreases but the arrangement is often a necessity as large computations need large computers in turn in need of pronounced powering, not possible anyway to host locally at the gear.

On-going technology shift manifested in ubiquitous wireless communication, and the Cloud and the Fog supports integration *off*. Then part of the computing including semantic classification (in the case of the SUITCYES project with image analysis and classification and ontologies) of the surrounding in stored databases of visual, audial and digital (social media) information is performed outside of the textile, "the off textile domain". By this, degrees of freedom are released for the textile domain enabling better production, comfort, use and waste performance.

Shannon-Weaver for haptic communicative textiles

Having introduced the Shannon-Weaver model and haptic technology and textiles is it now possible to map the components of SW in terms of textiles.

In the case of what is called haptic intelligent personalized interface, HIPI, the different components could correspond to (looking back to fig 2):

- Information source – could be the teacher for students having deafblindnessor interpreter or clues from any vision sensor
- Message – visual (and audial) content
- Transmitter – Vibration motors on the back of the haptic garment

- Noise Source– movement artefacts,
- Receiver – Skin of the wearer
- Destination – Mind of the wearer

It could be noticed that in reality it most often the case that there are many Shannon-Weaver process in serial, say from the teacher- to a computer or other input device that is then transmitted to the haptic garment where there is a wireless transponder that translates the incoming radio signal to voltages in the control units for the vibrators. There could also be feedback from the wearer.

Passive haptic properties of textiles

Touching upon or simply wearing a garment inevitably means having a haptic experience. Within the textile community the experience is in the realm of comfort. Comfort is a complex, multifaceted, subjective concept as its perception arises from a great amount of stimuli from an interaction of clothes and the surroundings,(Fourt and Hollies, 1970; Li, 2001; Roy Choudhury et al., 2011) which is relying on thermal, visual and tactile perceptions as well as psychological aspects and environmental effects.(Li, 2001; Liao et al., 2016)An experience is laden with subjective psychological as well as cultural goods. Two conditions are part of the sensorial comfort, namely the feel when holding the textile between thumb and fingers ("fabric hand") and the feel when the garment is touching the skin while wearing.(Das and Alagirusamy, 2010; Goldman, 2005)The fabric hand describes the subjective perception of a textile when in contact with the skin.(Behery, 2005; Zhang et al., 2016) Many studies aim to describe this property, which is dependent on various physical and sensorial factors,(Barker, 2002; Bishop, 1996; Peirce, 1930) such as the fibre type, the fabric construction (which influences the surface structure), and potentially applied finishes (Roy Choudhury et al., 2011). A big part of the textile hand can be assigned to the texture, which is the 'touch feeling of the surfaces'(Ben Messaoud et al., 2016). The main factors determining the comfort are surface roughness/scratchiness, hairiness leading to itching or prickliness, pressure, clinginess, a warm or cold feel when touching the textile and the fabric stiffness/softness (Kilinc-Balci, 2011a, 2011b; Li, 1998; Roy Choudhury et al., 2011). However, the sensitivity to textiles and thus the likeliness for discomfort diverge to a considerable extent between individuals, partly related to the age as well as other factors (Hatch, 1993; Kilinc-Balci, 2011a).

In general, haptics convey a wealth of information in a fast way during the interaction with one's physical surroundings, which 'needs little conscious attention, allows for abstract information encoding, and produces strong emotional responses'(Bau et al., 2009). Hence, textiles are able to express subtle distinctions between sensorial characteristics as a form of passive communication (Townsend et al., 2020). The comfort of an object as well as its aesthetics can be perceived by using touch as a means to explore senses and emotions.(Jeon, 2015). Touching a textile triggers sensuous imagery, which goes way beyond the touch sensation itself. This can be feelings of nostalgia or empathy, calling forth memories or creating expectations of the product. Thus, there is an *emotional dimension* attached to the sensory dimension when perceiving textiles by touch. Resulting from this, in addition to the perceived object itself, the person perceiving an object determines the experience arising from touch (Gibson, 1966; Jeon, 2015; Merleau-Ponty, 2002).

The surface structure of a textile can induce various sensations, e.g. a cold or warm feel, independent of the material composition (Hatch, 1993). This becomes visible for example when comparing two cotton bed sheets, one in percale and one in flannel. Even though both fabrics are made from the same raw material, the smooth surface of the percale is associated with comfortable cold sheets in summer while the hairy flannel implies the association of cold winter and cosiness related to the warmth of the bed sheet (Kilinc-Balci, 2011a). Therefore, in the field of fashion and interior textiles, texture is 'one of the most important […] design elements' (Gong, 2013). It can be used to express a designer's idea in form of visual and tactile impressions.(Gong, 2013; Sirikasemlert and Tao, 2000) This concept was employed by Eunjeong Jeon (2015) in an investigation of 'haptic seeing' via a series of tactile experimentation. In this, the act of designing was employed to communicate knowledge and purposely evoke emotions (Jeon, 2015). Further, Vogue recently titled 'Fabrics that feel like summer' (Besser, 2020). This is another example of how materials and their hand can induce expectations and emotions. According to the author the textures of certain fabrics, such as linen or crochet, evoke the association with summer and were therefore referred to as the 'textures of the season' (Besser, 2020). Furthermore, fabrics in fashion and interior can also mirror societal aspects characteristic of a certain time. This takes no halt for the texture and the hand of fabrics. For instance, Hartzell found that the use of velvet linings in the nineteenth century could be seen 'as literal and figurative mediators of the […] bourgeois desire to possess, articulated in the act of touching' (Hartzell, 2009).

Haptic qualities are a *crucial selling point* for all types of clothing, (Citrin et al., 2003) as 'they can greatly influence the physical and aesthetical aspects […] of an apparel item and easily change consumers' purchasing decisions' (Xue et al., 2016). The texture of a textile is a distinguishing property, particularly for clothes as well as upholstery fabrics, which makes textiles an inherently tactile material. The sensory dimension has a considerable role for the overall product perception (De Klerk and Lubbe, 2008). Depending on the type of clothing, the tactile properties can even be the main selling argument, as found by Holbrook in the case of a sweater purchase (Holbrook, 1986). Also for jeans and denim apparel, haptic qualities play a major role for the commercial success. Consumers tend to test the tactile properties, especially the fabric hand, to draw conclusions about other qualities of the jeans, such as the thermo-physiological and sensorial comfort, the durability of the garment and its shape retention (fabric stretch), and the physical mobility (Rahman, 2012). These observations underline the importance of the unconscious or conscious tactile perception of garments (Rahman, 2012).

During the 20th century, research regarding haptics in textiles was related to the feel, comfort and quality of the textile (also improving the invention of synthetic fibres). One example is the work of Kawabata that discusses fabric hand in relation to mechanical properties of fabric (Kawabata, 1989). Later there has been research made into the area of textiles and haptics related to virtual reality and robotics.

Active haptic textile interfaces

Active haptic textiles

A wealth of haptic mechanism have been employed in textiles(Jean-Loup, 2007). Examples of haptics in regards to textiles are efforts to make haptic simulation of the feel of fabric on the skin/hand (Volino, 2007). For Virtual Reality (VR) experience in gaming many types of vest have been developed. On type is the *ARAIG vest*, developed as a haptic garment to be used in tactical training where sensory feedback through the garment increases the sense of presence in VR(McGregor, 2016). Another example of a haptic garment is the *TESLASUIT*. The two-piece garment is enriched with haptic feedback to create a sensation feeling with the wearer and enhance VR (Teslasuit, 2020). Cutecircuit has made their *sound shirt* in a wireless shirt with 16 actuators that capture sound from different instruments and display them on different parts of the upper body, in this way conveying the sense of hearing music to persons that cannot hear.

Vibrotactile signals have short time constants and can be adjusted easily to conveying different signals by altering frequency, directions etc. Thermal signals, realized as for example Peltier elements, that build upon the principle of thermoelectricity have long time constants. Thermal actuators are perhaps then more suitable for "subtle" communication, such as conveying affection or presence.

To avoid blurring of signals garments could be made so that they limit the spread of the vibration resulting in a more focused signal. A study (Karnovsky, 2016) on vibration isolation in spacer fabrics was made by (Chen, 2016) who writes that thicker spaces fabric has a lower resonance frequency than thinner fabric and found this due to a lower stiffness, which can isolate the vibration at a lower frequency level.

