



Clothing as a game platform

The missing link in pervasive gaming

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Summary

Video games have lost their connection with the real world, tangible objects do not get a new meaning with the addition of rules and goals. This is for me the magic of games. Pervasive games try to break through to the real world and again connect the interactive experience with the player and its surroundings and bring back the magic. But currently we are missing the right platform to make the experience fully pervasive. Looking at a player wearing clothing we see one of the most interesting, adaptable and complete game platforms possible. E-wearables, wearable technology, makes this possible. My hypothesis is:

An e-wearable platform is the most fully pervasive game platform.

Current game definitions interfere with the definition of pervasive games. Therefore 'game' needs a new definition to give a clear understanding of pervasive games and still leave us enough room to experiment with the borders of game design: **a game includes rules and a player who tries to reach a goal.** With this definition I could look closely to what defines pervasive. **A pervasive game is a game that tries to pervade the real world, away from the digital screen including, but not exclusively, elements like social connections, space and time using electronics or software to process the data and dynamics of the game.** It is a category of games, just like board games, sport and video games. The application of the clothing of a player as a game platform has advantages: everything the player does, has repercussions. When you exercise more, you get more fit and the active part of the game becomes easier. E-wearables are my answer to successfully transform clothing into a platform. Clothing is part of the identity of the user, it is by all means pervasive and everyone learns from the day they are born how to use clothing. With clothing we, designers, have access to a lot of different data of the user. Body movement, affective data and daily routines can now be measured whenever the player is wearing clothing. Even when they are not being worn (sleeping), the clothing gives useful information. With the possibilities of a smart phone, the sky is the limit.

To explore this hypothesis I investigated this subject and built Woven, an e-wearable pervasive game

platform, together with Patrick Kersten. Woven is the first step exploring this direction. We created the first complete e-wearable game platform with a new game SPOOKY: an user focused pervasive game. It collects data from the user in a pervasive way and uses this to play a game.

Woven exists of two sets of a sweater and a pair of jeans. Many different electronics are placed in these sets: processors, speakers, sensors (heart rate, bend sensor), shaker motors, Bluetooth module, a 12 x 12 RGB pixel screen. To see how this platform performs, I created the game prototype SPOOKY. In SPOOKY players discover the world of ghosts by living their life and doing their daily activities. Ghosts attack the player fitting the activity of the player. Defeating the ghosts and capturing them and eventually using them to annoy other players, is the goal of this game.

The platform in its current form works beautifully, but there are still some weak elements in this platform. Checking the body movements, the audio from the speakers in the collar and the use of the screen on your belly is clear for the player and works as designed. But the connections of all the hardware components are vulnerable. When placed in one part and using flexible PCBs we can solve this problem. The bend sensors give enough data about the angle of body parts but they also react when pressed, this can result in fake data. The battery works for a couple of hours, but we would like to see a longer battery life or a battery that recharges by moving your body.

The game SPOOKY shows the possibilities of this platform and games even in its limited form. The game can be played whenever, wherever and however the player wants it. The game changes depending on the activity of the user. The social aspect of the game is very interesting and we are only scratching the surface of the social aspect of this platform. The results of Woven show that e-wearables is one of the most interesting pervasive technologies usable as a game platform. With this project we took the first steps to see this concept in the future on the streets. This game platform can be used for much more than only games, it is a whole new platform. It can change how people exercise, interact with others and objects in their surroundings. It weaves the possibilities of the user and their life to make the complete experience pervasive and fun.

Introduction

Games have been around and played for thousands of years by people all around the world, starting with dice, board and card games. These games all have something in common: with rules they turn tangible objects in something magical; games. But the last hundred years gaming has changed drastically. It started with mechanical arcade devices and after the arrival of the digital era changed into digital games. Nowadays a video game console can be found in every home, can everyone play games on their smart phone and the Internet gives everyone access to all these digital games. But during this process the biggest part of the connection with the real world was lost, actions in the real world have no influence on the game. Something that was fun and playful for six decennia was lost, when it changed to a complete focus on a digital screen. The magic of seeing common objects do something different with a game as a result, was not important anymore. To understand this, look at a simple example: a ball. A ball has been used for countless different games, every time when we introduce new rules we create a new game and even after thousands of years children still create new games with this platform. A digital game with a ball will never come close to the real life counterpart especially when you think about the ease of switching between different games. Digital games have lost their connection with the real world and designers and players desperately try to reconnect games with the world they love.

This powerful connection with the real world is for me, as a game designer, the magic of games. The magic is to give tangible objects a different meaning in a fun game. Creating games with this connection is developing right now, game designers try to implement the things they learned from making and designing video games and bring them back to the real world. Video games give game designers the possibility of dynamic interactions and this is something that was not possible before the digital era. Xbox Kinect and the Nintendo Wii are good examples of trying to bring the player more into a digital game emulating physical actions. Pervasive games do the opposite, they bring the game around the player, away from a digital screen, focusing on the context, like place and time of the player. But the context of the player is not the most important element, the player as a whole is. Looking at the

player wearing clothing we see the most interesting, complicated and adaptable platform there is.

