nuSense

Wearable technology to prototype
and create new senses

Umeå Institute of Design
MFA Interaction Design

Daniel Jansson
2015

About

Daniel Jansson is an industrial designer and interaction designer from Sweden. He graduated with a bachelor's degree in industrial design from Umeå Institute of Design and this report is part of his master's thesis in interaction design, also from Umeå Institute of Design.

He recently finished internships at Smart Design in San Francisco, USA, and Microsoft Research in Cambridge, UK. He has also worked in projects in collaboration with Microsoft, the Swedish Police, IKEA and Tetra Pak.

He is a passionate builder and maker, as much at home building in the workshop as in front a whiteboard or screen. His specialization is in prototyping physical interactions, items you can touch and experience.

http://www.switchandlever.com
daniel@switchandlever.com

nuSense

Wearable technology to prototype and create new senses

Abstract

nuSense is the result of a degree work on master level at Umeå Institute of Design exploring why wearable technology oftentimes tread a rather narrow path, with many different companies releasing essentially the same product with a new shell, and innovation being slow. Through research, interviews and user research, hardware prototyping and testing it became clear that developing for wearable technology is a very complicated task, for many reasons. Being able to build quick exploratory prototypes was nigh impossible if you do not have a grasp of hardware developing platforms and programming. Further, those outside the industry who just want to explore wearable technology lack a platform to do so easily, aside from buying ready-made solutions made to do one single prepackaged thing. Based on this a concept was developed to provide a platform to explore wearable technology, through modular building-blocks and an easy to grasp interface. This is nuSense.

Index

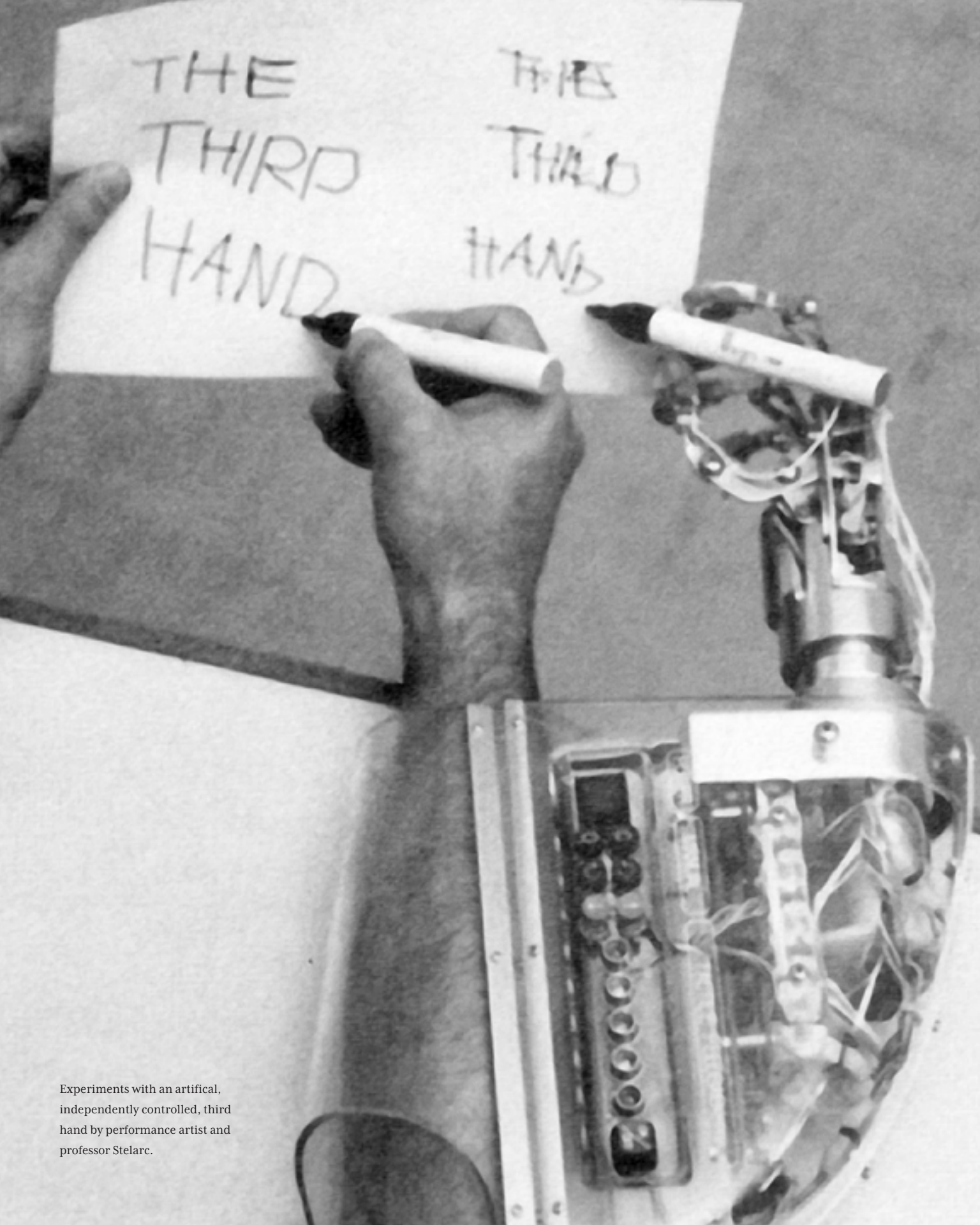
Introduction

A hundred years ago the world was a place where electricity wasn't commonplace, where news traveled slowly and if you wanted to connect to a friend you either wrote them a letter or went for a visit. If we had free time it was not spent looking at screens, but rather talking, crafting, reading or simply dreaming away. Now we are living in a world where over the last century we have gone from the invention of the wrist watch to now carrying around computers in our pockets far more powerful than those which put us on the moon. We are wearing devices which makes us experience our environment in different ways, even if it's just as simple as blocking out the sound of the city using headphones from an mp3 player to completely immersing ourselves in cyberspace through a smartphone. With devices such as Google Glass we are seeing even closer integration between ourselves, our bodies and technology already on the horizon.

Technology is creeping closer onto our bodies and into our minds seemingly whether we like it or not. Wearable technology has gone from a pipedream to reality in just a decade. We not only have the phones and mobile devices, but also technology such as the Nike+ FuelBand, Jawbone and FitBit to track biometric data through the day. We are seeing the advent of smart wristwatches, such as the Pebble or Apple Watch, of glasses such as the aforementioned Google Glass, or the Epson Moverio, and even smart fabrics which may radically change the clothes we wear. We are starting to tap into the power of the brain with devices which react depending on how alert and concentrated we are.

Smart devices have truly changed the way we live our lives, even to the point of acting as replacement and new senses, such as with augmented maps and GPS for instance, or to hand over our awaking time to apps and devices which wake us up when it's optimal for our sleeping rhythm. Humanity has a drive to fill in shortcomings in what we are already capable of with innovation, often times with new technology. If there is something we can't do, we invent a solution, even down to the point of inventing new and heightened senses. What are glasses, or even binoculars, but an extension of our eyesight, or hearing aids of our hearing? In a time where wearable technology seems preoccupied with mainly glasses of one kind or another, or wristbands and fitness trackers, there is a lot of opportunity to expand the field of wearable tech closer to our senses, to extend the world we live in and experience it in ways we never have before.

In a sense, we may come to have more in common with the fictional cyborg than what we may be prepared for. We may even ask ourselves, are we cyborgs already?



Experiments with an artifical, independently controlled, third hand by performance artist and professor Stelarc.

Background

"We are all cyborgs now" as Professor of Technoscience Donna Haraway put it back in 1991, meaning that we already have plenty of *"couplings between man and machine"* (Haraway, 1991, pp. 149-181). If such a statement was dramatically received 23 years ago, it is not such an amazing statement today. Only in the last few years we have seen the emerging market of both communication devices which we carry around with us at all times, you may know them as phones, as well as many other variants of wearable technology of which biometric trackers like the Nike+ Fuelband may be the most well-known. What all these devices are doing, perhaps unapparent to us, is transforming not only our physical selves but also the very interaction we have with the world around us.

The question is really, what about this wearable technology makes us cyborgs? The original definition of a cyborg comes from Manfred E. Clynes, who wrote in his article *"Cyborgs and Space"* (Clynes, 1960, pp. 26-27 and 74-76) that a *"cyborg deliberately incorporates exogenous components extending the self-regulatory control function of the organism in order to adapt it to new environments"*, or to simplify, that a cyborg is an organism to which external components have been added to adapt it to new environments. Where his work was mainly about how to get humans to survive in the harshness of space the term cyborg has been picked up by fiction, popular and news media, as well as by anthropologists, researchers and scientists. While the cyborg of today could be a person with a pacemaker, just as it could be a person with a smartphone in her pocket, wearing a prosthetic leg or even having an implanted magnet in his finger. In fact, anything which is an added technological device makes you into a cyborg, or as David Hess mentions in an essay published in The Cyborg Handbook:

"I think about how almost everyone in urban societies could be seen as a low-tech cyborg, because they spend large parts of the day connected to machines such as cars, telephones, computers, and, of course, televisions." (Gray, 1995)

He said this already in 1995, one does not have to make a great leap of imagination to see how much of a bigger role technology plays in our current lives, not to mention how much closer we are carrying it to both our bodies and minds.

So, it is clear that modern day cyborgs consist of a wide variety of people, in one corner you we have the consumers, those who may not identify themselves as cyborgs but through virtue of their everyday devices still fits the definition of the word. In another corner you have the ones with medical implants and prosthetics which changes and to most extents attempts to normalize lost function in one way or another. In the third corner you have another group, the bio hackers, the grinders, who take more of a rogue approach to augmenting their bodies, often by doing home brewed implants or other more extreme measures. What ties all of these groups together however is how their augmentations are used to alter the way they experience and use the world around them. In other words, act as supplements or extensions to their senses or abilities.

The medically augmented people, as well as those who hack into their own bodies, are still a fairly marginalized area. When it comes to the way most people are technologically augmented it's not through a prosthetic, or a subdermal sensor, but rather through the things we carry in our pockets, or on our wrists. The cellphones, the fitness trackers, the tablets and even to some extent the mp3 players, or even laptops are part of this segment of development. While prosthetics and biohacking is an interesting field in its own right it will still be a long time before that technology is accessible to the everyday John Doe. However, what is accessible, and growing rapidly, is the field of wearable technology.

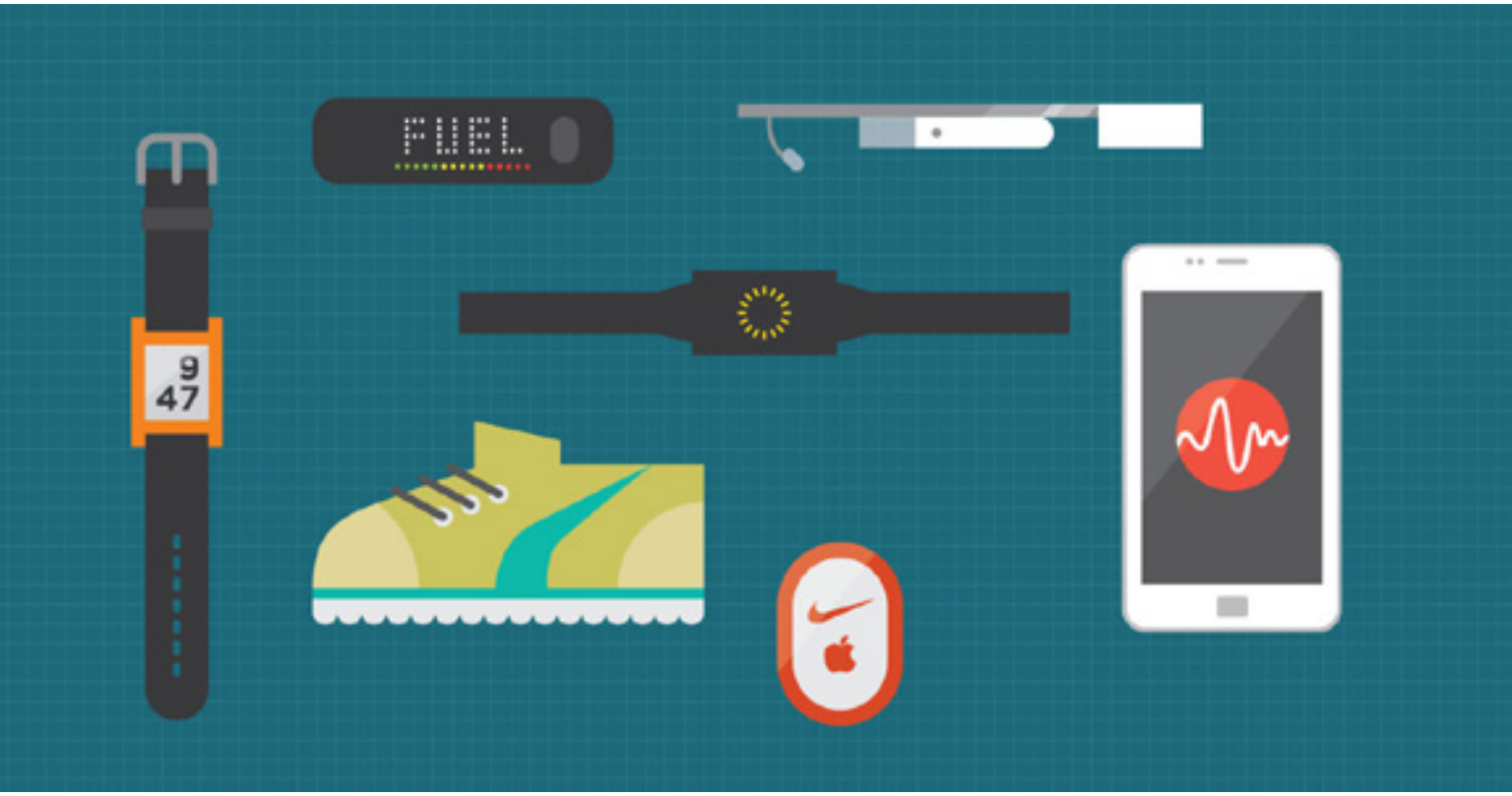
In this eclectic mix of smart devices, wearable technology, smart medical prosthetics and even biohacking we have to ask ourselves asking where this technological development is going. While we are now heavily technologically integrated beings we weren't only a decade ago, and twenty years ago it was rare to even have a cellphone. With this continuing development, where will we end up in another ten years to come? If the current consensus is anything to go by, the future will be a wearable one, and wearable technology may even take the leap of becoming implantable technology. Development of smart devices is escalating, we are developing devices which allow HUDs to augment our vision of the world around us, smart textiles popping up on the consumer market are finally bringing the whole idea of wearable technology full circle. However, as developer Q Manning said in a recent panel discussion hosted by the SXSW Interactive conference:

"I don't think wearable technology has found its niche. We all know we want it, but we don't know what we want it to do yet. We're all waiting for someone to solve that problem, but, unfortunately, Steve [Jobs] is gone." (Zorpette, 2014)

The colliding point of emerging technologies and the age old question *"What do we do with it?"* is always an interesting place to be. Just a few decades ago many computer developers couldn't imagine a future where everyone would have a computer. More recently when the first iPad hit the market no one really knew what it was good for either, but today they're so commonplace and capable that they are actually starting to outsell computers (Brustein, 2013). For this specific reason it's hard to say where exactly wearable technology will take us, but it is a worthwhile point to investigate, challenge and ask questions about.