We call actuators that specifically are used for tactile activation for *tactors*. These are placed in different geometric constellations, potentially all over the body, tight to the skin. We need a nomenclature for this.

Nomenclature[8] for active haptic textile interfaces.

We define *location* as the geometrical position on *the body* i.e. an anatomical measure, whereas *placement* is the positioning of some actuator (or sensor) on the textile, for example given by a matrix like denotation; "a6" etc. or "in the middle of the chest" etc. It is the purpose of our textile efforts in SUITCEYES to repeatable have the placement of a certain sensor on or above the same location. Some variation and discrepancy (order of mm) is probably not a problem from one time put on to the next or due to movements.

On the textile, which is a physical artefact, we place actuators, see fig10. In the foreseeable technological future these are discrete elements such as all the vibro-tactile elements.

Cell is the physical construction on or in the textile such as a pocket having a certain placement from which actuation could take place. The word could is important. If a cell is a pocket it could have or not have a vibrator and the vibrator could or could not be on, vibrating. Typically, we will have many more cells than vibrators in a garment which is fine as humans can handle only a limited number of stimulus especially if they comes spatially close to each other. Cells that have an actuator that is actuating are active.

When active, the singular cell is referred to as *Dot*, i.e. one active physical actuator at one placement.

Dot - actuator with a specific placement in relation to a location. It is our hypothesis in SUITCEYES that this mimics the pressure of the fingertip of the interpreter and that the dot works as some kind of equivalent to a (mathematical) point. We better reserve the term point to mathematical points (that have no extension just location or placement).

Line - set of dots with their placement adjacent to one another in a horizontal or vertical line.

Pattern - set of active dots. The pattern could either simultaneously light up (what we call static) or light up in a sequence (dynamic). Note, patterns are something that is on the garment and represented by different haptograms (see below) in turn represented in a graphical matrix form but is not necessarily what is felt by the person. It is the purpose of SUITCEYES to relate what is sent in to the person and how the person apprehends this.

A set of dots so that their placements (i.e. on the garment) is in a line; horizontal or vertical, up, down, left, right, diagonals are called a pattern. It is assumed that typically we will have cells placed in columns and rows similar to a matrix. As pattern a line could be either light simultaneously or in a sequence (then indicating a swipe for indicating a direction).

Panel- set of cells close to each other. It might be good to offer a number of panels such for the back, the upper arms, and the waist (perhaps in a belt then). It seems as SHL uses the possibility to switch scene by switching from a started description on one panel (perhaps the back) to another (the closest upper arm for the interpreter).

[8] Different fields are more familiar with certain nomenclatures. It could be that say "unit" could be more natural for "dot" in computing etc.

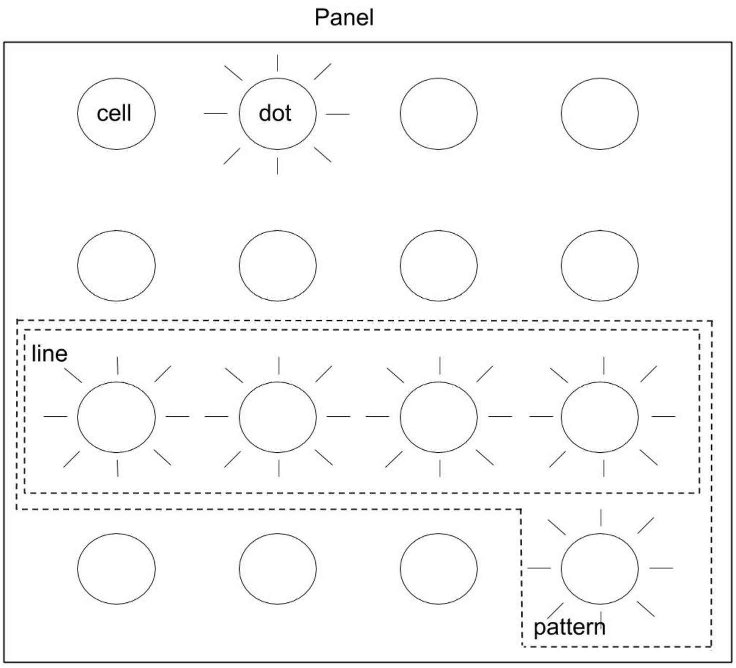


Figure 10.The principle of a panel consisting of a specific amount cells (when turned off) or dots (when turned on). A line could be either horizontal or vertical and a pattern includes both horizontal and vertical dots.

Haptograms - perceived patterns with a meaning as developed in the SUITCEYS project. Meaning could be given a priori i.e. by convention or posteriori (developed underway). SHL(Riitta M, 2008)is about the latter that then have partly become conventionalized.

Benefits of textiles for haptic communication

We now discuss opportunities with textiles for haptic communication. We use the term claim for these. Claim means that due to some foundation a normative thesis is expressed. Claims are based on what communication is, characteristics of humans and haptics$_a$, and essence of textile, (fig 1). In total this is four dimensions. Claims should be supported by arguments. Due to C19 situation taking place during the project, psychophysical experiments have not been possible, as access to subjects has been prohibited.

The identity problem of claims, what is one claim and what is another isfor sure to some degree subjective. Each claim is given a name, possibly added to that a phrase as a title. The discussion is then finished by a formal proposition, C_I, C_{II}, ... The presentation is done in a way inspired by any formal settings, like an axiomatic program. The hope is that this brings clarity. There is no natural order among the claims even if there is a slight tendency to start with simple ones and moving to complexity. The hope is that both proponents of $haptics_d$ who might not know much about textiles or have not pondered upon what textiles can offer or what textiles are, could benefit from this. The hope is also, oppositely, that representatives from the textile community, manufacturers, researchers, entrepreneurs, designers, who do not know much about $haptics_a$, $haptics_b$, $haptics_c$ and $haptics_d$ could get widened perspective and enter in to the realms of $haptics_c$ and $haptics_d$. Implicit is the focus on assistive technology and on people having deafblindness.

We start with a first observation:

0. Integration Ansatz

Textiles could be equipped with many different kinds of both sensors and actuators, both in a crafts- wise fashion and in an industrial setting. The smart textile community that has been around since the 90^{th} has brought this to a reasonable level of maturity today. One could talk about *integration*(Guo et al., 2016), which primary refers to integration of *function* and only secondary to integration of a certain physical device. A function can be realized in many different ways. *Integration on* and *integration in* approaches were discussed earlier.

C_0: Integration in textiles of actuators (and sensors) for technified haptic communication is to day feasible

When then go to the regular claims

I. The covering claim: Textiles cover large parts of the skin

With the skin being the decoder of haptic communication and many haptic languages (SHL, PTASL etc.) using several parts of the body beyond the hands, textiles in the form of garments that already cover large parts of the skin is anoptimal tool for haptic communication, see Figure

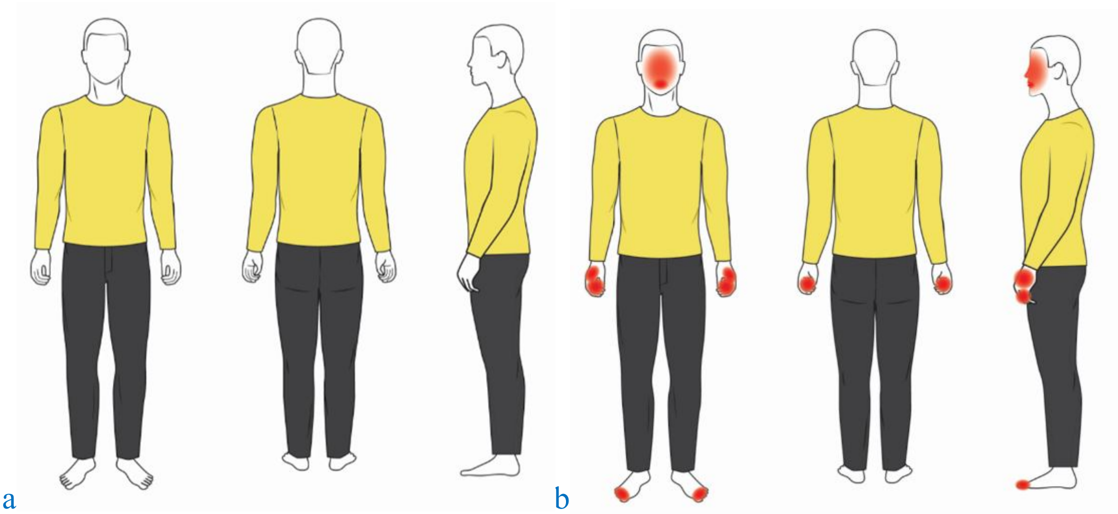


Figure 11.a) covering-claim, textiles cover the decoder of haptic communication –the skin. Illustrated is an almost universal division of a upper torso part (yellow) garment type and a separated lower part (that do not need to have separate legs) from the waist and downward(black).Both these are possible to put on and put off on in independent order relative to each other. Approximately 80% of the body is covered by clothing in a tempered modern Western culture. b) Human locations for highest sensitivity for passive touch added. As seen this and clothing are complementing each other.