E-wearables, wearable technology, could be the missing link. E-wearables are evolving, because of the affordable and small electronics. It is pervasive and that is what is needed. Clothing as a game platform with e-wearables and pervasive games would be a natural combination, but this is new territory. Pervasive games are relatively new. *Theory and Design Pervasive Games, Experiences on the boundary between life and play* by game researchers Markus Montola, Jaakko Stenros and Annika Waern is the most complete source about pervasive games and introduced the first handles of pervasive gaming, but it only focuses on the relation between pervasive games and the real world. The platform, which provides the facilities for a game to operate, is a crucial part of a pervasive game. By not looking at the platform and technology of pervasive games, I discovered that this changes some handles of pervasive games described in this book. It even so results in a weaker pervasive game, because falling back onto digital hardware, destroys the idea of a complete pervasive game. A pervasive game platform would be the perfect partner and with this idea we created a pervasive e-wearable platform with a pervasive game to investigate my hypothesis:

An e-wearable platform is the most fully pervasive game platform.

The creation of this platform and a pervasive game is the best way to explore this hypothesis and this paper is the result of seven months researching, testing and developing the platform and game. I worked together with Patrick Kersten in this Master project and we collaborated with fashion designers Marina Toeters and Melissa Petersen-Bonvie and Audio Designer Arne Höfer. In this paper I will look into the definition of a pervasive game and e-wearables, the possibilities of pervasive games, the position of the player and clothing as a platform and the theoretical advantages and disadvantages of e-wearables. I will also describe the practical results, challenges and lessons we learned during the build. But before this I will describe the platform and game shortly to give a better understanding of the context I am working in.

Project Woven

Project Woven exists of two parts: a platform and a game. Both areas are a new direction in both fashion and game design. With limited similar products it was important to create a solid concept for this platform, as fast as possible, to give us enough time to test, adapt and improve the platform and the game. We also had a limited budget, so we researched every part carefully. This resulted in the following blueprint.

The e-wearable game platform 'Woven'

The e-wearable platform exists of a sweater (inner layer is a long sleeve and outer layer is a sweater) and a pair of jeans to cover your whole body with sensors. The sweater is the heart of the platform holding all the necessary electronic parts. The sweater includes: three prototyping Arduino Lilypad boards for enough processing power, 144 RGB pixel leds to create a 12 x 12 display, eight fabric bend sensors to register elbow and shoulder movement, a heart rate sensor, active speakers built into the collar, Bluetooth module to connect with a smart phone, I²C Printed Circuit Boards (PCBs) to connect all the Lily pads, two multiplexer boards to extend the amount of analog ports on the Lilypad, three shaker motors and a shaker power board, a power converter and a rechargeable battery. The jeans only have four bend sensors to register movement of knees and upper legs. The jeans and sweater are connected with one connector in the right pocket of the jeans. All electronics are placed on the sweater to make the electric circuit and the area of electronics as small as possible. The game is an app for an Android smart phone, in this case the HTC Desire, running Android version 2.2. The smart phone is a compromise, because in the future we see all the hardware built into the clothing. The e-wearables and phone are connected through Bluetooth and can exchange data. This set-up was chosen because a smart phone is a powerful computer with all the necessary elements already built in. Building a custom computer for this platform would be excessive. The app handles all the input and output, such as audio and images, to use in the game. The app only needs to be turned on and the player can put the smart phone in its pocket or on a table. The interaction and feedback is done through the e-

wearable platform and the player, the phone is only there as a computer and not as an input device.

The game 'SPOOKY'

The final game concept changed multiple times during the build of the platform. We discovered more interesting ways of connecting the game with the player. Game design of a pervasive game for this platform was not an easy task, because of the many unknown variables at the beginning. With every bit of information, after every test we found out what worked and what did not. The final game concept is a short game with possibilities to add more content. But I kept it simple, while it still shows the core of the game and possibilities.

SPOOKY is an adventure action game for one or two players. It lets the player experience the hidden dark and funny world of ghosts, spirits and phantoms. During the daily activities of the player, the player will discover evil and friendly ghosts. The clothing will start to shake and light up. The player will hear ghosts talking, hanging around and doing what they do best, scaring people. At the beginning of the game the player meets a friendly ghost called SPOOKY who is the guide in this undiscovered world. Defeat ghosts by fighting with them, scare them and finally catch them. The game will look at daily routines to determine when a certain enemy attacks the player. The collection of ghosts can then be used to scare other players and make their clothing haunted.

With this, the foundation of the project was created. During this process it was really important to take a better look at pervasive games, e-wearables and the current available examples.