A sadder point of view is perhaps where wearable technology is right now. According to a report by PricewaterhouseCoopers, out of those who purchased a wearable technology device more than a year ago 33% say they no longer use the device, or use it infrequently (PricewaterhouseCoopers LLP, 2014). Unfortunately the report does not delve into the reasons why wearable devices are left behind, but do conclude that many such devices have *"under-delivered on expectations"*. With such a vast loss it's painfully obvious that the field of wearable technology still has

Examples of common contemporary wearable technologies.

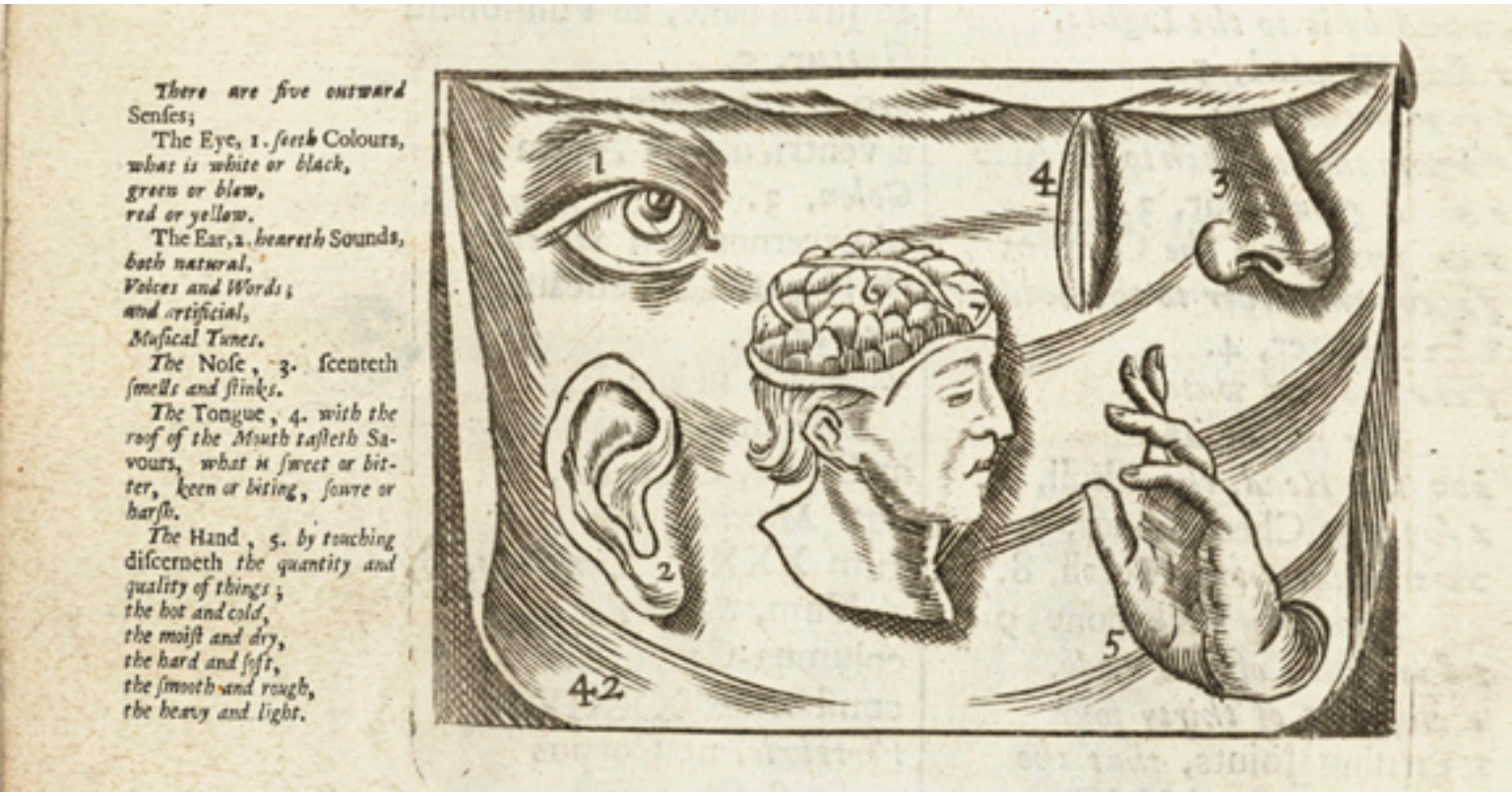


a long way to go. Yet, the same report further points out that the field is *"ripe for growth"*, especially so among millennials, so there is hope.

Perhaps a good place to start is to look at what this technological proliferation currently is doing with us, and how it changes our behavior. Even though the topic of cyborgs have been touched on before it only describes a part of a possible future. While it is possible that the future will be either dramatically utopian or dystopian, because or despite technology, it is altogether more likely that the future will be more mundane and more alike what we are used to, especially so if we are talking about the near future. While flying cars, teleportation, food materialized from thin air and network access everywhere and anywhere may very well be in our future, however distant, there is one thing which are unlikely to change: our senses. They've stayed largely the same even since before we took the step into being Homo sapiens.

Our senses are indeed something we all can relate to, each one of us has a sense of smell, of taste, sight, touch and hearing, unless born without or being damaged along one's life. These five senses make up much of the way we perceive the world. What one may not think about is however that there are many more senses than that. It was Aristotle that defined the senses during ancient Greek times in the second book in his series "On the Soul" and ever since then we have been more or less stuck with the misnomer of having only five senses (Aristotle, 2014). Even in William Shakespeare's King Lear the *"five wits"*

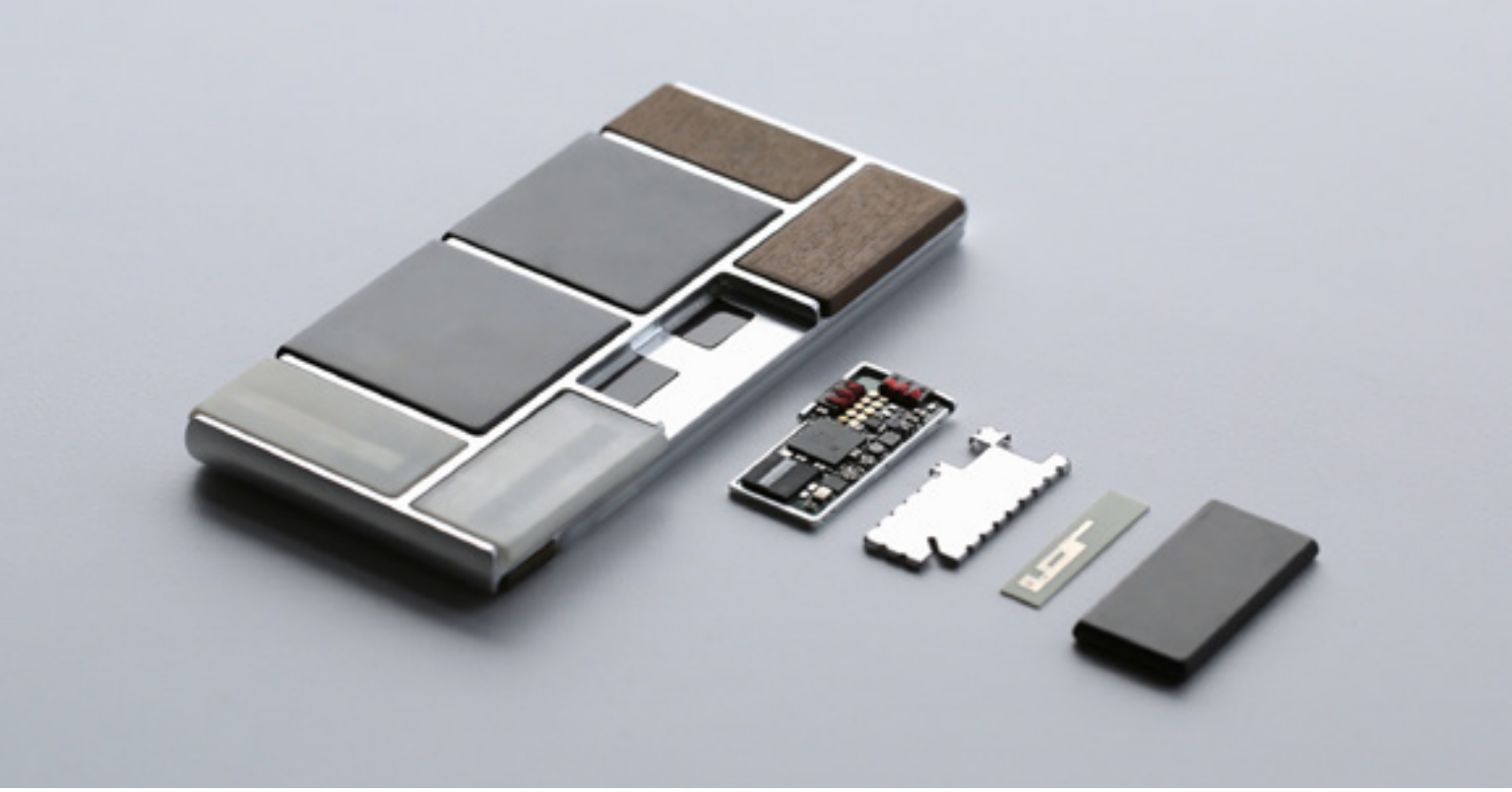
A page out of the book Orbis Pictus, first printed in 1658, describing the different senses.



Eidos concept by Tim Bouckley to alter vision and hearing.

are mentioned (Shakespeare, 1723). Outside of this traditional approach we may consider many other sensory inputs as senses as well, such as balance, the ability to sense temperature or even pain to mention a few.

Going further there are abilities which we don't have, such as perception of light outside the visible color spectrum, hearing ultrasonic frequencies, or sensing direction in the way that some migratory birds do. We have had a long standing tradition of, when we've reached the end of our capabilities, innovating and inventing new ways to overcome our shortcomings. We tame horses to travel and move faster, we invent the wheel, eventually the car, the airplane and so on. The same development continues for the sensory field as well, when we can't see further, we invent binoculars, when we can't hear we invent a funnel which amplifies sound and directs it into our ears, yet for the most part these have been direct magnifications of already existing sensory inputs. This is, though, changing rapidly since the discovery and taming of electricity and eventually computing, which has led us to create electronic sensors which can sense and trigger based on a world which we do not have access to as analog human beings. Not only that but we can sense things to a far greater fidelity than before, and be able to do more precise analysis of the sensory data as well. A simple example would be the GPS receiver which exist today even in mobile phones, giving you very precise information about where on the globe you are. Because of this information you can be served not only with maps and directions, but localized information about things which may be important, anything from traffic jams to the hottest shopping deals. Regardless if it's on the macro or micro level sensors are giving us more insight into the world in which we live.

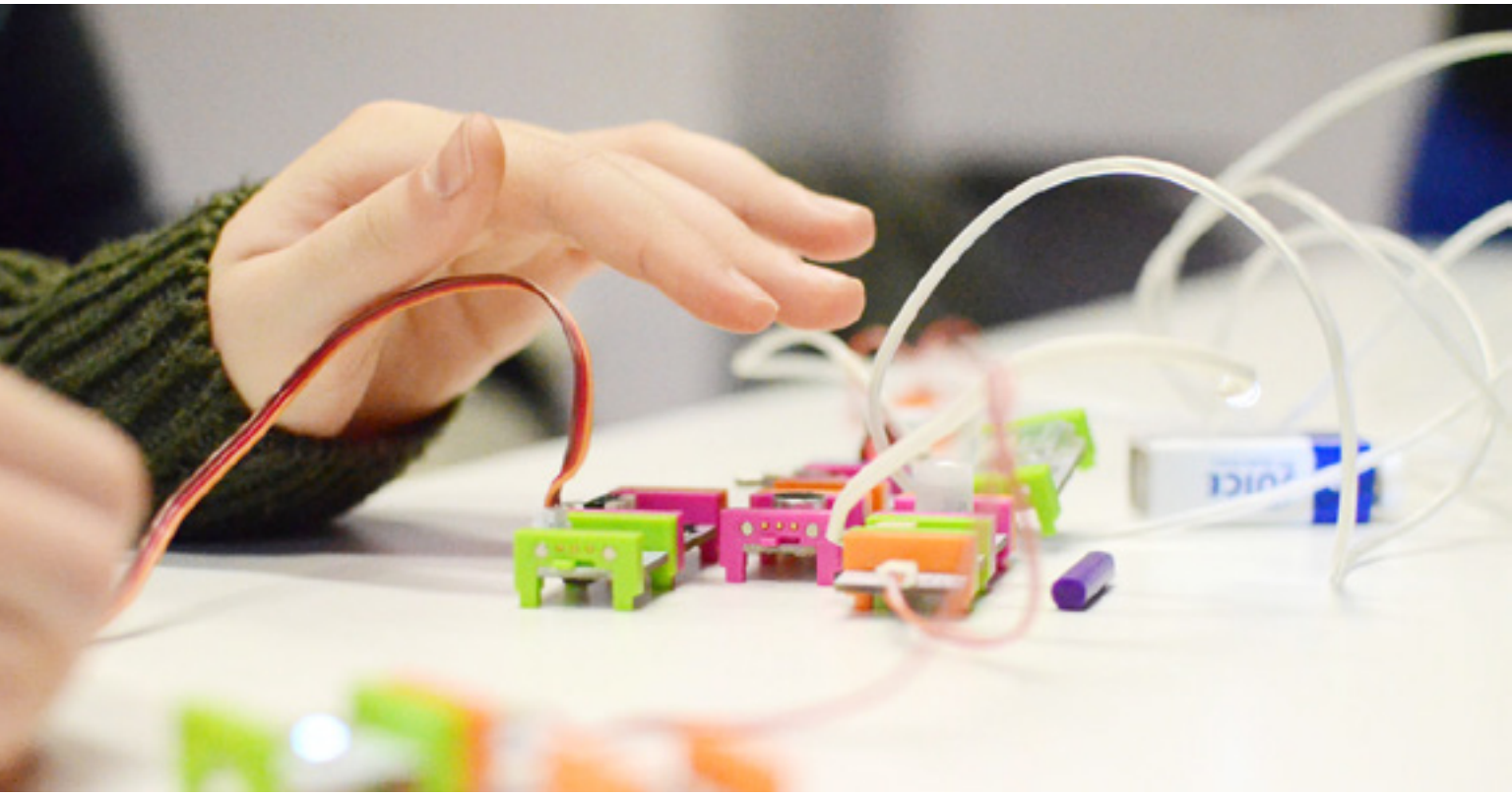


Google's Project Ara.

With accelerometers and gyros in our smartphones always being with us and always on the ready, you may even consider the idea that we are tacking on new senses onto ourselves. While the choice of sensors for carryable devices such as phones still are limited it's a kin to adding on new senses, based on what fits your needs and desires. Of course, currently these senses more comes as an added feature to a device, and is rarely if ever the core reason why you get the device to begin with. What if we have a chance to expand on this thinking though, and can more freely add senses, and start augmenting our own inputs and outputs?

What we're hinting about here is essentially a type of modular approach, where you pick and choose what you want from a set of abilities. This type of approach has been used for some time in for instance the manufacturing industry, where you can design factories and create flows essentially based on building blocks representing machines and production flows. It has also gained a lot of traction in architecture; pre-fabricated homes where the buyer or architect can choose from a set of modules and customize them to their own desire. The modules are then delivered to the building site and erected to form a house in a way which is both cheaper and faster than to build it from scratch on site.