Garments address different body parts, and the degree of coverage of the human skin is depending on temperature, climate, weather, culture, social norms, and social context. In modern western culture and in a tempered climate zone the torso, the legs including the feet, and often the arms down to the wrist are covered. Based on this approximately 80% of the skin is covered by clothes[9]. Simultaneously this means that cutaneous receptors in most cases have a very short distance to textiles. By this the receptors are also addressable by textiles useful from a haptic communication perspective.

It is interesting to compare anatomical locations for clothing with anatomical locations for human tactile sensitivity, fig 11 b. Hands, especially finger tips and face, especially lips belongs to the most sensitive parts for tactile passive stimulation. They seem also to be the first choice when engaging in active touch. Simultaneously, hands and face, sometimes head, are not covered by textiles. Thus, as seen in fig 11, parts covered by the typical worn repertoire of garments used in tempered climate and modern society is more or less the exact complement to the zones of the human body with the highest sensitivity for passive as well as active touch.

There are for sure textiles for the areas not covered by the clothing of fig 11 a – socks, stockings, gloves, mittens, hats, caps, mouth-nasal masks, eye masks, wimple, veil, niqab, are for sure textiles but there are reasons for not taking at least the hand zones in use for people having deafblindness and others:

[9] In Nathan Wales: Modeling Neanderthal clothing using ethnographical analogues in Journal of Human Evolution Vol 63 6 pp 781-795 Dec 2012 clothing in an paleolithic and hunter-gather context is studied receiving to the same number of approximately 80% coverage.

- Hands (and fingers) are needed for carrying things and for balancing
- Hands (and fingers) are needed for performing any human-human tactile sign languages
- Hands (and fingers) are needed for active touch including manoeuvring a cane
- Textiles on location such as lips are unpractical, disturbing, and rendering low comfort

We can address many different body locations by textiles, in the form of garments but also as interiors. In the latter case, bed linen, mattresses, sofas, sofa pillows could all be equipped with haptic actuation.

Much of tactile sensory studies have been devoted to the most sensitive body areas such as lips and fingertips. The knowledge of human spatial resolution human temporal resolution capability for larger parts of the body is not that examined, especially not for modalities beyond two-point pressure discrimination and vibro-tactile (coin vibrators). In any case there are large zones on the body open for exploration for technified tactile communication.

C_I: Textiles offer communicative access to body zones complementing hands and fingers that are valuable to reserve for other (communicative) purposes.

II. The know-how-to use claim. Textiles are known and therefore vehicles to humans

All humans are interacting with textiles. Textiles are known to humans. There is a general almost intuitive public knowledge of how to put on a sock or a vest. This means that how to use, wear, put on, undress, interact with common types of clothing, handle, store, approach, maintain does not need any learning. When introducing new technology, such as assistive device and user interfaces (UI), one has to consider a certain learning curve, see fig 12. A learning curve describes how a quantitative measure – often time in seconds to perform a task – changes as a function of time spent on performing i.e. learning the task. It is important to be clear on what the learning curve really refers to. Is it a garment itself, which is one type of artefact for a special purpose (keeping the wearer warm) or is it the garments as an assistive (tactile) device which has another purpose (namely communicating).

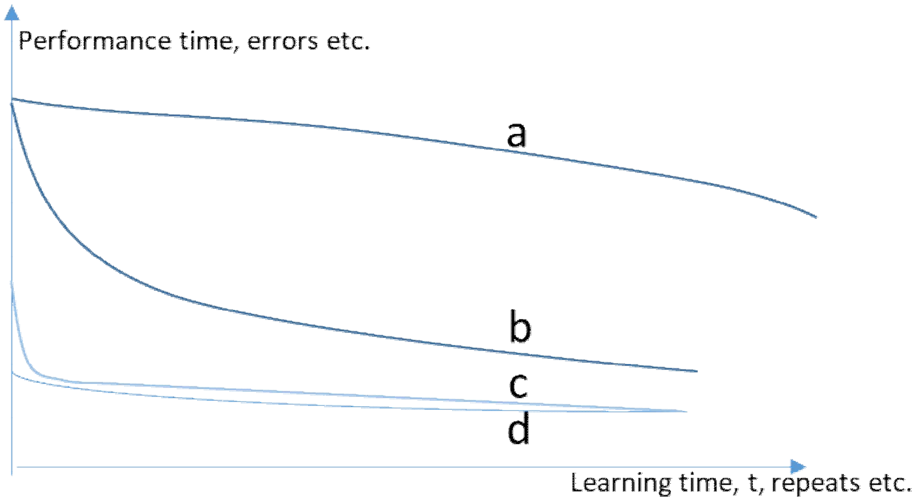


Figure 12. Learning curves for three types of assistive devices. a) is a device that is difficult to use. It takes long time when first encounter the device to accomplish a task. It is not much easier the following occasions. It is difficult to use. b) is also tricky to work with the first time, but soon it goes much easier. The learning curve is sloping steep downward. When the user has learnt the task it successively is less and less better performance. d) is a device that is easy to use already from the beginning (starts as a low level) and then one it is not possible to make it much better even after training. This could be a garment c) is device that starts from a somewhat larger level but very quickly approach the curve d. This could be an assistive device based on a garment.

Assistive technologies such as for $haptics_c$ could take advance of this. Equipping well known garments with functionality for tactile communication and simultaneously minimizing any extra efforts for starting the haptic technology by displays, buttons, instructions would render an easy-to-use device.

Textiles have a low start value for the learning curve, measured for example as no of errors made when putting on a jacket. Textiles have an almost flat learning curve by themselves as they are so well known already. So if there is no complicated extra starting procedure for the haptic functionality haptic textiles have an advantage compared to other devices such as vibrating smart watches, braille readers etc. The learning curve for a $haptic_c$ garment is thus steeply going downward, such as c in fig 13. This is useful both for the elderly often having technical illiteracy and persons with mild cognitive impairments. This is not to say that any haptic sign system itself does not need teaching and a long learning period.

As garments and their handling are so well known any $haptics_d$ could free-wheel on not only learning but also on other aspects such as efficiency i.e. how quick can users perform task when they have obtained a familiarity with the device; satisfaction i.e. how pleasant is it to use the device; error performance i.e. how frequent users make mistakes and how easy can users, both those wearing the device and interpreters, say, recover from the errors; and memorability, which is how easy is it to (re)start using to a device when having learnt how to use it but being absent from it for a while.

C_{II} : Textiles in the form of garments offer $haptics_c$ and $haptics_d$ beneficial user experience, including steep learning curves as textiles are so well-known to users.

III. The coplacement-colocation claim: Textiles enable simple positioning of actuators at a specific anatomical body location

Textiles in the form of garments are made to be shaped after the complex concave-convex topology of the human body with protruding limbs. They are made for handling repeated positioning- repositioning cycles when taking them on and off, so that visual appearance and comfort is maintained over time. Sleeves on the garment always end up on arms of the wearer. Or, better formulated taking account of children and people with disabilities such as difficulties bowing down for taking on their socks, garments have the inherent potential to coordinate a placement on the textile with an anatomical location on the body, they are copositioned.

This is an excellent start for any assistive technology that is dependent on addressing a certain body location. Manual positioning, either by the wearer him/herself or by any care-giver, of actuators and sensors if any), which is both highly time consuming, and therefore expensive for health providers and ask for qualified skills in terms of physiology-critical positioning could be replace by just putting on the right T-shirt with built.in haptic actuators.

The correct placement is done automatically each time when the garment is put on.