The category pervasive games

The term 'pervasive game' exists of two parts 'pervasive' and 'game'. Before a pervasive game can be defined, the latter must be defined first. Many other designers and researchers have done this before and I will only briefly describe the definition of a game, that I used, because this is not the focus of this supportive narrative.

Huizinga (2010), the first researcher to create a definition for games, describes in *Homo Ludens* the borders of a game as a magic circle with rules defined beforehand, this can be an arena, a stage or a screen. Everything that happens in this circle is part of the game and stays in this circle. Seventy years later game researchers Zimmerman and Salen (2004) try to give a complete definition with all the necessary elements to define a game in their book *Rules of Play Game Design Fundamentals*. A game is a system where a player or multiple players challenge each other to overcome certain obstacles. The player and game must follow certain rules to change the game in a measurable outcome different than the beginning. But this definition results in a contradiction with new categories of games that try to discover and play with the borders of games, especially pervasive games. Montola et al (2005) start with describing these definitions, but do not give a new definition for a game. Instead they use a negative definition to define pervasive games and they do not give a true definition of a game that works with every category of games. "A pervasive game is a game that has one or more salient features that expand the contractual magic circle of play spatially, temporally, or socially" (Montola et al 2005, p12). Pervasive games break with the system and magic circle and this asks for a new definition of games to define what a game is and not what a game is not. Playing with the demarcations is what results in new original concepts. When I look at games I always have the following basic definition of a game, because without this there is no game and it still gives me enough space to explore new and interesting game concepts including pervasive games:

A game includes rules and a player who tries to reach a goal.

When the rules and goal(s) are removed, it becomes a toy. It only supports play. When it only has a goal it becomes a puzzle. Without a player there is no one to reach the goal and this makes the game just an artifact. There is not always a closed system or an outcome that is different; the journey can be the experience. A closed magic circle has no influences on the area outside the magic circle, the real world. Influencing the world around you is a central part of pervasive games. Therefore a closed system cannot be an element, which defines a game. "Pervasive games expand the gaming space" (Walther, 2006, p12).

Defining pervasive

The bigger definition of pervasive can be found in the name: pervasive or to pervade. What a pervasive game pervades is the real world. Benford (2005) describes that pervasive games place a part of the game into the real world. The player is not connected with a console anymore or a fixed place. The game is available at any place and any time and it is using elements like time or position in the game. This does not answer what a pervasive game actually is, it explains what a pervasive game does. Walther (2005) starts to define this in *Atomic Actions & Molecular Experience: Theory of Pervasive Gaming*. A pervasive game takes place in a game world that is a mix of tangible and immaterial objects. This is achieved by often using electronics or programs to process the data necessary for the game. It is a mix of the three pillars: reality, augmented and the virtual. Eva Nieuwdorp (2005), a game researcher focusing on pervasive games, looks at pervasive games with the help of describing the platform as a combination of hardware, software and a liminal interface. A liminal interface is the mind of state of the player. The liminal interface has two levels. The paratelic interface, which applies to leaving behind the conventions of the life world domain, and the paraludic interface, which brings the player to accept the new conventions that exist in the world of the game. This is similar as the idea of seeing the magic circle as a contract (Montola et al 2005), but still pervasive games even break with this contract. The mind of state depends all on the pervasiveness of the platform, a fully pervasive platform will make this step, including the two levels instantly for the user. There is no difference between the game and the real world anymore, they are fully mixed and connected.

Pervasive games are often described as augmented reality or mixed reality games. An example by Mcgonigal (2003, p1) in *A Real Little Game: The Performance of Belief in Pervasive Play*:

“Pervasive play, I explained, consists of “mixed reality” games that use mobile, ubiquitous and embedded digital technologies to create virtual playing fields in everyday spaces. Immersive games, I continued, are a form of pervasive play distinguished by the added element of their (somewhat infamous) “This is not a game” rhetoric. They do everything in their power to erase game boundaries – physical, temporal and social — and to obscure the meta communications that might otherwise announce, ‘This is play’ “

The current trend and direction of game design of pervasive games blurs the definition. Only a small part of the different genres of pervasive games are defined. The eight genres described by Montola (2005): treasures hunts, assassination games, pervasive larp, alternate reality, smart street sports, public performances, urban adventure and augmented reality games, are just the start. These available pervasive game genres have become synonyms of pervasive games and this often results in misunderstandings when game designers are designing pervasive games. But looking at examples of these genres similarities are found. The games use electronics and software. They try to not use a digital screen and expand the gaming space. This gives a basic definition of pervasive games:

A pervasive game is a game that tries to pervade the real world, away from the digital screen including, but not exclusively, elements like social connections, space and time using electronics or software to process the data and dynamics of the game.