The idea of modular thinking is also slowly making its way into the consumer market, maybe most reported recently through the soon to be released modular smartphone, Google's Project Ara (Google Inc, 2015). It hints at a phone which you would never need to replace, only buy new modules for when old ones need updating, or as desires change. Maybe you want to trade your memory module for a bigger battery module, or maybe you want to inject new abilities



LittleBits prototyping platform.

into your phone by installing a new sensory module. Engineering difficulties aside, with this thinking the sky truly becomes the limit for innovation, also for developers. If there's a technology out there that you would like in your phone, simply design a module, program an interface between the technology and the Android operating system in Project Ara and you're off the ground running.

Sadly Project Ara is still standing quite alone in the consumer market, and in the developer world modular design, even for prototyping, is still somewhat missing. There are platforms such as littleBits which aim to get people into basic experimentation with electronics by creating modular components which easily click together to form a circuit (littleBits Electronics, Inc, 2015). There are also products such as the Cubelets which is a modular robotic system aimed at kids to get them into understanding behavior based on inputs and outputs (Modular Robotics Inc, 2015). There are other similar technologies out there as well, many which appear to be derivative from each other and none really adding anything substantial, aside from their own take on the same concept.

If we move back to the aforementioned wearable technology and contrast that with modular technology there is an apparent void. It's a largely untested area, but one that should make sense if we want to move beyond creating wristbands and glasses and actually branch out in creating wearable devices which have a chance to make an impact not just on how we keep healthy, or how we access the internet, but maybe also how we experience the entire world around us.

That's not to say that there has been no work done in the field of wearable technology which augments our senses. Perhaps the most famous example is

Neil Harbisson during his TED talk titled *"I listen to color"*.

Neil Harbisson who was born entirely colorblind and developed a system which allows him to hear the frequencies of color around him (Harbisson, 2012). Or Steve Mann who has been developing wearable computing since the 80s, even going as far as being dubbed the *"father of the wearable computer"* by some thanks to his efforts and continuous development of his EyeTap device (Clarke, 2000). What they have in common though is that they're using highly personalized technology which is not accessible for anyone on the ground level who just want to play around or experiment with different inputs and outputs.

As of now there are plenty of prototyping platforms available for physical prototyping, there is the Arduino, the Beaglebone and Raspberry Pi to mention a few. For the Arduino platform there is even the Lilypad which is intended towards building wearable technology. While the Lilypad succeeds somewhat at its core, the issue pops up when you want to attach sensors and actuators which are not made for wearable use. To get any sort of use out of them you oftentimes need to build a hardcase enclosure to protect the electronics, and then the ability of a Lilypad to easily be sewn into a garment diminishes quickly.

While the Arduino may lose points in the wearable department, it's still a great platform to build upon. It's been around for a few years at this point and has gained a vast community of users and developers, and it's compatible with a lot of preexisting technology. Couple this with a programming language which, while daunting to the beginner, is fairly logical and easy to get into and you have a great platform to build upon, if not adopt as is.

Supporting Research

Early on in the project users were asked to fill out an online survey aimed at finding to what extent people already consider themselves as technologically augmented, and to what extent they would feel comfortable having augmentations. The survey covered a broad range of ages and geographical locations, as well as a 50/50 split down the gender line. As the survey reached out through social media it had some bias towards the western world and people in their 20s and early 30s.

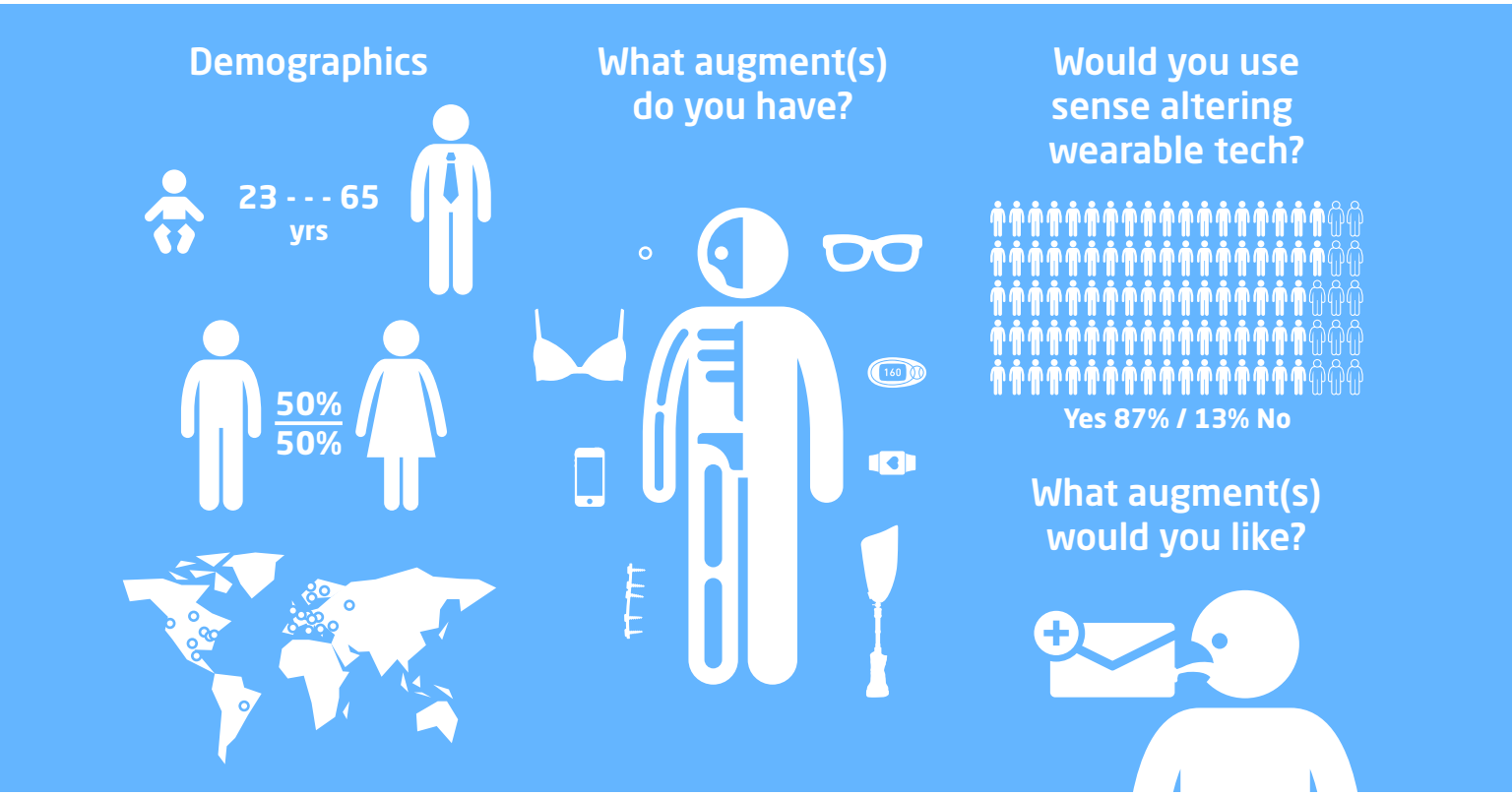
When looking at the group of people who already consider themselves augmented in one way or another, the augmentations they list range from eyeglasses and contact lenses, to activity trackers, to titanium plates and even one person listing a bra. Perhaps with the exception of the glasses none of these really enter the realm of affecting our senses, they simply improve upon or restore function.

The really interesting thing happened when looking at the group who didn't consider themselves augmented but either wished they had augmentations, or didn't want them at all. Out of these two groups 87% were still open to the idea of wearable technology which could change the way they experience the world, in other words, change what we sense.

Further, when the respondents were asked what kind of augments they would choose, if the sky was the limit (and after sorting out the people who simply wanted to fly), there were quite a few insightful answers reflecting upon primarily updating our preexisting conditions. Some wanted the ability to have zoom lenses instead of eyes, super hearing, full awareness of one's physiological systems, increased memory, having a "calm-button" to even one person showing interest in tasting email notifications.

Finally, when asked whether they would consider replacing a body part with another, fully technological but otherwise identical or better one, 95% answered a resounding no. It's apparent that once you break the skin most people are not so much interested any longer. While the exact reasons for this probably deserves an entire research paper of its own together with the earlier responses to the survey it points toward an interest and an openness to wearable technology which in one way or another augments the way we experience the world.

Summary of data from the *"Our Modified Future"* survey.



Research Outcomes

Having now taken a thorough look at the subject of technological integration, and especially wearable technology, a few points stand out quite clearly.

1. Wearable, and especially carryable, devices are at this point near ubiquitous. You would be hard pressed to find anyone who does not have some sort of technology on their person at some point during the day. However, wearable technology in particular have a long way to go, and consumer wearable devices exist in a fairly narrow band of mainly glasses and armbands.

2. Wearable technology has, as put by the aforementioned report made by PricewaterhouseCoopers, *"under-delivered on expectations"*. The reasons for this may be many, but it's safe to say that the research and development of wearable devices, especially as it's an emerging field, is a costly one. Therefore it can also be risky if your device bombs on launch, so avoiding risk and going with the safe bets makes perfect sense.

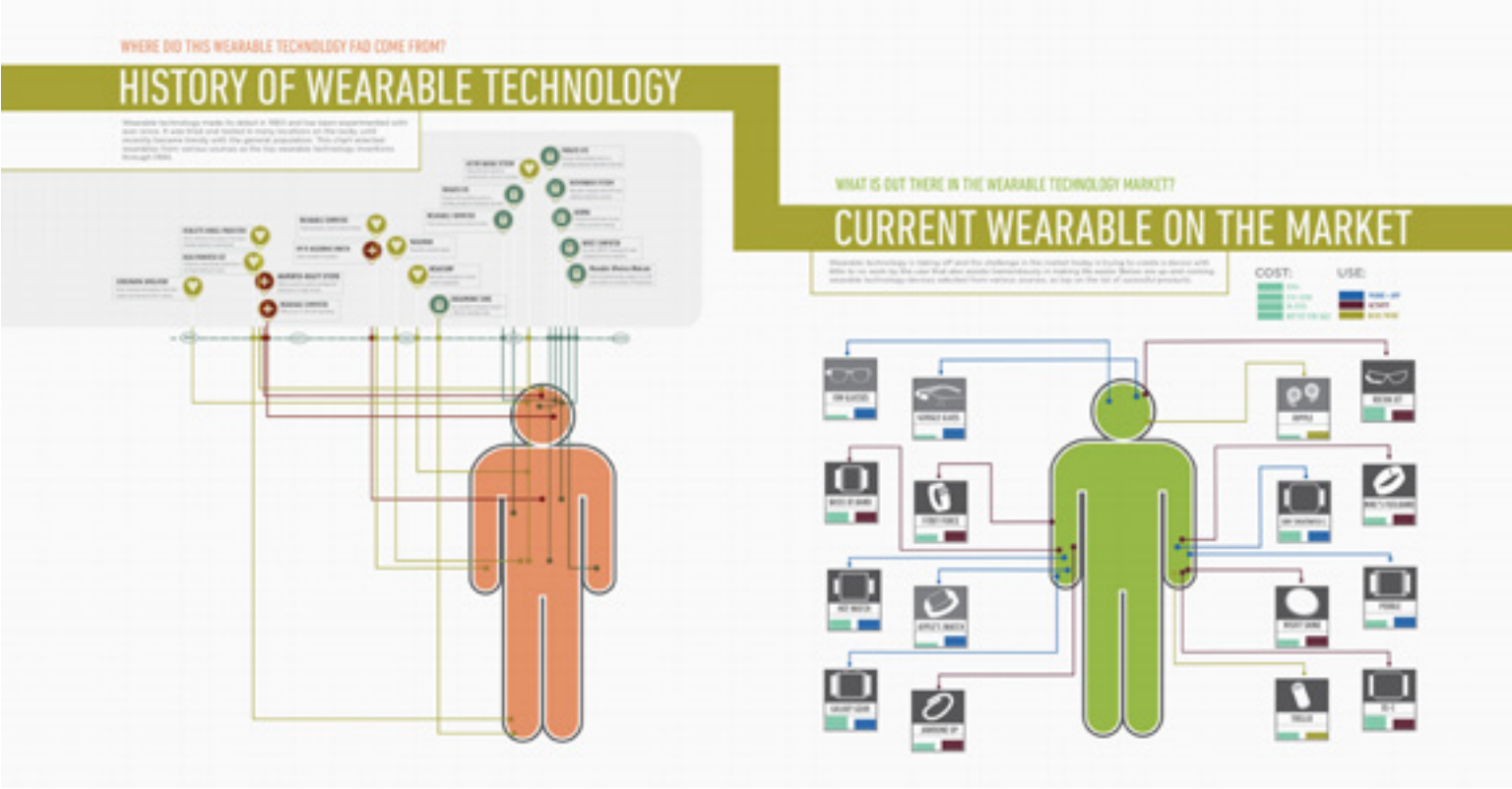
3. There is a wealth of untapped possibility within the field of wearable technology. Sensor technology in particular is blossoming and we're seeing ways of sensing the world that we could only imagine before. Not too long ago the compass was a fairly bulky apparatus, and is now embedded into every mobile phone worth its name, together with a slew of other sensors. Exploiting these sensors to a greater extent would further enable sensory augmentation on a scale we have not seen before.

4. Modular technology is a well explored field, with modular prototyping platforms making appearances. Yet it is a field that has been left untouched within the area of wearable technology.

So what can we do to open up the field of wearable technology and make it blossom beyond armbands and glasses? At the moment hardware prototyping is predominately geared towards stationary devices. It's easy to get an Arduino and start building something which lives in a single place. However, there is a lack of a proper platform geared towards wearable technology.

Moving on from here we will explore the field of wearable technology and sensory augmentation to further define where more work needs to be done and to be able to define better a framework for the final concept.

Wearable technology, where did it come from and where are we now, according to Dimensional Innovations.



Exploratory Prototypes

As this project took more of a path towards augmenting and creating new senses some exploratory prototypes were built. The idea was to open up ways to explore our environment in different ways than which are available to us currently. There are pioneers in this field, many which resides within the biohacking and body modification subcultures. One augment which has gained some notoriety in both subcultures is the subdermal magnetic finger implant, in which you essentially implant a small neodymium magnet under the skin in one's finger. While this may be seen as somewhat macabre it allows the user to sense electromagnetic fields around him. This could truly be seen as a new sense, although one may argue the exact use of such a sense.