An example of this is The Black dress developed within the SUITCEYES project by HB, fig 13. It has a matrix of vibro-tactile elements on the back for technifying and mimicking SHL. This dress is made in definite size aimed for fitting a definite person in order to fulfil the requirements that each time it is put on the vibrators end up at the exact body location and that the inherent distance between the vibrators are kept constant and above human spatial resolution limit (of appr. 4 cm distance)

Figure 13. The Black dress developed within the SUITCEYES project by HB. On the inside of the back there is matrix (white lining) of 4 by 4 pockets where coin vibrators can be placed. Vertical symmetric in this matrix there is the back zipper that gives access to the vibrators as well as enabling taking it on and having a close fit. Green parts are a developed seaming technique for housing electrical conductors for powering and signal control.

This logic works well for persons able to put on and put of their own clothes and stand in an up-right position. There might be some variation of the placement (i.e. on the textile) and location (i.e. on the body). The discrepancy in the co-ordination of location and placement is due to

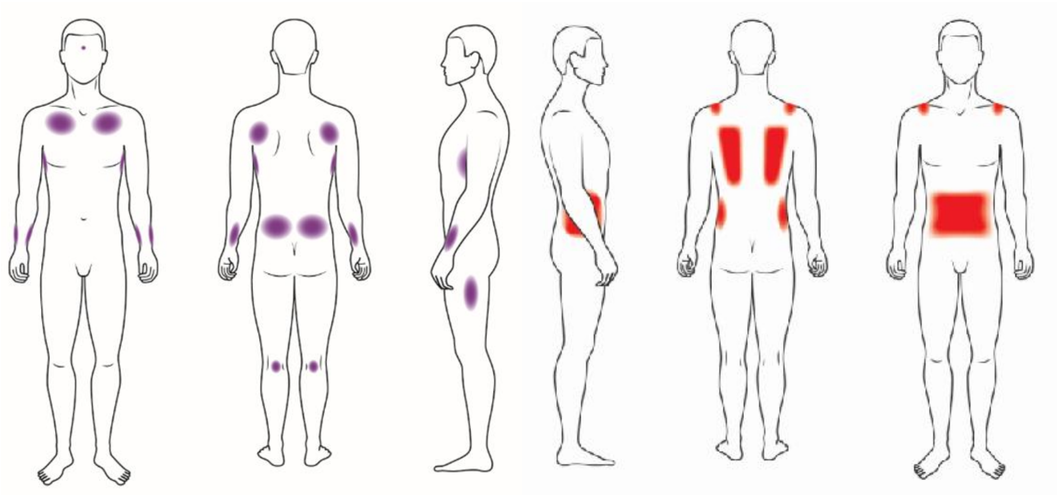
- Ability and focusing capability to putting on clothes. Children, the elderly, an immobilized hospitalized patient, a person with cognitive disabilities and an outward acting aggressive person with deafblindness all have their own challenges and reasons for not reaching colocation-coplacement success. Timescale for change in positioning in this case is in the order of day or week, $\mathcal{O}$(days). The garment could be worn in one way the first day and in another the next day (such as when home-care personnel cannot adjust a vest thoroughly one day due to lack of time but the next day could put it on in a better way)
- Change of body posture for example changing from standing to sitting. Placements on the textiles under such a mechanical load that there was tension in the fabric when standing could be folded or losing all stiffness when the person is sitting down. Timescale for change in distance location-placement in this case is in the order of seconds to minutes, $\mathcal{O}$(min).

- Movement of body during daily activities such as reaching, walking, bending, and exercising. Timescale for change in distance location-placement in this case is in the order of seconds, $\mathcal{O}$(sec).
- Dislocation due to movement aging, shrinking, elasticity, no form stability etc. of the textile goods. Timescale in this case is in the order of weeks-months, $\mathcal{O}$(week).
- Dislocation due to change body shape and mass – both due to become meagre and obesity. Timescale in this case is in the order of years to decades, $\mathcal{O}$(y).

C_{III}: By textiles placements on the external device, textile in this case, and anatomical location can be made overlap from one usage to another, rendering time efficiency as well as positioning and operation quality, that a layperson cannot match by manually placing tactors.

IV. The 2D claim – textiles can host sets of tactors

As mentioned, a rich haptic signalling system or even haptic language need a two-dimensional distribution of tactors. Textiles with its characteristics of being able to cover surfaces and volumes (mentioned as the Covering claim I above) such as the human body and its skin offer this. We have been arguing for this in (Lindell et al., 2020). Few locations on the body offer larger areas that are flat and those that approximately are, are small of the order of cm^2, fig 14a, thus this is not a feasible strategy. Instead locations with larger areas where there is no switch between convexity and concavity might provide a surface where it is possible to maintain mechanical contact, fig 14b.



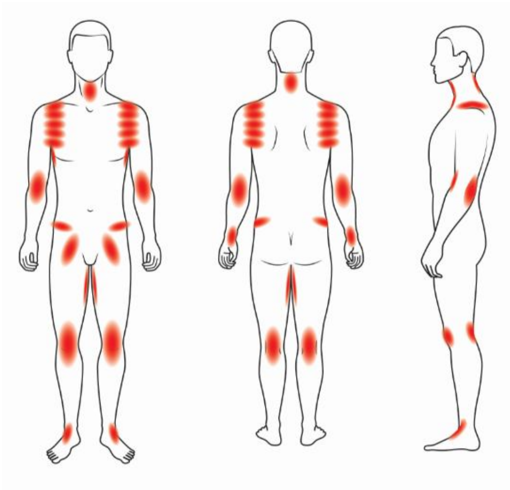


Figure14. Human topology. upper-left) zones that are approximately flat i.e. having zero curvature. upper-right) locations where there is noswitching between convexity and concavity for moderate posture changes. lower) locations where there is bending. All these are factors to consider for locating any haptic communicative devices.

Even if it is not the only choice, we assume a clustered $m \times n$square system with freedom for the distances in row direction, all being d_1 and distances in the vertical direction, d_2, se fig 15. The$m \times n$ matrix has every tactor (commonly vibro-tactile elements) in either of two states; active ('high voltage sent') and non-active ('low voltage applied or nothing sent'). Each tactor could be active for an individually controllable period.

There are $m{\cdot}n$ tactors. As every tactor could be in two states (Low and High) there are 2 times 2 times 2 times….= for m, n= 10, say (which could be feasible on the back of a person), this is a ridiculously high number of combinations, i.e. signs, possible to generate, around 1.26 $\cdot 10^{30}$. Of course far outside of any human discrimination capability.

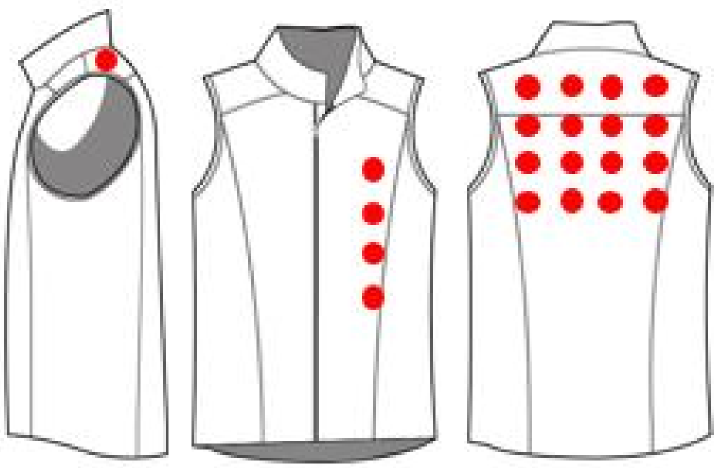


Figure 15. Placement of the tactors in a a) 0 D, b)1 D and c) 2D arrangement of tactors.

Having just one tactor could be called *pointwise actuation* or *zero dimensional actuation*, 0D.We notice that this is a much used situation in many types of contemporary wearables with a buzz function but that the informational content in any message sent is highly limited, more or less only working like an alarm function. This is what is used in smartphones for alerting for an incoming phone call, text messages or alarm clock. Instead, arranging actuators in a linear order, *one dimensional,* 1D, opens up for temporal sequencing of the actuators, still being part of the same message. This enhances the potential richness of the information that can be conveyed but cannot be driven too far as the spatial resolution of human tactile sensitivity is limited and varies. *Two dimensional actuation*, 2D, is the arrangement of actuators on a limited part of the body so that the set of actuators still could be said to be in a plane or having maximum one single curvature. If of more complicated geometry, switching between concave and convex shape, (*pseudo*) *three dimensional,* 3D, could be the term used. This also includes the case when covering different body parts. But full-fledged three dimensional actuator arrangements are probably of less interest as humans cannot by tactile sense detect things outside of each other and actuators risk to cover each other.

There are several reasons why 2D is more interested than 0D and 1D:

a. 2D is containing 2^{mn} signs, were *m* is the number of rows and *n* columns. The number of combinations grows fast, beyond human discrimination capacity, but is not different from a linear array with the same number of dots.

b. As mentioned, 0D, can only convey some information that is synonymous with "Something is happening" but nothing more (like *what* is happening, if several things are happening, from where somethings is happening etc.). 0D is necessary indexical and symbolic in a semiological parlour, whereas 2D could potentially also mimic reality in some very simple meaning and being iconic.

c. 2D opens up for dynamic patterns (so 1D), dots could become vibrating in certain order

d. For the 2D case it is possible to let columns and row carry meaning. Rows could, say, stand for a certain general class (say: related to food/eating, related to moving, related to friends/relationships etc.) and magnitude could be expressed as how many columns in row that are used. This could not be done for 0D and 1D.

e. By 2D *directional* information is possible. By activating some of the actuators in a sequence this could mimic from where a certain phenomenon is coming (left-right, up-down). See also Directional faithfulness clam below.

f. If there is an (predetermined) origin it is possible to illustrate *close and far away*

g. It is possible to illustrate "*much"* easily in 2D by having all vibrators active simultaneously but this also goes for 1D with "higher-lower" possibilities and, say, "left-right", "little-much".

h. This leads to that *quantification*, and that *numbering* is possible in 2D.

i. The human physical surrounding is inherently three-dimensional but for sight it seems possible at a given moment to project that into some two-dimensional sphere around the perceiver with maintained experience. Humans (or human culture) seems to be open to that two-dimensional structures convey a good-enough experience, exemplified by paintings, photos, TVs, movies, computer screens. It is much easier to map these(sense switching) to a 2D haptic array than 1D. In fact, when an interpreter is describing a room in SHL with interesting objects, significant persons etc. a map is drawn on the back of a person with a frame for the walls, and signs for what is important and where that is placed giving some apprehension for the spatial distribution.

j. As said, within such mapping *localisation* of interesting objects are possible in 2D.

k. Human could perceive and discriminate 2D sign combinations more easily(Lindell et al., 2020)

l. Human have(Lindell et al., 2020)the ability to more easily remember different patterns and their location as associated to a meaning in 2D than 1 D.

m. 2D is a step towards *haptic pictures* (i.e. leaving symbols) which are such that they mimic the tactile aspects of an object with a lot of tactile contrast of its parts

C_{IV}: As textiles are inherently two-dimensional and are pliable adopting to the human body topology they can act as 2D haptic communication devices and by this transferring rich messages of symbolic, iconic and indexical nature.

V. The constriction claim: Textiles promote tightness

Tactile stimuli must be sensible and for this any tactor such as vibro-tactile elements must have good mechanical contact with the skin at the proper location. A certain pressure is necessary. Furthermore, any vibration must be managed so that vibrators or junction points do not break due to their own vibration. Textile systems could handle this. The textile community is the experts handling factors of sizing and grading which impact the fit to the human body.

Textiles promote good mechanical (thermal, electrical) contact with the skin. One prototype where this was especially manifested was the chessboard vest, see figure 16.

Textiles could be made elastic and by this offering a tightness to the placement supporting the transfer of any mechanical vibration or heating or cooling.

Figure16.The Chessboard Dress developed within SUITCEYES project by HB. This is in principle more of a psychophysical testing device than a full-fledged consumer product. It addresses the problem of the need to positioning vibrators at a certain body location but having a garment that fits different body sizes. It is here solved by making a kind of weave construction with warp and weft "tails". Behind each of the crossing points seen a coin vibrator could be inserted which then actuate on the skin side. Tails in the weft direction are having astrap function tightening up the

C_V: Within the textile repertoire are pliable, elastic materials fitting close to the human topology which enables good mechanical and thermal contact to the skin by exerting a certain pressure.

VI.The compliance claim: Smart textile could support compliance

Textiles are taking part in almost all human activities, throughout life, indifferent to age, sex, occupation, social class, culture, religion, and ethnicity. Then enriching the textiles with haptic actuators could mean that also the $haptics_d$ is taking part in the daily life activities - and by this being used.

Textiles have form factors adapted for humans, are soft and pliable and provides comfort. They should therefore be pleasant to use thus supporting usage.

These are arguments for compliance. Compliance is an ever-present problem for any ordination of medical treatment. It is the degree to which how patients are following the ordination of care-givers. Compliance is also relevant for assistive technology. If not used no benefits from the device will be obtained.

Letting the medical realm meet the behavioural, the concept of user experience is key to compliance. If there are minimal new things to learn, memorize and do, compared to putting on the garment that either is so familiar for the user or, even, should have been worn in anyway the hypothesis is that compliance is supported by the textile.

For example – using the placement-colocation claim above - textiles enable simple positioning of actuators at a specific anatomical body location. By textiles many steps in a procedure for putting on, say, electrodes for electrotactile stimulation, could be elaborated. Such electrodes should be picked from a package, that should be opened, whatever (neutral garment the patient is wearing should be taken off, the body locations for the right position of the electrodes should be found (often needing pre instructions or even a profession), perhaps gel should be applied, each should be connected to a cable, connecting the cables to a common unit, taking on the whatever garment, starting the communication act.

All this are impacting negatively on compliance.

There is a new paradigm within medicine and care. For a long time medical care was treatment after a trauma or after signs of a disease i.e. a post treatment perspective. Lately there isa salutogenic perspectives, promoting healthy food, daily exercising, no smoking etc. i.e. a pre- treatment perspective. As technology supports longitudinal monitoring a paradigm of life long medical treatment is now seen. Smart textiles could be an important factor for this,

> C_{VI}: As garments are familiar easy-to-use artefacts adding $haptic_c$ communicative functionality to them might positively impact compliance and long term use.

VII. The directional faithfulness claim: Textile enables 360(540) degree sensing

Many senses are directional. Within the field of view, vision gives information of where the dorsal object is, i.e. information on from which direction the flow of photons is coming from which is including an estimate for the distance to the object and an estimate of the angle to the object. The same is true for audial stimulus. For $haptics_a$ this is even more pronounced. Due to the fact that even in passive mode we know not only *that* someone touched us but also *where* on the body haptic stimulus occurred the $haptic_a$ sense is directional. This statement is further strengthened including the kinaesthetic sense. Sometimes it is possible to interfere the vector character of mechanical stimulus; from what direction it entered and where it is headed such as in a swinging nod from another person's hand, sometimes more complicated (van Beek et al., 2013). In fact the human body could sense haptic stimulus from beneath to the foot, normal to the legs and torso and from above on the head or shoulders or stretched-out arms. This is 180 degree in a vertical plane and 360 degree in a horizontal plane, see Fig 17. This could be called 580 degree sensing.