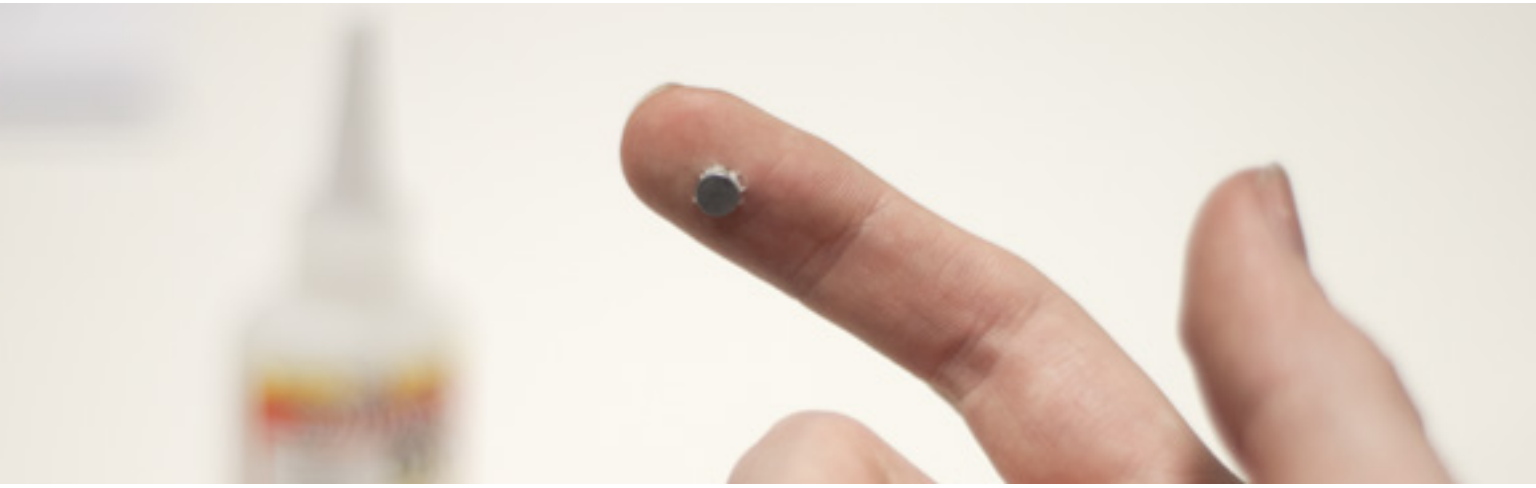
To be able to try this out, without doing bodily harm, a magnet was superglued to the tip of an index finger. While it is true that the sensory input is lower through the skin, than if the magnet would have been inside the finger, some insights could still be gathered. Users with these magnet implants say it becomes second nature, and that they eventually stop thinking about it being there, and even after some time stop feeling its effects. The superglued magnet definitely worked, however it required the wearer to focus on what was going on to be able to read any usable input out from it, rather than noise from anything which emit an electromagnetic field (which all electronic devices do to some extent, unless shielded). This in turn leads to other senses being blocked in order to focus on what is going on.

Further sensory augmentation was done through two other prototypes. The first augmented your vision by, like a sideways periscope, mirroring your sight so you could only see behind you. This made normal interaction with everyday tasks exceedingly difficult, and forced you to think in whole new ways to perform normal tasks. As disorientation combined with nausea set in quickly, and lasted throughout wearing the prototype, the experiment was cut short for the safety of the subject and those in the vicinity.

The second prototype offered an interface which allowed you to sense the distance to other objects through vibrations on your finger, essentially giving you a tactile depth sensing eye on your hand. Navigation through spaces was entirely possible, even if slower than normal, by keeping your eyes closed and sweeping the device back and forth detecting objects in your path. After wearing it for extended times it was only really in the situations where you could not already see clearly that it became useful, rather than acting as a complement to your regular vision. In a sense both prototypes were a success and failure, a success in the sense that they worked as imagined and designed, but a failure in the sense that they did not expand on your senses unless other senses were already being hindered or removed. The hand mounted prototype did however again shine light on one thing, that new senses become second nature rather rapidly. After less than an hour of use the hand moved more or less autonomously in response to obstacles in its way.

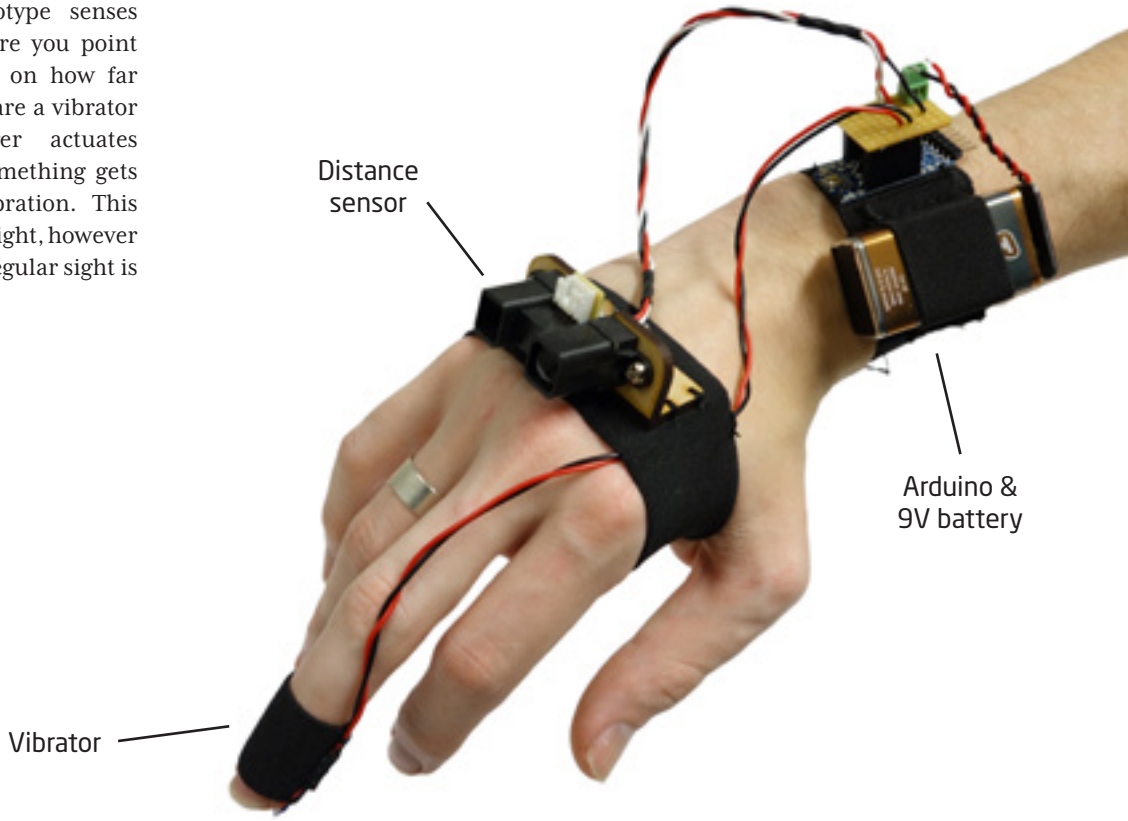
The difficulty in designing for sensory augmentation using current technology shows that there is much that can be done to make sensor technology more accessible even for those already adept at electronic prototyping, but maybe especially for those who are not.

Rare earth magnet glued to tip of index finger in attempt to grant the ability to sense electromagnetic fields.



While wearing the prototype everything you see is directed through mirrors set up perpendicular to each other to show only what is behind you. Looking up becomes looking down, left becomes right.

The arm mounted prototype senses the space in front of where you point your arm and depending on how far away objects in your path are a vibrator attached to your finger actuates accordingly. The closer something gets the more violent the vibration. This enables a sense of tangible sight, however mainly useful when ones regular sight is inhibited.



Users

This project doesn't exactly aim at, but at least tries to keep three different user groups in mind, each with their own set of needs, but each which could benefit in their own way from the final concept.

First and foremost this project is intended for those interested in playing around, experimenting, with extending their senses. This may be someone who has already played around with technologies which involve your body in a very active way, such as the Xbox Kinect for instance, and would like to see in what ways we could not only use ourselves to change technology, but in what ways we can use technology to change ourselves. In this sense it could also be used in a teaching environment, to allow students young and old to experience how it is to tap into a world beyond our reach. This group also contains the extreme users, those already entrenched in programming and using prototyping platforms like the Arduino. These are the ones who would push the concept forward, to develop new peripherals and to act as catalysts for people's creativity, much in the same way as is already done with the Arduino and other prototyping platforms.

The second group would be those developing for wearable technologies. For designers and engineers alike there is currently no toolkit allowing easy experimentation to develop for wearable devices. You will have to sink considerable time into programming for sensors and actuators, in a platform such as Arduino, to even knock out a simple wearable prototype. Having a system which can be easily set up and put together in a more plug'n'play fashion enables this user group to iterate on their concepts faster, and more accurately, to ultimately reach their end goal more well informed. These are after all the ones who will be pushing wearable technology forward, into a realm beyond the wristbands and glasses. Making that path easier to walk will no doubt aid in that development.

The last group are the ones into bio hacking and extending their bodies with more direct technological interventions. They sometimes call themselves grinders, and what they do can range from implanting magnets under the skin in their fingers to sense electromagnetic fields, to implanting RFID chips, to even implanting full circuit boards with sensors to read biometric data from their bodies. While many grinders still act on the theoretical level, as access

Hardware hacking at DEF CON 21.

to getting implants and doing surgery onto your body is still extremely hard for most, a system to enable them to still play around with extending their bodies in ways could help their development into full-fledged cyborgs. Even though what they do, or desire to do, may seem morbid by many people's standards, they are as a group still pushing what is humanly possible, and what they do may very well play a deciding role in the future integration between body and technology. It is in a way, simply one step beyond wearable technology.

While each of these three groups definitely could benefit from the results of this project in their own way it's not exactly designed specifically for either group, or all of them. The project, and concept, is intentionally left broad and somewhat open ended to allow users to find and create their own purpose through the tool. When designing for one specific group it will no doubt, if you're successful, work great for that group, but in doing so you may also lock out many others. Sure, you can squeeze the square peg into the round hole, but it takes some doing and the fit is far from perfect. In that sense it's no different from the Arduino platform, where users have taken to it and created things far beyond the imagination of the creators. Or for that matter it's also no different from a hammer, it becomes a very democratic tool as it's one you don't need to fit into a tightly defined group to be able to use. Its purpose is not for a user group to use the result of this project, put it down and move on, but rather to create their own purpose, and to have something to build upon.

Biohackers Tim Cannon with Shawn Sarver charging a device previously implanted in Tim's arm.

Concept Structure

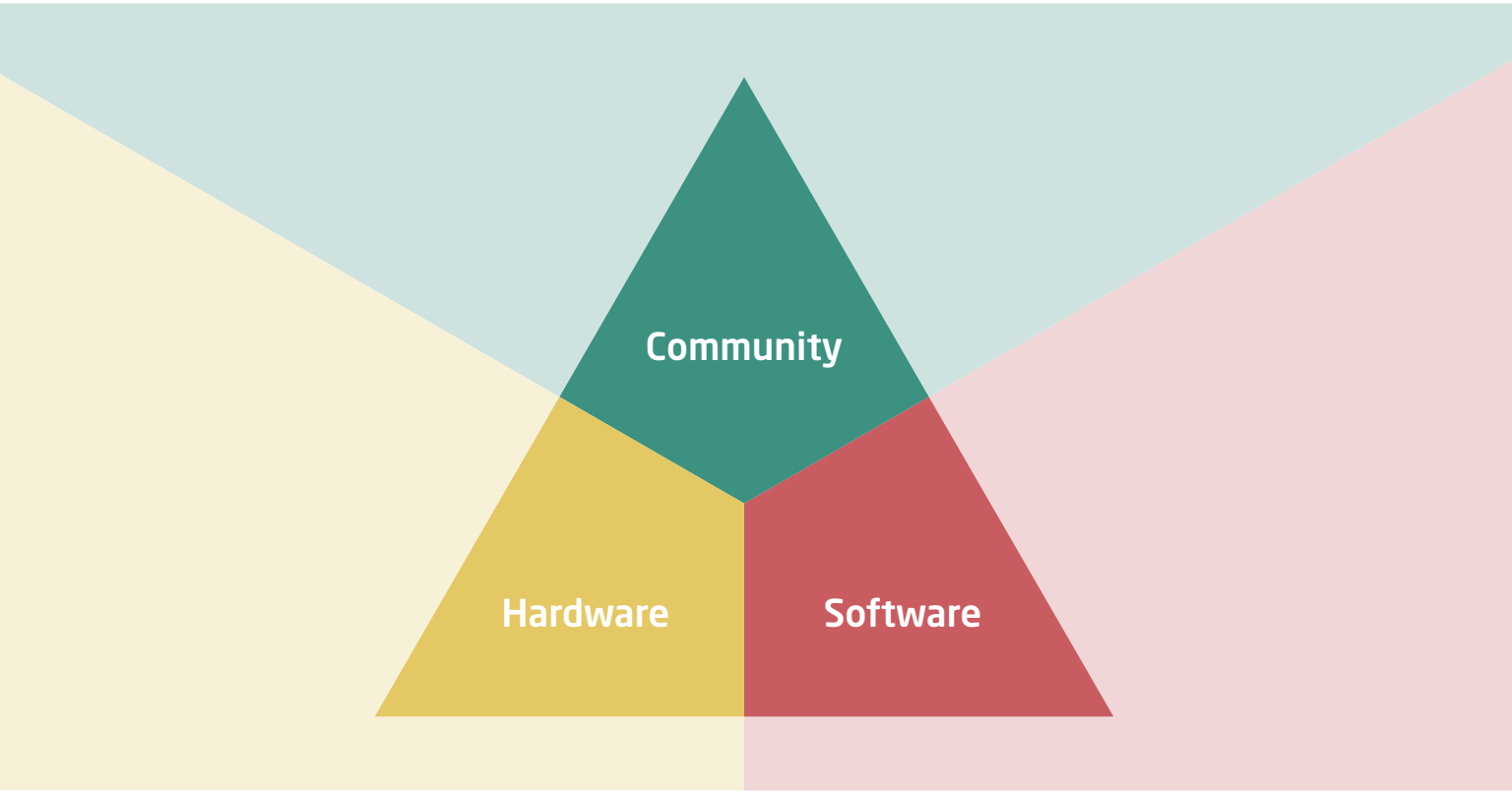
We have now established that we're working with modular wearable technology to extend or create new senses. However, since we're not just creating a product for a specific user at a specific time but rather something which the user fills with their own purpose, it requires more components than just a physical product.

If you look at the aforementioned Arduino platform, and compare it to other similar development platforms, there are two things which makes the Arduino rise above the rest. First of all is an easy and friendly IDE (Integrated Developing Environment, or the program you use to program the Arduino boards), which enables the user to quickly get started with programming their boards. When you're having users which may not be highly technologically adept to start with programming and physical prototyping you definitely want to lessen the sharp corners wherever you can, and creating software which is easy to use with a minimum of settings required goes a long way.

The second point is having a strong reference system and community to provide not only help but also inspiration for new projects, and also to push the possibilities of the platform forward. While there is no doubt that there are many other great platforms than the Arduino, the fact that you can easily find information on forums and having a rich help and example database to learn from means that you will move forward with your projects faster and with more ease than you would otherwise. All this aids in lowering the threshold to get your prototypes up and running, and hopefully also lessens frustrations. When you run into either a practical or cognitive wall and you have no one to ask, or nowhere to turn for information it takes increased perseverance to push through, something which may result in many projects being left unrealized.

To recap, a successful prototyping platform definitely needs all three legs to stand on: the hardware, a friendly IDE and a rich user community for when you require assistance.

Three part concept structure.



nuSense logotype.

nuSense

nuSense is a concept split in three parts, as mentioned on the previous page, it combines the wearable, modular hardware with the software, the IDE and a community website to complete the circle. While each part could be strong on its own, it's really in the combination of elements that nuSense comes to its own. It's hard therefore to think of it as a single concept, for just wearable technology, but it's rather a system which puts the user in touch with the hardware through a readily available support structure.

The focus in this project has been to connect the pieces together, rather than design each piece in isolation. In the end the system fails if any of the three legs are removed. While one may argue that the concept wouldn't exist without the hardware, and that it could exist in isolation, the whole point of extending the field of wearable technology hinges on the interaction between people, not just human computer interaction. Therefore a living community of users is absolutely essential to the success of a platform such as this.