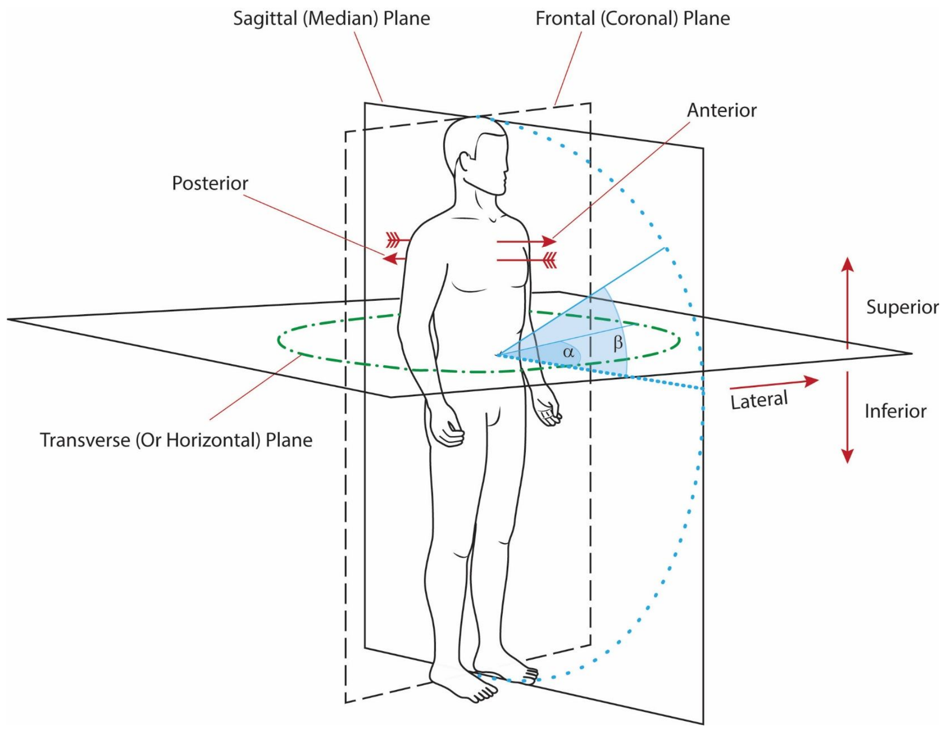


Figure 17. Human and planes, sections and directions used with medicine. The anatomical posture is when standing straight up, with the body at rest, arms hanging free. Anterior or ventral means nearer to the front of the body. Posterior or dorsal means nearer to the back of the body. Superior or cranial means nearer to the head. Inferior or caudal means nearer to the feet. A sagittal plane is a vertical plane passing through the middle of the body, dividing it into right and left halves. A frontal or coronal plane is a vertical plane at the right angle to the sagittal plane. It divides the body into anterior and posterior parts. A horizontal or transverse plane is at right angles to both the sagittal and the frontal plane. It divide the body into superior and inferior parts. Lateral means to the side (left or right) from the body middle. Directions to incoming object that is about to generate tactile experience could be given by two angle, α, and β. The former is in the middle transverse plane, the latter in the median sagittal plane.

By textiles in the form of garments or collection of garments it is possible to maintain this directionality haptics$_a$ show and *directional faithfulness* is possible. That is that by tactors distributed over the body stimuli could be sent in from in principle all directions to the human body. This builds upon the Covering claim above.It is the basis for haptic body displays, projecting the world to the body. Such a system is not possible for smart phones with vibrators of Braille machines or haptic watches or point like nobs.

An example of attempts to achieve a haptic communication device obeying directional faithfulness is shown in fig 18. What is denoted the *full body modular suit* consists of multiple panels that, together, cover large parts of the body. Figure 18a shows the basic pattern construction of the full body modular suit. All pieces are interchangeable and made from Velcro fabric to provide ease of use and tightening. The horizontal and vertical lines provide guidance to put actuators (vibration motors) in any specific matrix.

In fig 18 b the complete outfit is shown. Each panel is to be used independently on the others creating flexibility in what part of the body the haptic communication is to be done.

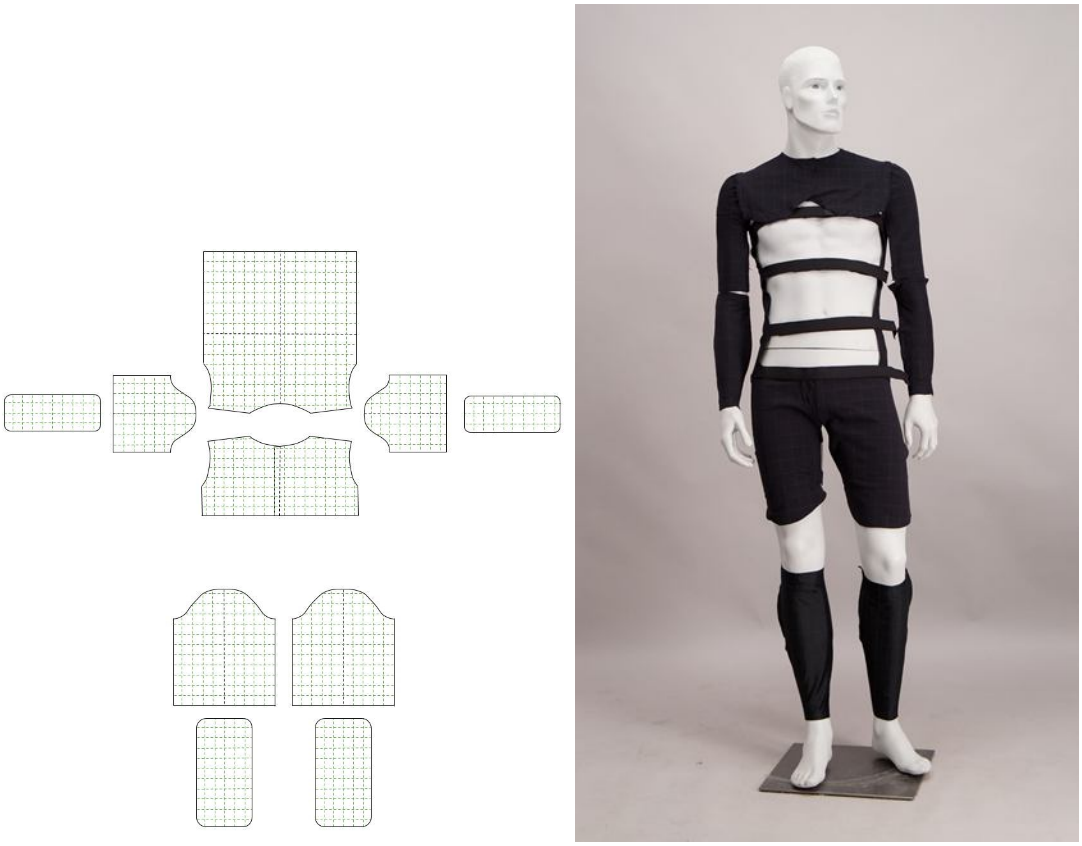


Figure 18.Full body modular suitmade within the SUITCEYES project at HB.a)Parts, principle and pattern construction b) the full body modular suit on a mannequin

C_{VII} : Textile,by using a collection of garments enables 360(540) degree sensing, which coincide with the character of the tactile sense

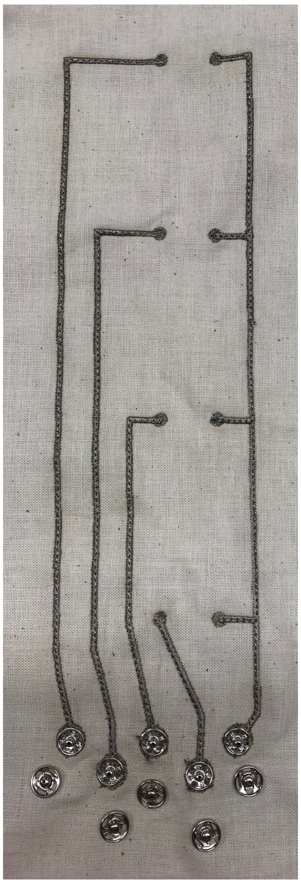
VIII. The carrier claim: Textile is an infrastructure for adding functionalities

Any reasonable advanced haptic communicative device needs a number of sensors, actuators, wires, powering etc. Furthermore, these are, due to the 2D argument, directional faithfulness and weight balance, to be distributed on the body. Textiles could, due to the covering claim but also to the fact that textile have mechanical strength and that a large spectrum of attachments techniques have been developed, serve to carry these items as well as connecting these. There is the possibility of a textile electronic infrastructure, with connectors, perhaps prepared with connectors for attachable devices, as well as mechanical infrastructure taking the mechanical load of the masses of these devices.

Contemporary haptic devices not being textile based cannot much this easily. Different kinds of patches then need to be put on separately. Wire management becomes negative to comfort.

As textiles should be used anyway in a daily activity, enriching them with electronics does not “cost” anything from a user perspective. If well done, there is nothing extra to do, think of. There is no change in comfort and no impact of the daily routine.

An example of a (part of a) textile electronic infrastructure is shown in Fig 19. Here embroidery with conductive thread is employed. It is one technique for creating a *pliable and flexible infrastructure* for haptic systems such as a setup of sensors and actuators.



Connectors and snap buttons were used, see fig 19. One part of the snap button was sewn to the circuit, the other connected to the specific actuator, hence also providing modularity.

Adjusting the stitches and adding a running stitch through the circuit lowered the resistance.

In fig 20 the overall approach of integrating electronics in textiles is shown.

Figure19. Embroidered circuit with snap buttons as part of a textile electric infrastructure that can carry different devices.

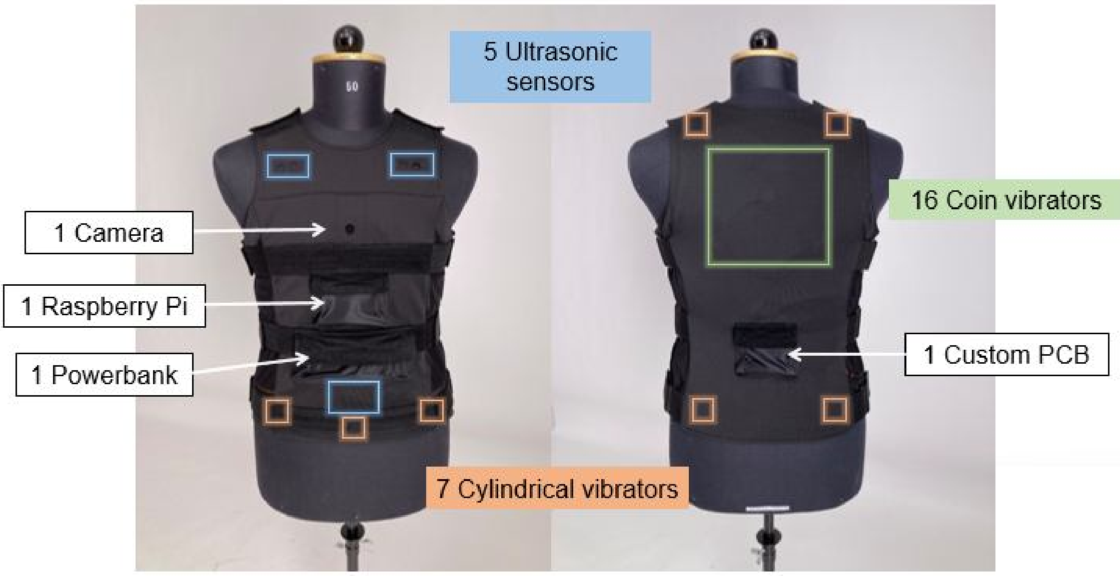


Figure 20. Textile as an infrastructure enabling HIPI device developed in the SUITCEYES project by HB. Squares are indicating devices that are on the inside of the garment.

C_{VIII}: Textiles act as both a natural mechanical, for carrying spatial distribution of devices, and an electrical infrastructure, proving powering and signaling built-in pathways for haptic devices.

IX. The portability – wearability claim: Textiles are portable

Textiles in the form of garments are per definition used for to be worn. They follow the human body and human form factors. They have low weight. Textiles are therefore portable. They are therefore also excellent examples of wearables. In figure 21 an example of a garment aimed for haptic communication is seen. It has a slick fit, having a matrix of vibro-tactile elements on the back and having all the electronics integrated on the garment.

Figure 21. The gamification vest front and back developed within the SUITCEYES project at HB.

$C_{IX:}$ Textiles in the form of garments are by definition made to be worn and are portable which make them a natural platform for haptic communication technology.

X. The clue claim: Textiles takes part in everyday activities and are therefore vehicles for such

Textiles being, the synthetic class of material most close to humans, both take part in, and trigger a vast number of simple, almost unnoticeable, often automatic, every-day human activities, se table 2 below, column 1 and fig 22. In many of these textiles take part, column 2. If textiles become equipped with sensor (or actuator) functionalities clues of what the person is doing, is about to do, an estimates of intentions could be carried out. Thus, every day, habits can be explored and used for turn on a function, turn off a function, they could create definite before and after automatically. Then devices could be controlled automatically but without any extra cognitive load. It should of course immediately be noticed that there could be ethical issues about control and privacy and patient independence.

The types of artefacts supporting control (starting, stopping, adjusting to certain level etc.) of certain technical functions are called *user interfaces* (UI)(Wigdor and Wixon, 2011). *Natural user interfaces* are those – most often, but not necessarily, graphical ones on a computer screen - that are based on intuition in a given socio-cultural context and nominally have a very short and quick learning curve. Here we have an even simpler interface that is free-riding on other artefacts. It is a new form of human-machine interactions beyond key boards and buttons.

1	2	3	4	5
EVERY DAY ACTION	TEXTILES IF INVOLVED	INTERACTIONS	INDICATION	LEADING TO
1. Take on a sock	Socks, stockings	Widening, stretching, sliding over the skin, relaxing	"The person is about to start the day" or "The person is freezing"	Start fall alarm, stop night alarm
2. Take off a sock	Socks, stockings	Widening, stretching, sliding over the skin, relaxing	"The person is about to finish the day" or "The person is warm"	Stop fall alarm start night alarm
3. Pass a doorway	-	-	"The direction of a walking person is known	Remote lock-up of doors
4. Button a button	shirt, trouser, dress	button, pressing, stretching fabrics	"Prepare for the day"	Start a radio for listening to new
5. Zip	shirt, trouser, dress, skirt	zipping, stretching fabrics	"Prepare for the day"	Communication to job that I will soon leave home
6. Brush the teeth	-	-	"Prepare for the day"	Play music in the bathroom
7. Unzip	shirt, trouser, dress, skirt	unzipping, stretching fabrics	"Finish a phase of the day", "going to toilet"	Light up the toilet, close cameras due to intimacy
8. Put ones hands in pockets of the trousers	trousers and their pockets	sliding, stretching, holding	"person is freezing"	Turn on potential heating in clothes

Table 2. Every-day action (shadowed column). In some of these action textiles are involved. In some not. In the former case the type of textile is given and what interaction the one performing the action is having with the textile and what is happening with the textile. This gives clues for how to design sensors and what physical mechanisms these could be built on. The action gives an indication of what intentions the agent has (had) and in what situation the agent is in, thus enormously narrowing the sphere of potential next step the agent will take giving estimates of what functions to be in operation of the wearable. Some such suggestions are given I column 3 "leading to" which of course is just suggestions

Figure 22. Examples of trivial every-day actions related to textiles. left) Putting your hand in a pocket. right) button a button.

C_X: Textiles take part in seemingly trivial every-day actions being part of a person's daily life and if these events are captured by this offering insight in daily life that could be used for maneuvering technical functions.

XI. The concealed-empowerment claim: textiles for personalization

People in general are different, so are people having deafblindness. There are different needs and preferences. Personification and customization of assistive devices are then important. This is a general trend within the pharmaceutical industry, so also for assistive devices. Making the latter in textiles opens up not only for an individual fit, which the textile community has a long experience of, but also for individualization of other aspects, not least the expression of the product.

The individual might want to avoid any stigmatization. Then any assistive device should be concealed, hidden, working and acting in silence. By textiles it is possible to make it so slender that it could fit under other clothing. It is possible to make "Invisibles"[10], clothing not seen but functioning in the background. It is a low profile product. On the other hand, other persons might also want to make a statement, acting empowering for the persons own sake or toward others. Such a textile device has a strong expression. It is seen, heard, and felt if so. It is fashionable. It generates a high profile.

There is then something that could be called a*concealed-empowerment scale or spectrum* for assistive devices. In fig 23 an example of the empowering version of haptic communicative device in textile is seen. This is an example were textiles are so compliant that other clothing could be worn external to the assistive garment and furthermore that your ordinary clothing could be used without the need of buying new, larger-sized clothes. It is furthermore (not

[10] A term that should be interpreted metaphorical avoiding visiocentrism.

illustrated) possible to design the very communicative garment more expressive or less expressive in terms of colour and design.

There is also another dualism and that is between cloths directly to the skin (concealed, good skin contact, but cumbersome to take on and off, needs washing) and those worn outside of other gear-like military ballistic protection. The latter iseasy to take on and off, needs strong vibrators, vibrators might interfere with other gear. Concealed ones are also good for not interfering with other technologies present.

Textiles can accommodate these needs and is able to cover many further kinds of needs.This, also enhance both compliance and longitudinal use, claims above.

Figure 23. Left) Empowering expression worn external to other clothing. Right) concealed function when the communicative garment is worn inside of other clothing.