In the following pages we will outline the nuSense concept in whole, detail the software and hardware requirements, talk about the aforementioned community as well as consider the impact of what such a concept may have on both users as well as the industry of wearable technology.

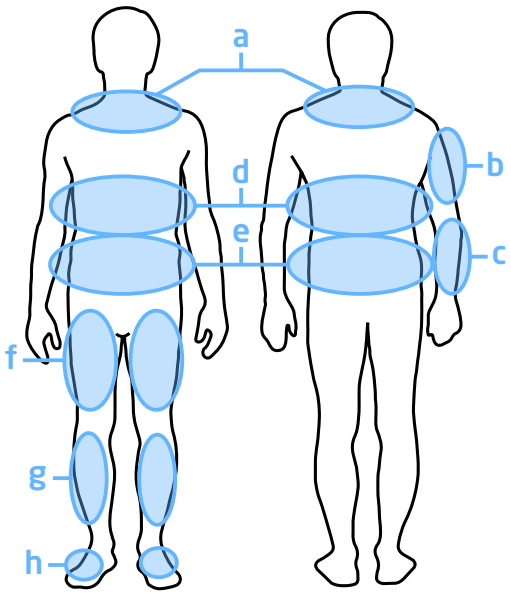
Design Guidelines

It's easy to say the magic words *"Wearable Technology"* like it's an umbrella term with already defined content with in turn set rules. In reality, however, wearable technology exists in a very fluid field, one which likely will continue to stay fluid for some time to come. The guidelines for wearable technology are often vague, and therefore often does not give definitive answers on hard questions, possibly because it's a very complex subject to research to begin with. One such complexity, especially more so when dealing with wearable technology than other ergonomic concerns, is that every human body is different from the next. They do, however, for the most part fall within a certain spectrum. Most people aren't 2,30m tall, most people weren't born with six fingers on each hand, but some are and some were. Even though exploring these outliers would be interesting, that may also be a project in and of itself. For sanity's and practicality's sake keeping within the limits of some sort of standard deviation in relation to body type would be necessary.

As nuSense is a concept for designing and developing for wearable technology the next hard question we need to focus on is placement. If we accept that we're designing for human bodies which are to some extent similar there is still plenty of dissimilarity between different parts of the same body. A wearable intended for the arm would have its own set of rules and guidelines from a wearable intended for the head, and so forth. There has been research done to try to define both ergonomic form and placement of wearable technology for optimal comfort and use. Early wearable research done by Carnegie Mellon University mentions that designing wearables requires *"unobtrusive placement"* and a *"humanistic form language"* (Gemperle, 1998). The question is how true that statement is when developing a platform for prototyping? Could adhering to a list of guidelines or rules hinder creative prototyping?

The second issue with designing for unobtrusive placement is that you're then actively designing against certain placement, or at least making such placements less desirable. When prototyping, or for that matter creating anything, you want to be as little limited by your tools as possible. Surely, a project may have its own set of limitations which will guide how you prototype, but having a tool which would either not do what you intend, or even prevent you from

Comparison between ideal wearable placement according to Carnegie Mellon research and allowing the user to make their own mistakes.



The general areas we have found to be the most unobtrusive for wearable objects are: (a) collar area, (b) rear of the upper arm, (c) forearm, (d)rear, side, and front ribcage, (e) waist and hips, (f) thigh, (g) shin, and (h) top of the foot.

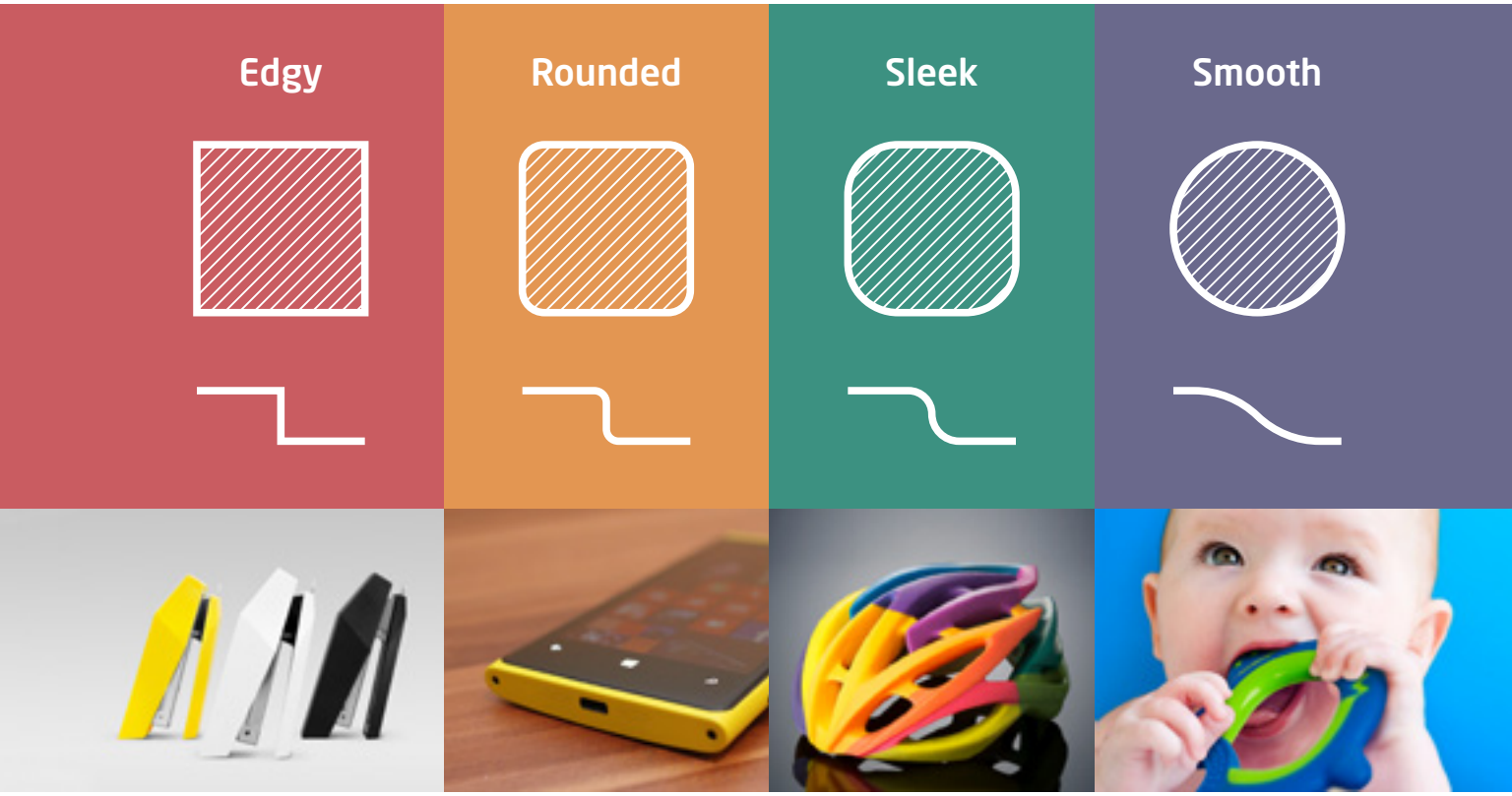
doing it, quickly becomes frustrating. So, while designing for wearable technology requires a certain set of rules and guidelines, creating a wearable prototyping platform could require somewhat of a new approach. Basically, instead of designing out the possibilities to make mistakes with your product, as is common in consumer products, you want to leave the option of failure in. This doesn't mean that the product should be shoddy, or of low quality, but that you should be allowed to use it in the way you intend, not only in the way the designers do, even if it's entirely impractical.

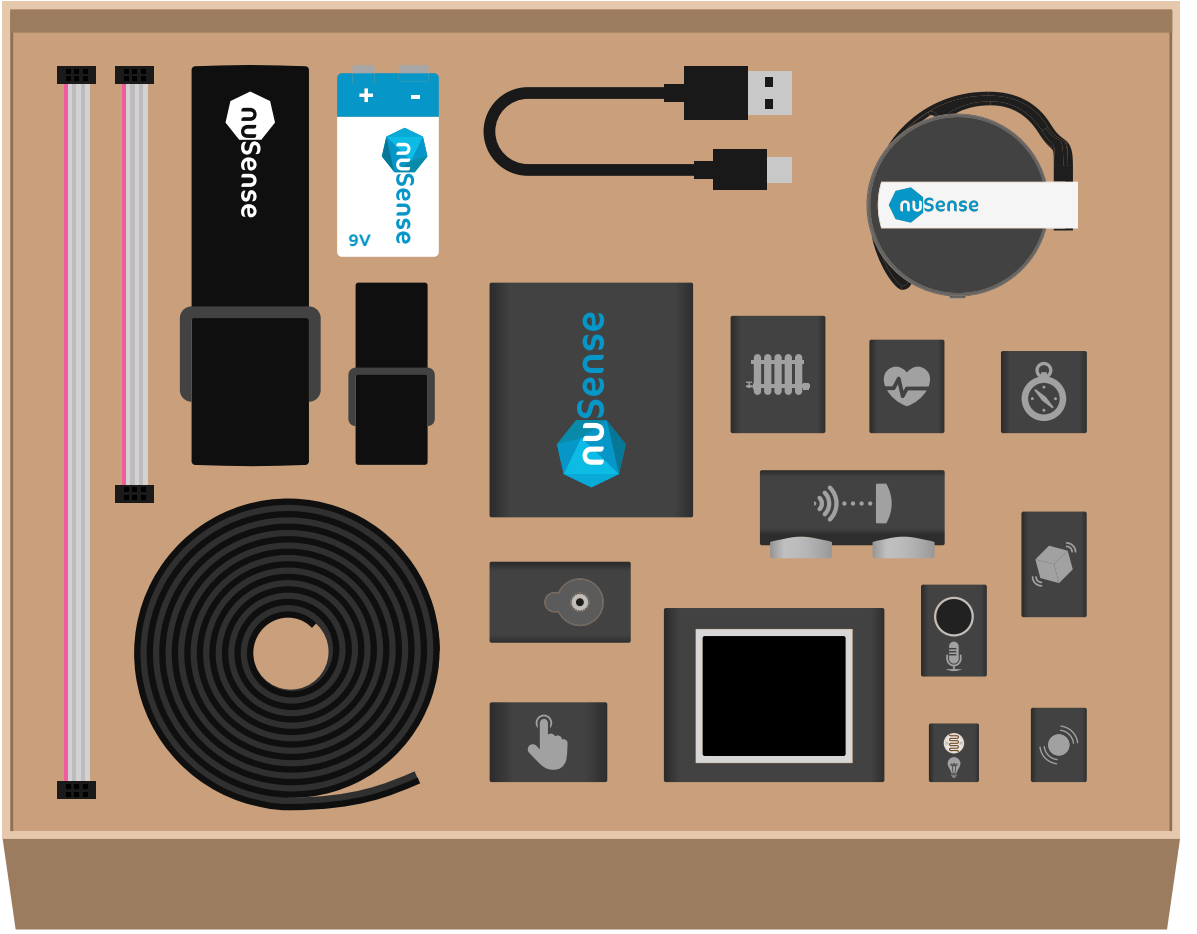
Concerning ergonomics, the *"humanistic form language"* is fairly ubiquitous whether you're designing wearables or a wearable prototyping platform some added concerns come into play. How do you design for a technology which simultaneously should work regardless of placement? It goes almost without saying that the form language of designing something to fit on an arm would be different from designing for the head, or the face. The answer is don't. Even though it may be a design sin to consider keeping design to a minimum the simpler and more homogenous the shape of the parts of this prototyping platform are to each other the easier they can be applied across the ergonomic gamut. The difference, however, may be how each part is attached or handled. An application to the arm may require an armband, whereas an application to the chest may require a sticker, or a necklace, and so forth.

Just because the form is simplified does not mean that it should be devoid and without form. One still needs to draw a proverbial line in the design sand between designing something without defining features, and having features which may be esthetic but would obstruct normal use. The smoother and less form features the closer we move to baby toys, on the other hand the edgier something becomes the more you sacrifice in terms of comfort. The sweet spot runs somewhere down the middle, well defined form and shapes but with well rounded corners to go with.

It's an issue which is anything but trivial, and while one attempt to show a solution is through nuSense this is also likely a field which could do with an in depth research lasting much longer than this project currently allows.

Gamut of form softness.





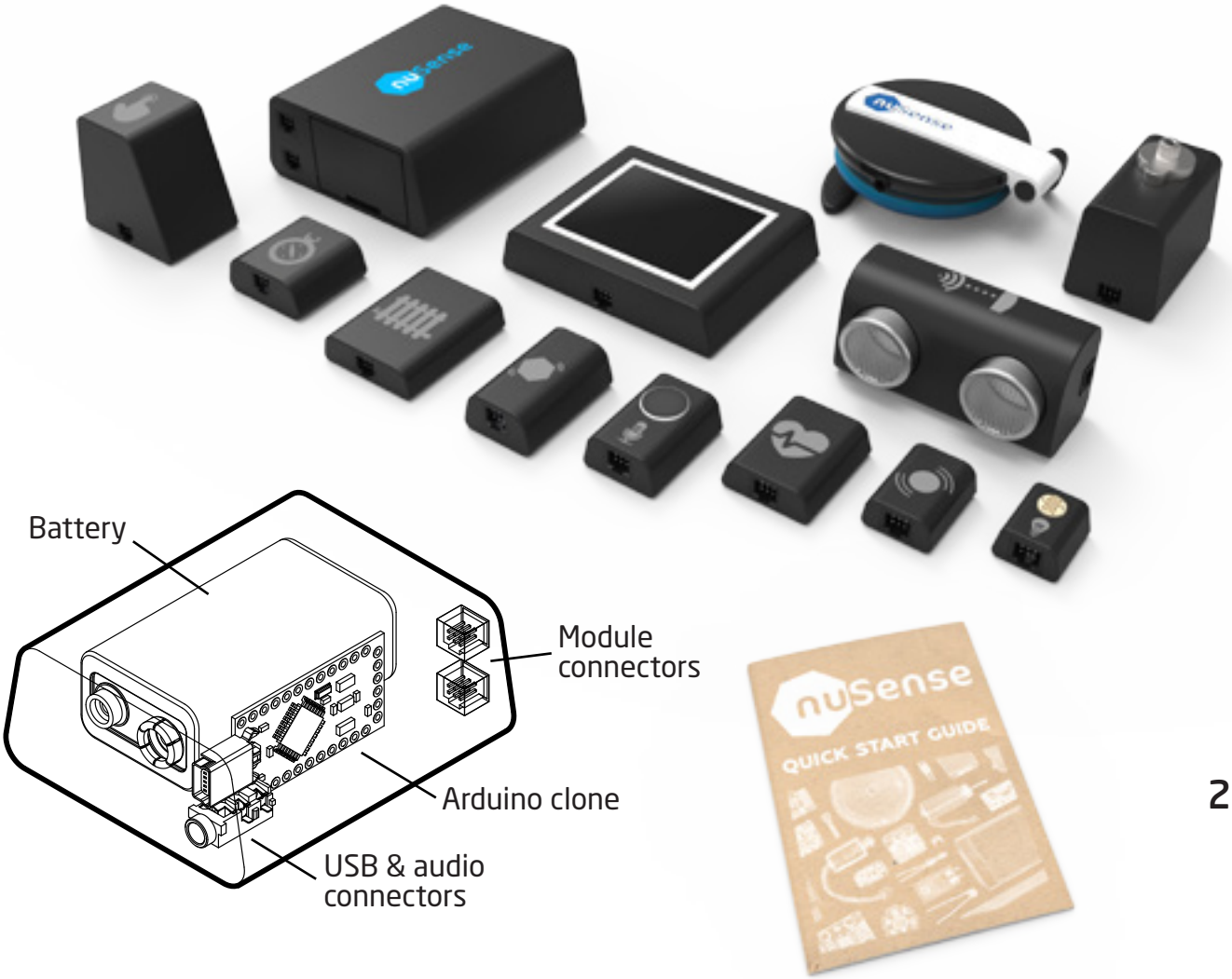
nuSense Hardware

nuSense comes as a kit, with everything you need to get started with creating and experimenting with modular wearable technology. In the starter kit you get the basic building blocks, a few sensors, a few actuators, a base unit, cables and battery, to get a running start. With the kit you also get a small folder explaining each part, what it's capable of and having a few examples what you can do with the different parts of the kit.

The sensors in the starter kit are mostly based on the senses we already possess, you get a distance sensor, a direction sensor (compass), an acceleration sensor, sound sensor (microphone), light sensor and a heartbeat sensor. With these sensors you can already reach a fairly broad spectrum of the world around you, and allow you to tap into some things which are available, but not easily accessible, such as telling the direction you're pointing, or sensing your movement with a higher granularity.

These sensors only read the world around you, and to avoid nuSense simply being a data collection project, you need some outputs as well, some actuators to trigger based on what the sensors sense. Just as you get six sensors, you also get six actuators, also following the line of the sensors with being based on triggering the more basic senses. It has a vibration motor, a speaker, a pushing actuator, for poking or tapping you, a small screen for visual input, a heating pad and a motor.

To mount the individual modules the kit also comes with elastic straps, to fit around various extremities such as arms, wrists, head and such, as well as pieces of adhesive backed Velcro. This enables the user to choose the position of the modules, relative to their own bodies, using technology which should already be common to them, i.e. Velcro. In comparison, one could have designed a whole new mounting system for the modules, but then the users would have been reliant on that system when building, instead of technology which

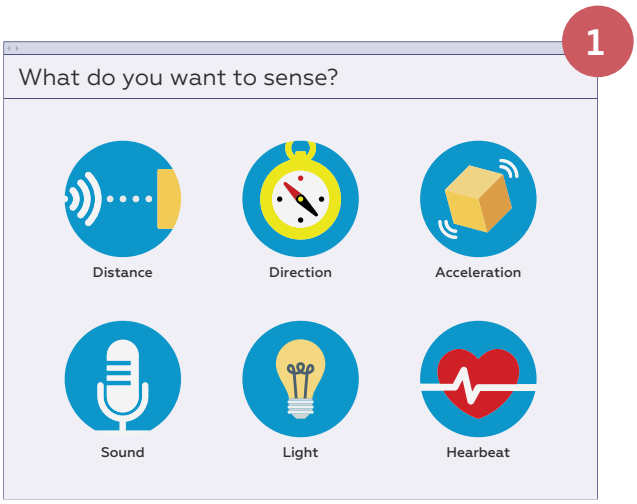


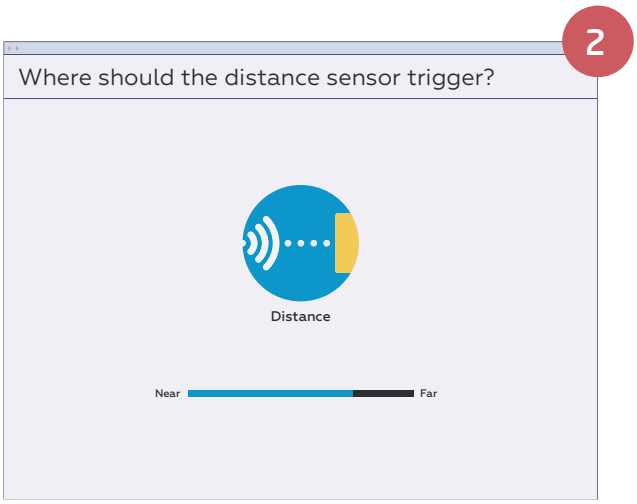
is available through any fabric store. If new mounts are needed you would be locked into an infrastructure, rather than being able to make your own. From a corporate view it may mean an extra point of profit, but it could also mean the failure of the system, and is as such a short sighted point of view.

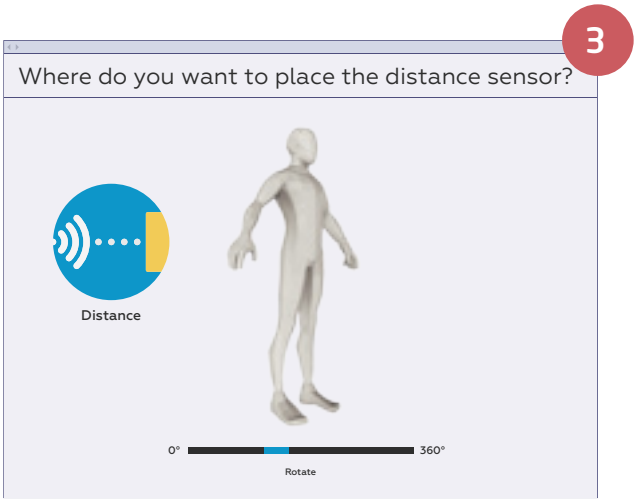
The aesthetics of the different hardware modules are also left more simple and utilitarian to blend in with the user's own style, rather than to contrast it. Some design requirements had to be fulfilled though, since we're working within the field of wearable technology. The modules are intentionally not any larger than they need to be, to maximize the possibility of placement, and all edges and corners have a nice and gentle rounded shape, not to be in the way during regular use.

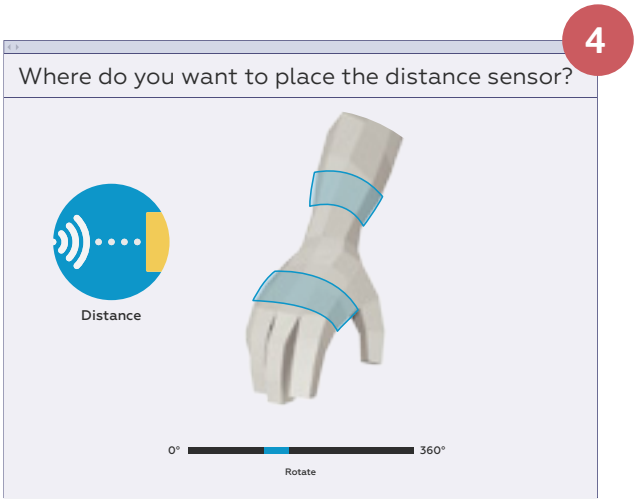
While the modules in the kit itself are made from injection molded plastic, a consideration made both from the design and cost, the more experienced user could easily buy sensors from any vendor and make their own enclosures, using different methods. The initial purpose of nuSense is to get people into experimenting with wearable technology, especially when dealing with inputs and outputs, but the extended purpose goes more into both offering an easy entryway into building and programming wearable prototypes. As such, when one feels comfortable, nuSense can be modified to use new sensors, enclosures made through 3d printing, hand modeling, wood working, or whichever method one may feel comfortable with.

To further facilitate this move towards a deeper understanding of wearable technology you also have the possibility to buy more sensors for your nuSense kit, as they become available. The starter kit has everything you need to get off the ground, whereas the Expansion and Full kits contain more sensors and actuators to broaden the horizons even more.







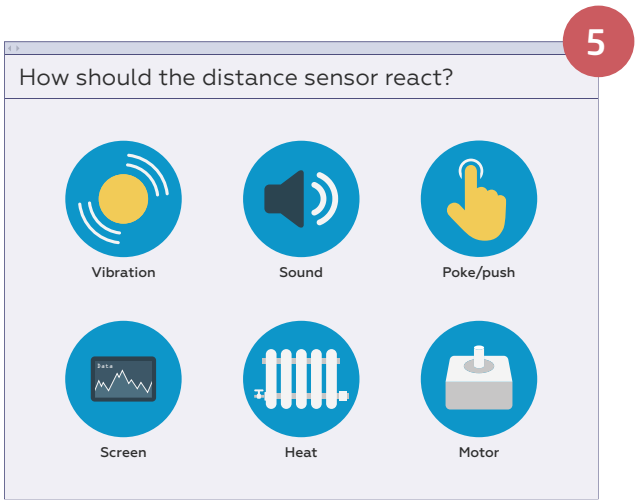


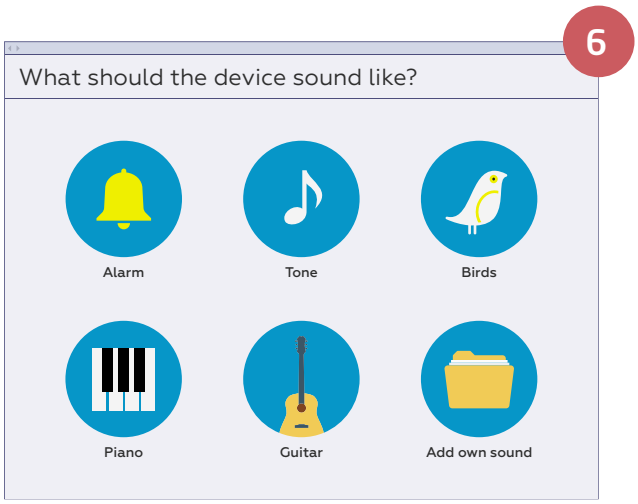
nuSense Software

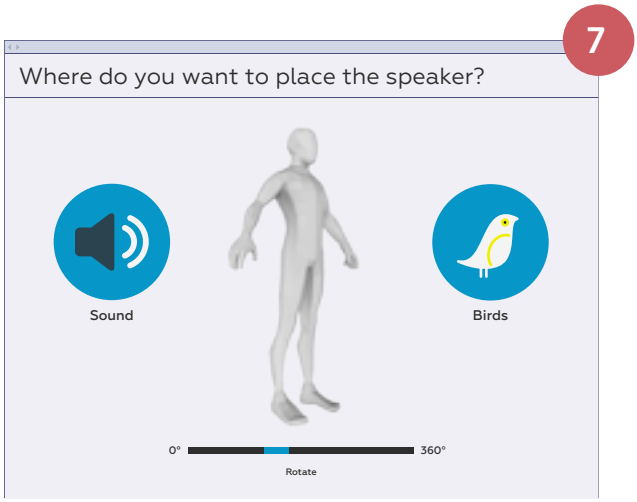
Having all of these sensors and actuators does not mean they magically know their purpose without input from the user. Beyond hardware you need a software level to allow the set up of each sensor and actuator.

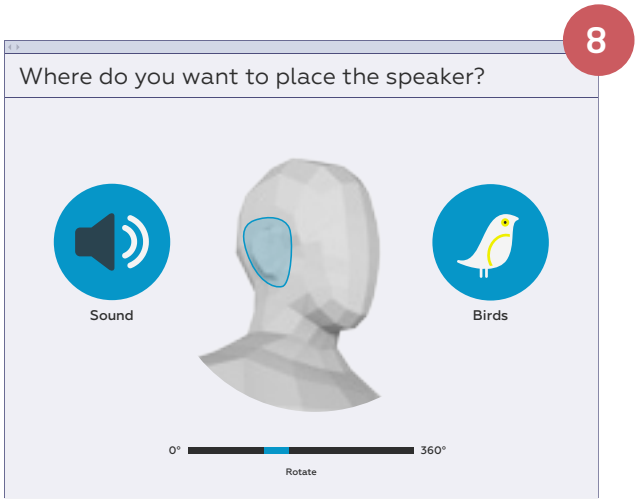
The intention behind the nuSense IDE (Integrated Developing Environment) was to leave as much of the more complex levels of developing in the background. Instead of writing behavior in code, nuSense is based on a graphical interface, using sliders and easily understood wording for values and actions. For instance, instead of having a distance sensor act between the values 0 and 1023, as is common when you're using for instance Arduino, we have it react based if something is "near" or "far". While this removes some of the granularity of what the sensor is actually capable of, it adds far more ease to the user and a security in feeling that you know what you are setting up.

Once you've gotten your kit, read through the small quick start guide and installed the software you'll be presented with essentially a wizard, taking you through the creation of your project. First you get to choose which sensor to use (1), which in turn have very self-explanatory names, and easy to understand pictograms. Once chosen you get to set up how it should trigger (2). This will look slightly different depending on which sensor you choose, some will be set up through sliders, others through checkboxes and such, but all using easily understood terminology for what the sensor actually does. Next step is to choose the placement of the sensor in relation to your body (3, 4). With the elastic Velcro which ships with the package the placement is entirely up to you, but some recommended areas are displayed in the interface. The software will however not forbid you to place anything anywhere, even if it may be seen as a silly choice. The idea being that the frustration of having something not working as intended once you build it is less frustrating, and more of a learning







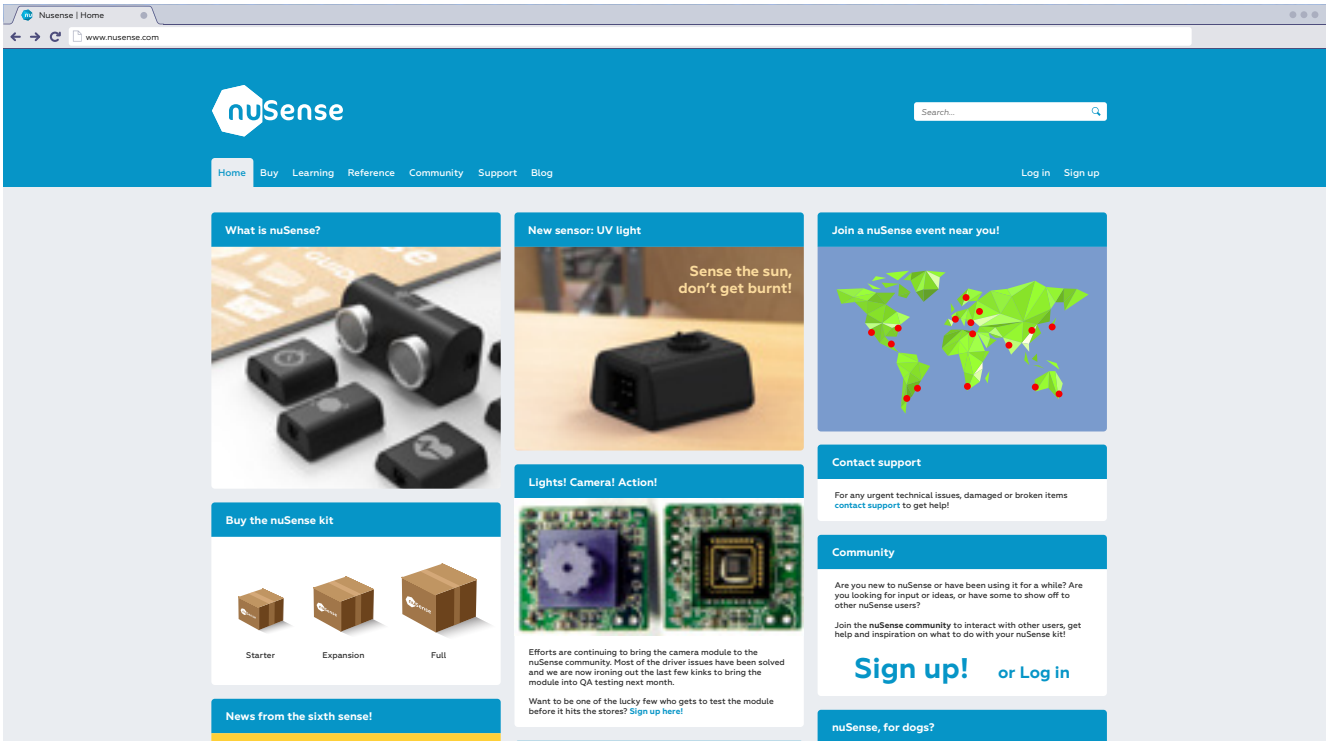


experience, than dealing with software that restricts you from doing what you want.