C_{XI}: including textile in assistive devices for haptic communication opens up for a broad spectrum of expressions on a scale from empowerment to concealed solutions, supporting personalization

XII. The channel claim: Textile is a medium for haptic communication

As said in the communication chapter there are *channels* between the sender and the receiver. For human-to-human and machine-to-human or even physical surrounding-to-human communication the receiving human being is in a system with her/himself immersed in a medium (or channel in the SW parlour). Medium is the physical means of which the signal is send through (Fiske, 2002)

Channels are carrying the message from one site to another as intact and at as low cost and with as low resource demand as possible. Channels are physical entities, following physico-chemical laws. In Lasweell 1948 telephone line, fibre optics electrical circuits, wire cable are given as examples. For haptic communication with the receptors in the skin as decoders these are only secondarily of importance. What is really interacting with humans are the following, which we call medium;

- Air. The medium for vision and hearing but also for touch bythe wind, so also for (radiative) temperature. Includes dissolved gases generating smell.
- Water. Rain, hand washing, swimming generates touch experience. Via water is taste generating molecules conveyed. Liquid water and moisture also impacts temperature experience.
- Own or other person skin. Skin is connected to touch as well as temperature sensations.
- Food. Food most often water solved or dispersed is connected to taste but also, touch, and temperature.
- Textiles. By textiles touch and temperature experiences are conveyed. Textiles are also cross-interacting with water in garment comfort.

In terms of *interaction time* an hypothesis is that human daily has the order of magnitude for different kind of interactions as say; a) air-skin 100% b) textile-skin 99% (clothing and bedlinen and towels are absent only when taking a shower or similar) c) visual objects – eyes 60% (seeing people have their eyes open most of their time awake) d) audial sources-ears 50% (hearing people are listening most of the time when not sleeping) e) objects-skin including hands 40% e) food-mouth 10%.

Textiles thus play an extremely exclusive role among materials. It is the class of synthetic material that is the most occurring medium.

It can then be employed for haptic communication through clothing. This is seen already in SHL but could be further taken use of by acoustic signals, pressure, ultrasound etc.

How to construct such textile is open for exploration. There might be ways to amplify, concentrate or even transform signals through the fabric before it receives at the cutaneous receptors.

Fiske elaborates on the peculiarity of 'dress' as a medium, since it is also tightly connected to *code.* Throughout clothes and the way we dress we already convey different codes intertwined with our culture, yet also clothes inhabit e completely con-communicative property of protection, isolation etc (Fiske, 2002). This view gains assent from (Adam, 2012) who discusses the influence that clothes have on people involves "two different factors independent from each other, being the symbolic meaning of the clothes *and* the physical experience of wearing them" (Adam, 2012)

C_{XII}: Textile is the most important synthetic material class acting as a medium and as such to be considered for haptic communication.

XIII. The contouring claim – textiles kinesthetically support body self-awareness

One of the most fundamental questions of one own existence is to differentiate between what is me and what is not me, what is inside and what is outside of my body and where this border is. For certain patient groups it is problematic to make these discriminations, so in these cases;

Geometrical body ≠ perceived body

Asomatognosia (Jenkinson et al., 2018)broadly refers to a spectrum of altered states of bodily consciousness not explained by a global mental impairment. It includes sense, feelings and judgement that smaller or larger parts of my body does not belong to me.The terminology on this is not fixated(Dieguez and Annoni, 2013). There are also related other symptoms, such as visuospatial neglect, anosognosia, delusions, and sensorimotor impairment. Asomatognosia has often been distinguished from somatoparaphrenia, in which there is the occurrence of illusory, confabulatory and delusional ideas of the body and its ownership. For many types there is a coupling to right-hemisphere stroke.There are some indications of this, such as loss of self-location, for people having deaf blindness(Ho and Millière, 2020), It might be that vision and hearing continuously and unconsciously supports the delimitation of an inside and outside. Loss of these senses might impact body and limb awareness. It could be that this is under-reported by people having deafblindness.

In any case the question of what is inside and outside, close and far relative to my body has many facets(Faccio, 2012). Much discussed is proxemics (Hall, 1966). Originally a research field on how humans use space in social communicative interaction (Hall, 1966)embracing a concept like intimate zone,it has also been used (Gemperle et al., 1998)in a more specific meaning for wearables and the location of i-on devices on the body. The idea behind is that the brain perceives an "aura" around the body. This is not the same as the geometrical body contour. Of course, minimize thickness as much as possible is the preferred first rule. But there are locational regions where humans are extra sensitive for protruding objects. It will not just be irritation, collisions will happen, devices will break. Any attachments should stay within the persons "aura zone" so that perceptually devices become a part of the body.

Textiles are following the body shape, have some kind of protrusion but is often within the aura zone of proxemics. Textiles could tighten up the body contour perception, which also follows from the covering claim and the constriction claim.

C_{XIII}: Textile, in the form of garments, could potentially support body self-awareness and perceived body delimitations by activation of kinesthetic reminders due to mechanical resistance in the fabric.

Design aspects for textiles for haptic communication

Making a textile-based assistive device for haptic communication is a highly complex endeavour. There are thousands of aspects to consider. Furthermore, these impact each other in intricate ways. We conclude by briefly listing important finding, of use for any manufacturer. Implicitly we focus on people having deafblindness.

- Design for the human body requires a humanistic form language. Textile is an enabler for this, by drapability able to handle the dynamic human shape and interchange of convexity and concavity to ensure a comfortable, stable fit. Human contour is mainly convex. A maintained concave interface for surfaces critical for good tightness to the skin such as for vibro-tactile elements is then important.

- Inverted, it could be noted that convexity of the outside of the garment deflect surrounding objects. Protruding elements, say sensors, risk bumps and being stuck in outside objects. Thus, a plain appearance is to be looked for.

- Fabrics that have ruggedness add to robustness of the device.

- Fabrics most commonly need to be resistant to food and body liquids, as a haptic device takes place in every-day activities involving exposure to a wide variety of such impact. Fabrics should be able to wipe off.

- Avoid attractive tactile parts meaning that people who are living their life through touch also are attracted by things that give a peculiar tactile experience. This could include exposed Velcro parts, brush structures, gaps where one could put in ones nail etc.

- The appearance also for others than the wearer and interpreters is important. There are a lot of electronics in this kind of assistive devices but the expression should not be close to a bomb vest.

- Psychophysically it is known that a geometrical i.e. placement-wise L (or T or O) is not necessary the same as a perceived L (or T or O). There is then always three domains;
    i. On-textile (or any wearable) placement wise
    ii. On the skin, location-wise
    iii. What is perceived of the pattern on the skin

  that impacts each other in the order i, ii, iii. The last one is furthermore dependent on learning. Sensitivity and perception is dependent on the type of stimulus. The common vibro-tactile element rendering vibration is just one out of many modalities. There are also two other impacting factors – movement of the textile and different anatomical postures.

- For the development of a device psychophysical calibration is needed so that the tactor arrangement is such that a geometrical circle(etc.) is perceived as a circle on the back.

- If indeed vibro-tactile elements are used, one should strengthen perception by vibrating extra at the corners of the geometry or at the start of a geometrical line. This might imply that one could try to make some "indentation frame" in the very textiles so wearers feel the corners to start. This have to be balanced both in terms of adaptation and skin irritation.

- Dynamic patterns are better than static ones. Or stated even stronger: static ones are hardly useful for making any interesting pattern at all because they are not possible to be identified and resolved by humans, except for simple geometries.

- One should avoid having two (not to say even more than that) vibrators vibrating simultaneously at different locations on the back. This is just perceived as "a lot of things are happening on by back" not like distinct tactile signs.

- Vibrators need to be mechanically isolatedto ensure localized vibrations and avoid spreading. For this 3D printed housings are proven useful.

- Electronics generate heat. There is risk for overheating both of the potentially embedded electronics and the wearer. Mesh constructions for ventilation has proved to work for outward ventilation. Insertion of insulting foam layer between the electronics and the skin for inward heat management.

- Any high voltages and currents and charge should be insulated. Devices should not be left unattended if there is a risk for electrical danger.

- Modularization is a beneficial logic for these complex devices. Modules enable customization, individualization, for different disabilities, personalities, stigma, sizes, missions, if other clothing worn or not worn. Modularization is also good for repair and for post use separation from a recyclability point of view. From a communicative perspective, spatial separation of different panels enables semantic and theme-wise separation clarifying communication.

Discussion

Going beyond the visual and audial communication dominating in modern western society is not only interesting but also imperative as when one or both of these channels are disturbed or absent, as for; people having blindness, people having deafblindness, people having deafness, fire fighters, fighting pilots, armored vehicle drivers, divers. It might also be that there are new sensations to explore within NANV communication.

It is the hope that the present text could be a start of a more elaborate program of experimental studies. Such a program with the abovementioned thirteen claims as a common axiomatic Ansatz would open up novel areas and widen the borders of perception.

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