A similar setup phase is done with the actuator: which one (5), how it should trigger (6) and placement (7, 8). At the end of the wizard you're presented with what you will need to build the project you've designed, and how to plug it all together. After everything is hooked up you simply connect the base unit via USB to the computer to load the project code onto the device. Wear it and experience the world in new ways!

The base unit itself contains the power source, which is a rechargeable 9V battery, as well as the brain, a custom circuit board running on Arduino logic. It also has connectors for the sensors and actuators, as well as an audio jack for plugging in the sound actuator, or more appropriately named, the headphones. Even though the kit ships with its own headphones, the fact that nuSense keeps to regular audio connector standards means that the user could also use any headphones they are comfortable with.

Beyond the wizard interface lies a mode which you can activate once you've reached the boundries of what you can do with the nuSense kit alone, or for that matter if you're already comfortable with programming and physical prototyping. nuSense is a system designed not only for the novice user, but also for those with a greater wish to push the field of wearable technology further. When you activate the super-user side of the interface you can write your own code for what you want the sensors and actuators to do. Or for that matter you can set up a project using the wizard and then dive into the code of that project and modify it to your heart's content. Since nuSense is using Arduino code to run you can find a broad community, even outside the boundries of nuSense's own community, to inspire and help out.



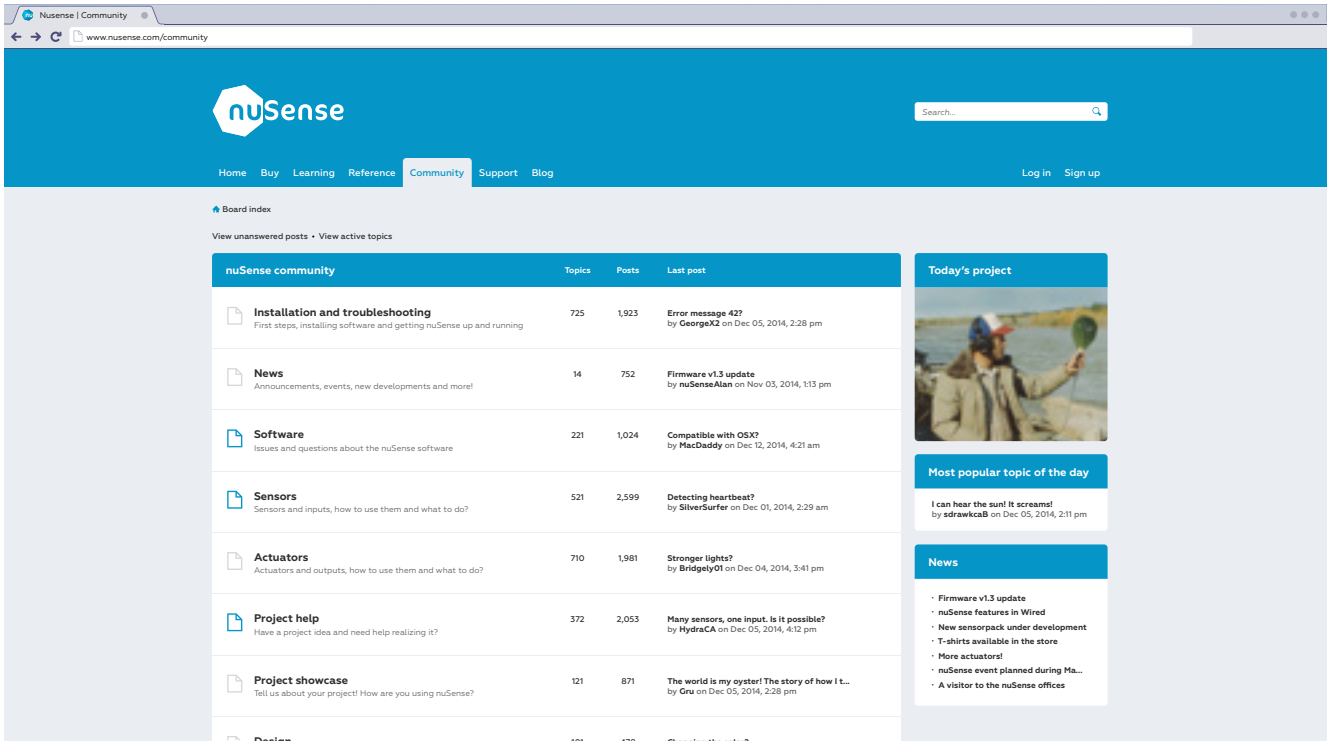
nuSense web home screen.

Web and Community

As with all products users will run into issues, regardless if it's caused by themselves, by the hardware, software or force majeure. While some issues, like broken hardware, may need to be escalated to actual support cases, most of what you run into can be solved by other users who have either run into the same issues themselves, or who are so well versed in the product that they can offer help regardless. While the nuSense help documentation has plenty of examples, and a good reference as to what the different parts of the kit can do, it only reaches so far. One major element of the main nuSense website is the community, catering to new and old users alike, people who want help with their projects, those just wanting to show off and everyone in between. It's a point of inspiration when you're looking for new things to do with your kit, as well as news on what may be coming up in the world of nuSense. Not to say the least, from a corporate point of view, it's also free support.

Early on during the project an interview was conducted with Paul McCarthy, who together with his son Leon built a prosthetic hand for Leon, using a 3d printer. He mentioned the importance of co-creation, and how their project was fueled by the exchange of ideas and discussion between himself and Leon. One doesn't have to look further than to the vast amount of communities online solely made for the purpose of exchanging ideas, or to the Maker movement which thrives on this exact kind of exchange.

As far as community design goes it's a fairly scaled back forum structure, with



nuSense community page.

sub-forums separating different parts of the community for ease of use. It's a tried and tested formula which has been used in communities around the web for well over a decade.

Eventually, as the community grows and some users end up spending more time and effort there than most, they can be elevated into forum administrators tasked to help keep the forum running. These are also potentially the people who would help to push nuSense forward, to help develop new modules and to suggest important updates and changes to future releases. Some of these "super users" could very well also be made part of the nuSense team to encourage further growth. Much like with any developing platform nuSense will need to grow over time to be able to survive, and as technology evolves so must it. The input from the community will be invaluable in such a situation, in understanding where focus needs to be put, and where interest lay to move forward.

As nuSense is based on Arduino there are also vast communities already set up to cater to it, so while the nuSense community is solely for the nuSense platform, the ease to get help can be extended far beyond its own community. This is as opposed to developing a proprietary technology, or using one of the lesser popular developing platforms available. Arduino is not perfect, but the fact that it has such a well-supported community, as well as compatibility with just about any sensor and actuator technology out there, makes it ideal for nuSense.

Use Cases

While we have touched on the topics of users already, looking at who to focus on while developing nuSense, the question is still how nuSense would be utilized. We have the user groups already defined; those exploring the sensory realm, those developing wearable technologies and those who extend their bodies through technological means, but how could these groups actually benefit from nuSense?

For the first and last group, call them collectively The Experimenters perhaps, the answer is fairly straight forward. Through using nuSense they could explore and tailor how they experience the world around them. It would not necessarily be to create new devices, which combine the nuSense sensors and actuators, which lasts forever but rather something which could help them better define what it is they want in the long run. These two user groups are already defined by having a strong interest in hacking technology, and would likely have no problems learning how a new system works and how to bend it to their desires.

The user group which would be of greatest benefit would more so be those who are developing wearable technologies, the designers and engineers both working through consultancies, in-house or even at schools and in research. Currently if you want to experiment with wearable technology you need to find a developing platform and bend it into a wearable shape, unless you even go so far as to create something from scratch. Sensors and actuators are not currently adapted to work on a wearable level, and the experiments tend to become cruder than they need to be. Perhaps most importantly is that it takes vast amounts of time to prototype, so if you want to sketch in wearable hardware it's a timely exercise. Speeding up the time between iterations also means that experimentation becomes freer and less costly, even if simply through man hours. Companies could be more inclined to venture beyond armbands and glasses through a greater extent as research and development cycles go faster, and become cheaper.

A good example may be in Google Glass. Looking below the development stages of Google Glass over two years can be seen, and how they started development with hacking a phone, and eventually building up to custom hardware, etc. While there is nothing wrong with hacking existing devices, we've all done

Development stages of Google Glass over two years.

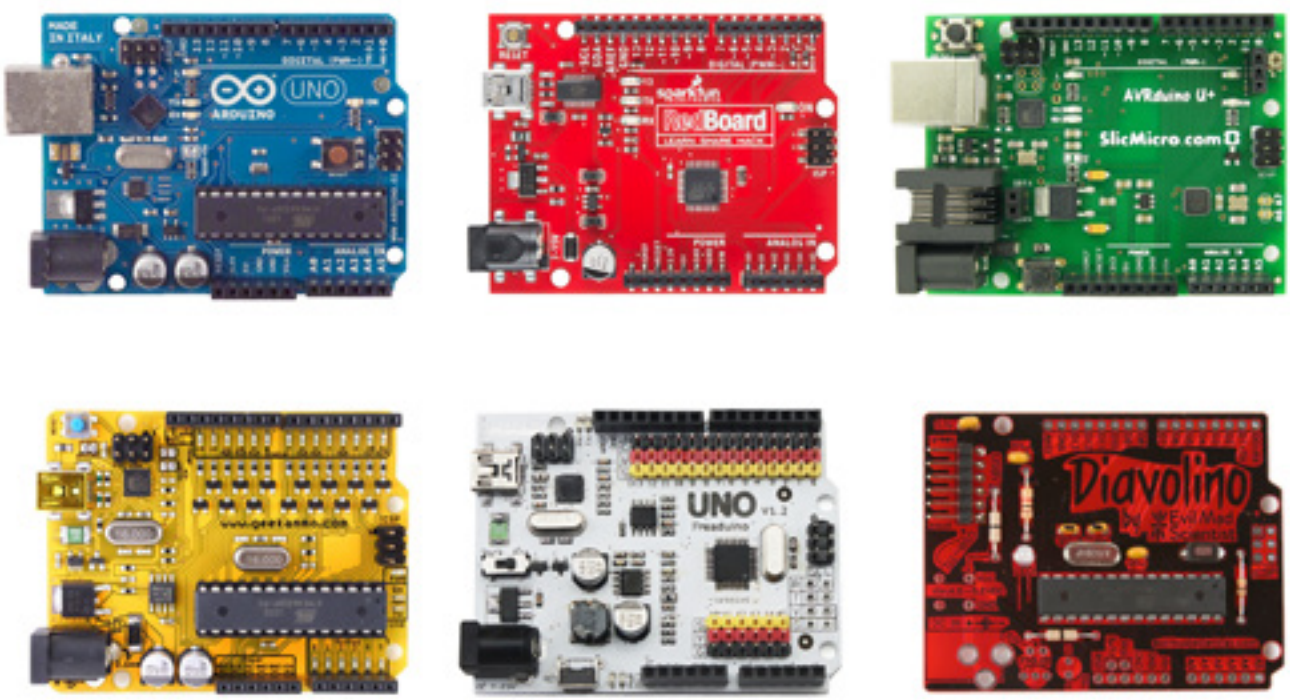
it at some point, one may still ask if the development cycles couldn't have been shortened and even some cancelled out by using a development platform already tailored for the purpose?

As nuSense would fundamentally be an open source platform it would also democratize its use, as anyone would have access to it, regardless of prerequisites (aside from having access to a computer). This also means that anyone could develop not just new peripherals and modules for nuSense but could essentially clone the platform.

A good example how this would work could again be seen in Arduino. The Arduino platform is entirely open source, all the way from the code to the circuit board design. Nothing is stopping anyone from opening up their own Arduino manufacturing and selling Arduino compatible boards. This is with one exception, they cannot use the name Arduino as it's trademarked to Arduino. A similar framework would be set up around nuSense, where anyone could clone nuSense to their hearts content but have to keep the nuSense branding off it, calling it at most nuSense compatible.

This kind of development opens up for a lot of possibilities, just as for Arduino it meant the release of many tailored clones, for different use cases it could mean the same for nuSense. Arduino clones have come out in all shapes and sizes, being able to run almost anything imaginable. What exactly a similar exploration would mean to nuSense is only up for speculation, but could definitely include a much broader set of sensors and actuators, as well as modules for more extreme situations. Perhaps we would see a whole new developmental spurt of underwater wearable technology, or for emergency personnel, two areas which already use wearable tech and where development is rife.

Original Arduino UNO board compared with five clones.



Summary

The later times of this project time was spent observing a group a class of second year master students in interaction design at Umeå Institute of Design trying to design new types of wearable technology and the hardships they went through both in trying to make quick prototypes to test ideas, as well as building their final concepts. The regular hardships in trying to get hardware to work, hooking up electronics correctly and programming for them still apply, but the problems exponentially increase when you have to consider the closeness to the body, the movement and the general wear and tear on the devices. This is different from making a portable or carryable device, in the sense that they are a lot more forgiving simply due to often being enclosed in a hard shell, or having very clear areas of interaction. As wearable devices becomes part of your body in the same way as clothes or jewelry the entire device becomes a point of interaction, and thus a point where things can go wrong.

The second hurdle was often simply understanding the data received from the sensors used, and how they related to what the user was doing. When you turn a knob on a box, it's not hard to tie action with received input together, but when things start becoming more arbitrary and you have to take more complex sensor data into account it's often hard to reach anywhere meaningful, and you do so simply by virtue of spending a lot of time.

The observation very much mirrored the data collected earlier during the project, about the hardships of developing for wearable technology. While the subjects

Exploration in wearable technology illustrative of the complexity in working with wearable tech.

tried all tried to develop very different and new wearable concepts it was easy to see, at the very least from an outsider's perspective, how they could both have saved themselves headaches by going the simple and safe (and perhaps boring) route, and also how desperately they could benefit from using a more tailored development platform like nuSense when realizing their concepts. Especially so if they hadn't explored wearable technology before.

nuSense definitely fills a function when being able to iterate quickly on your ideas, as going back and making changes to your project is as easy as hooking up the USB cable and loading over new project code. Even if you need to go into the code and change bits and pieces yourself it's still a lot easier simply by the code being pre-generated for you and you don't have to worry about how to communicate with the sensors and actuators, but only focus on the values of how they should act.

As for the quote early on during the project, that wearable technology still hasn't found its niche. nuSense is likely not part of that niche, though it could very well be the tool which could help wearable technology to reach there. Primarily that hinges on attracting an active user basis, one that's goes beyond trying and discarding, but actually stays with the platform and is interested in seeing it develop and grow.

Garment making during wearable technology project.

Conclusions & Reflection

In the end does nuSense reach the initial, perhaps somewhat lofty, goals this project set out on? From the beginning we covered, in short words, the distance we've travelled as humans from the caves all the way up to modern time, and perhaps at the same time how little has actually changed since then. While we've added layers to our existence, both in terms of clothing and technology, we are still much the same creatures we were thousands of years ago. Will nuSense fundamentally change this human existence and push us into post-humanism completely? Some may argue that we are already there, that we are all indeed cyborgs already, so where does nuSense fit in?

Personally, I don't think nuSense as a platform fits into this equation any differently than other tools do. What a hammer is to a nail nuSense is to wearable technology, and extending our senses. While it may play a role in the technological development yet to come, it's not bound to be the focus of the development, but rather a tool to help further and implement wearable technology to a greater, and hopefully smarter, extent.

Looking back this project could have taken many other different turns and twists. From the beginning technological integration with the human body was in focus more than wearable technology, and the idea that we were already cyborgs took somewhat of a critical standpoint towards the technology around us and what we do with it. The project could very well have gone towards challenging those concepts, and made a critical design outlining a dystopia which may yet come to be.

While nuSense ended up being a fairly straight forward concept that fills a quite well outlined void in wearable technology: the lack of a proper prototyping platform, there were also other voids which it could've filled. When dealing with wearable technology there are many different solutions to the same problems, the wheel has been reinvented many times to solve the same issues. That is one reason why nuSense falls back on using Velcro as a fastening system, instead of relying on yet another new technology. The opportunity still exists however to draw up an entire new design language and guidelines for how to deal with wearable technology in close proximity to the human body.

In the end it's possible that this project bit off a bit more than it could chew. From the beginning I did not expect the complexities which the project had in store, it felt like a fairly straight forward tangible design project and it was only over time it became abundantly apparent that working with the field of wearable technology by far isn't as straight forward as it may first appear. In the end nuSense is a concept which solves a very real problem that stifles technological advancement, perhaps not in the sense of what technology we develop in the short run, but definitely in how we design for that technology. This design could lead an increased interest in wearable technology, which in turn leads to greater technological research in the long run. nuSense definitely doesn't save the world, but maybe it could help designers and users alike feel less lost in this technological realm, especially so as technology creep closer onto our bodies.

Future Work

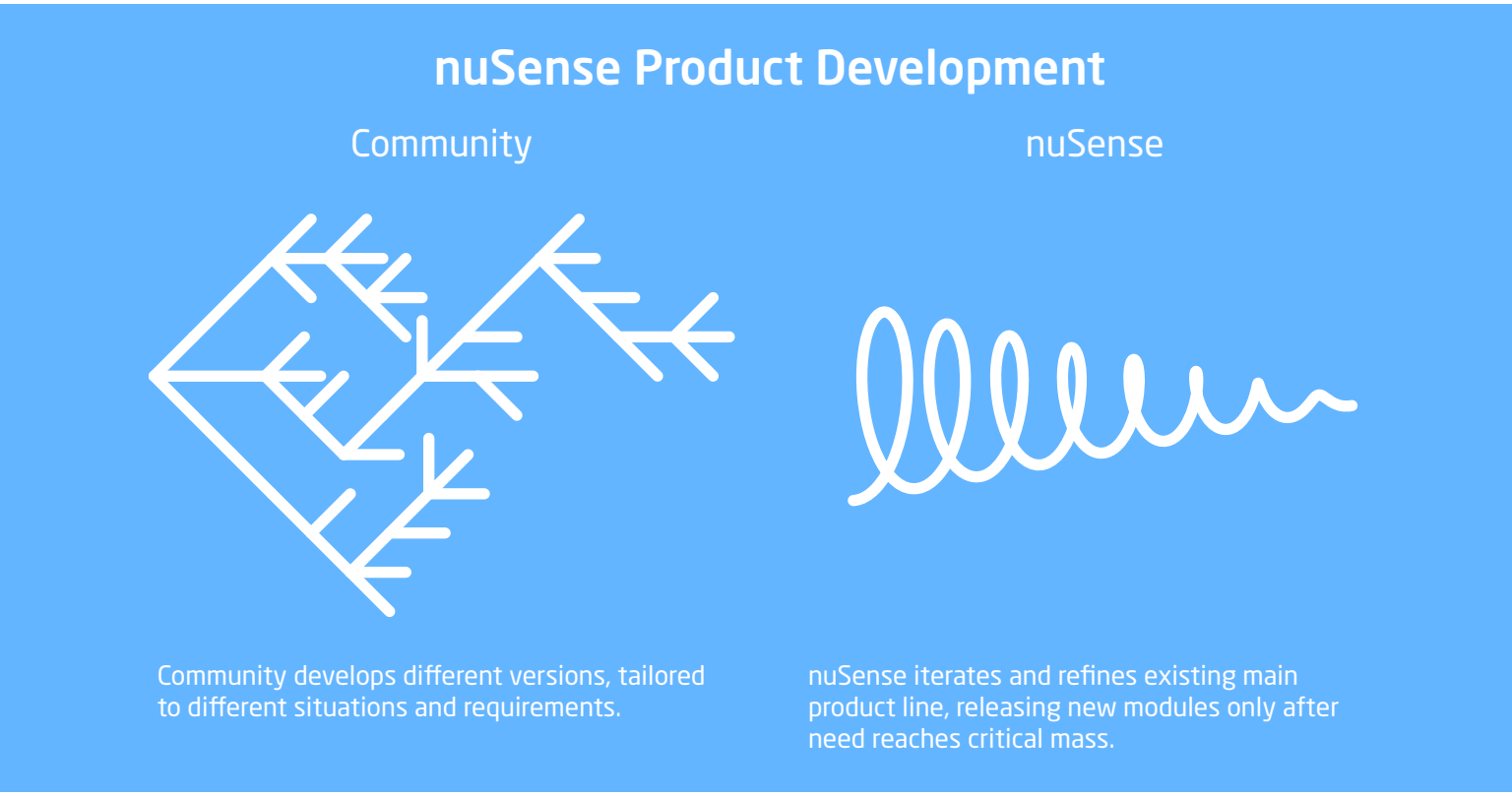
As the limitations of this project grounds it in the technology available today there were some concessions which needed to be observed. For instance, the debate whether to use cables between the modules or go wireless ended up on the side of cables, even though practically they may be less than ideal. This decision was based on power and signal restrictions. While there is technology available today to solve signaling on a low power budget, such as Bluetooth Smart (Bluetooth SIG, Inc, 2014), many of the sensors and actuators themselves have higher power requirements. Embedding a battery and a wireless chip in each module would not only increase the size of the module, but also make the price of the kit balloon.

However, if battery technology can continue making steady improvements, and communication chips becoming ever cheaper as they become more and more ubiquitous, it's not farfetched at all that these modules would become entirely wireless. The benefit for their usability would also be increased from experimenting to reaching a broader audience which could be interested in actual everyday usage of the kit.

As the current form of nuSense is utilitarian in nature there would also be a lot of work needed to bring it up to a more attractive level. This could though be something for version 2 or 3, when early adopters and the community has had a chance to give input and brought the system to where they see fit. By the time an official nuSense version 2 or 3 is ready for launch more tailored clones for specific situations may already exist on the market. This is not a bad thing as it would leave nuSense to focus on being the main backbone behind the development, rather than designing for every specific use scenario, if one could even map out such a thing.

While it's doable to draw out guidelines for how to design for wearable technology, things like smooth shapes and soft materials, it's only after it's been tested and vetted by users you know if it would work on not. It's unwise to expect nuSense to bring a revolution to the ergonomics of wearable technology, as that's not the main point of the system.

Two sided product development process.



References

Aristotle. (2014). Complete Works of Aristotle, Volume 1 the Revised Oxford Translation. (p. 844) (J. Barnes, Ed.). *Princeton: Princeton University Press.*

Bluetooth SIG, Inc. (2014). The Low Energy Technology Behind Bluetooth Smart.
Retrieved January 7th, 2015, from http://www.bluetooth.com/Pages/low-energy-tech-info.aspx

Brustein, J. (2013, September 12). Holiday Shoppers Will Help Tablets Outsell PCs for the First Time. *Bloomberg Business Week.*
Retrieved April 15, 2014, from http://www.businessweek.com/articles/2013-09-12/holiday-shoppers-will-help-tablets-outsell-pcs-for-the-first-time

Clarke, P. (2000, February 9). ISSCC: 'Dick Tracy' watch watchers disagree | EE Times. *EE Times.*
Retrieved January 5, 2015, from http://www.eetimes.com/document.asp?doc_id=1141227

Clynes, M. E., & Kline, N. S. (1960). Cyborgs and Space (pp. 26-27, 74-76). *Astronautics, September.*

Gemperle, F., Kasabach, C., Stivoric, J., Bauer, M., & Martin, R. (1998). Design for Wearability. Proceedings of the Second International Symposium on Wearable Computers ISWC'98. *IEEE.*

Gray, C. H. (1995). *The Cyborg Handbook* (pp. 371-78). New York: Routledge.

Haraway, D. J. (1991). A Cyborg Manifesto Science, Technology, And Socialist-Feminism In The Late Twentieth Century. *Simians, cyborgs, and women: the reinvention of nature* (pp. 149-181). New York: Routledge.

Harbisson, N. (2012, June). Neil Harbisson: I listen to color. [Video file].
Retrieved January 5, 2015, from http://www.ted.com/talks/neil_harbisson_i_listen_to_color

littleBits Electronics, Inc. (2015) LittleBits: DIY Electronics For Prototyping and Learning. Retrieved January 6, 2015, from http://littlebits.cc/

Modular Robotics Inc. (2015). Cubelets Robot Construction for Kids | Modular Robotics.
Retrieved January 5, 2015, from http://www.modrobotics.com/cubelets/

PricewaterhouseCoopers LLP. (2014, October 21). Wearable Technology Future is Ripe for Growth – Most Notably among Millennials, Says PwC US. *PricewaterhouseCoopers LLP.* Retrieved February 4th, 2015, from http://www.pwc.com/us/en/press-releases/2014/wearable-technology-future.jhtml

Google Inc. (2015). Retrieved January 5, 2015, from http://www.projectara.com/

Shakespeare, W. (1723). King Lear, A Tragedy (p. 48). *J. Darby.* Act III, Scene III

Zorpette, G. (2014, March 11). "Naked Truths" About Wearable Electronics. *IEEE Spectrum.*
Retrieved March 17, 2014, from http://spectrum.ieee.org/tech-talk/consumer-electronics/gadgets/naked-truths-about-wearable-electronics

Image List

6. Leuthard, T. (2011, November 5). Man sitting [Photograph]. Retrieved from http://www.flickr.com/photos/thomasleuthard/6472493913/

8. Stelarc. (1982, May 8). The Third Hand [Photograph]. Retrieved from http://criticalresponse.wikispaces.com/Rob+Lee

10. Author Unknown. (n.d.). Examples of common wearable technologies [Illustration].
Retrieved from http://blog.utest.com/2013/07/02/what-the-wave-of-wearable-tech-means-for-software-testers/

11. Comenius, J. A. (1728). The outward and inward senses [Illustration]. Retrieved from http://catalogue.wellcomelibrary.org/record=b1309789

12. Dezeen Limited. (2013, May 1). Eidos by Tim Bouckley, Millie Clive-Smith, Mi Eun Kim and Yuta Sugawara [Photograph].
Retrieved from http://www.dezeen.com/2013/05/01/eidos-sensory-perception-masks-royal-college-of-art/

13. Google Inc. (2014). Project Ara [Photograph]. Retrieved from http://www.projectara.com/ara-developers-conference-old/

14. George, L., Ultra-lab. (2014, February 28). Taller para niños/as de littleBits, 28 de febrero 2014, Espacio Miscela, Madrid [Photograph].
Retrieved from http://www.flickr.com/photos/62141688@N08/12906097445/

15. TED Conferences, LLC. (2012, June). Neil Harbisson: I listen to color [Photograph].
Retrieved from http://www.ted.com/talks/neil_harbisson_i_listen_to_color

17. Dimensional Innovations. (2013, December 18). Wearable Technology Lacks Innovation [Infographic].
Retrieved from http://www.dimin.com/blog-post/wearable-technology-lacks-innovation/

20. Vice Media LLC. (2013, August 4). Def Con, Day Two: Def Con Is for Winners [Photograph].
Retrieved from http://motherboard.vice.com/blog/def-con-day-two-def-con-is-for-winners

21. Andrew Russell, Tribune-Review. (2013, December 21). Biohackers work toward building $6M man on do-it-yourself budget [Photograph].
Retrieved from http://triblive.com/news/allegheny/5078068-74/cannon-implanted-north

24. Gemperle, F., Kasabach, C., Stivoric, J., Bauer, M., & Martin, R. (1998). Fig. 1. Design for Wearability. Proceedings of the Second International Symposium on Wearable Computers ISWC'98 [Illustration]. *IEEE*.

Featherstone, T. (2010). Wearable Structure: Side Bump. Retrieved from http://tracyfeatherstone.com/Wearable-Sculpture

25. YOW!design Inc. (2012). Edgy Stapler [Photograph].
Retrieved from http://urbanprefer.com/EN/Product/Detail.aspx?ProductID=6e982f7e-87ab-445a-bc12-c87cf8684fd1

FoneArena. (2013, January 25). Nokia Lumia 920 [Photograph].
Retrieved from http://www.fonearena.com/blog/61103/yellow-nokia-lumia-920-photo-gallery.html

Haaretz Daily Newspaper Ltd. (2014, March 3). A bicycle helmet printed by Stratasys' Objet500 Connex3 Color Multi-material 3D Printer [Photograph].
Retrieved from http://www.haaretz.com/business/.premium-1.577728

DCA Design International. (2014, April 2). Aquafresh Milk Teether [Photograph].
Retrieved from http://www.red-dot-21.com/products/aquafresh-milk-teether-oral-care-teether-21916

32. Google Inc. (2014, March 20). Evolution of Glass over two years [Photograph]. Retrieved from https://plus.google.com/+GoogleGlass/posts/axcPPGjVFrb

33. Arduino LLC. (n.d.). Arduino Uno R2 Front [Photograph]. Retrieved from http://www.arduino.cc/en/Main/ArduinoBoardUno

SparkFun Electronics. (2014). SparkFun RedBoard - Programmed with Arduino [Photograph]. Retrieved from http://www.sparkfun.com/products/12757

SlicMicro LLC. (2012). AVR.duino U+ [Photograph].
Retrieved from http://www.slicmicro.com/avrduino-arduino-uno-rev3-compatible-with-extra-features-p-1002.html

The Little Bird Company Pty LTD. (2013). Magpie (100% Arduino Uno Compatible) [Photpgrah].
Retrieved from http://littlebirdelectronics.com.au/products/magpie-100-arduino-uno-compatible

ElecFreaks. (2012, April 24). Freaduino UNO Rev1.8 MB_EFUNO [Photograph].
Retrieved from http://www.elecfreaks.com/store/freaduino-uno-rev18-mbefuno-p-414.html

Evil Mad Science LLC. (2010). Diavolino [Photograph]. Retrieved from http://shop.evilmadscientist.com/productsmenu/tinykitlist/180-diavolino

37. Based on [Buxton, B. (2007). Fig 149 & 150 [Illustration]. Sketching User Experiences (p. 388). *Elsevier/Morgan Kaufmann.*]

Unless indicated above, images and graphics included in this report were created by Daniel Jansson as part of the nuSense project.

UMEÅ UNIVERSITET

Umeå Institute of Design
MFA Interaction Design