The definition of pervasive games is a start. But the position of pervasive games in relation with other games is not clear. It cannot be described as a genre of games, because a genre only talks about the kind of goal or gameplay/mechanics of that specific genre. A pervasive game consists of more elements; the use of technology and the context is different. It is a complex combination of different elements, that games have, adding different new variables in the real world. Björk (2007) in *Understanding Pervasive Games through Gameplay Design Patterns* describes pervasive as a complex property of games instead of

a genre of games. Pervasive games can even better be described as a concept that overlaps a big part of current games and crosses the border to use other elements outside the circle of current games. It is an over-arching concept or activity, like a mobile game, a location-based game, a ubiquitous game, virtual reality games, augmented reality games and adaptronic games (Lindley 2004). Simply put, it is a category of games. Just like board games, sports and videogames are categories of games.



Figure 1: Level of Pervasiveness existing pervasive game genres

Still the games differ in how pervasive they are. There are different levels of how pervasive the game is. The perfect pervasive game will not use anything digital and uses everything located around the player. It is important to highlight the difference here between digital and electronical. A digital space, like a map or an area on your phone pulls the player out of the real world into a limited digital world. When the game handles everything electronically it keeps the player in the real world and it does not break the illusion. The lowest level of a pervasive game is an alternate reality game, trying to simulate a complete world in a digital space. Augmented reality can be seen halfway the scale, because of the digital objects placed over the real world. The other six genres are near the top, but not at the highest level. These games all depend on a certain area, certain time or certain game masters to make the game work, breaking only with the game when the player steps out of this zone. Nieuwdorp (2007) shares this vision to look at pervasive games with different levels of pervasiveness. Then it can even be applied to other areas, like toys. The highest level of pervasiveness has not been reached, until now with e-wearables as a pervasive game platform.

One element that everybody agrees on, is that the game pervades the real world away from a digital screen. Some elements are socially, temporally or spatially, but the data of the player itself is forgotten in this description. The body and movement of the

player, the emotions of a player, biometrics like heart rate, skin resistance and body temperature, the lifestyle of a person while that person is not playing the game, are all variables usable in a pervasive game. This genre can be seen as a user focused pervasive game, focusing on the user, context of the user and properties of the user. With SPOOKY we just created one of the possibilities in this genre.

Application pervasive games

Designing a pervasive game has many extra elements over a video game, which need to be designed and defined by the game designer. A videogame designer looks at the platform, screen and controller. A pervasive game designer must look further than this and for this information the designer needs sensors and different kinds of technology. Current game design does not look often at where or when the player is playing or the use of the technology. It only looks at how often the player plays and the position of the player will always be behind a digital screen. To create a pervasive game it is important not to forget this during the game design process. *Pervasive Gaming: Testing Future Context Aware Applications* by Gentes (2011) warns for the dangers and the difficulty in developing pervasive games. Current game design does not look at these dangers. There are many variables available and you need them. When an action does not work, it breaks the illusion of the pervasive game. Using technology is the most interesting and dangerous method. Montola (2005) explains that the current pervasive game genres are technology sustained (without technology there is no game) or supported (technology is used, but not crucial). The latter is better, because the game will not break when the technology fails. But with technology more is possible and it does not rely on other people or different systems it does not control. With a pervasive technology these two are combined to create a self reliant and deep game with the advantages of both worlds. Seamful design (Chalmers & MacColl, 2003), also mentioned by Montola (2005, p167-168), gives technology a role in the game or when the perspective is changed, it places current technology fittingly in the real world. These problems are solved by using a pervasive platform, in this case e-wearables. And therefore it is a shame, that e-wearables is missing in the current literature.

Including clothing of the player as a platform also has an interesting side effect. The game will not be the only challenge for the player, but also the action itself. The experience of performing an action, like successfully punching with your hand, is already a reward for the player; the in-game reward is a big extra, increasing the positive reward of the player (Bianchi-Berhouze 2007). Body movement is only one of the variables; affective sensors can register biometrics from your body. These sensors make it possible for the game to be aware of the state of the player. The data from these sensors opens many new dynamics and mechanics to pervasive game design. "The possibilities for an engaging, contextually- aware game system are endless" (Magerkurth, 2005, p5). These challenges can be overcome with proper game design and rely more on the game designer. The player gets more freedom and the game must work in every scenario, because otherwise the pervasive nature of the game will be compromised. It is important that the player still has its freedom in the game, without losing the goal that the player must reach.

Position and identity of the player in pervasive games

The player is one of the most important elements in a game, especially when the player wears the game platform. Therefore it is important to check the position and identity of a player in a pervasive game. Identity is a very important aspect of life right now especially with social media and avatars for every game. But the difference between the identity of the player and an avatar must be highlighted. People are anonymous and can choose what they share with world creating their own identity. This is often encouraged by games with achievements, profile pictures and status updates. This is something different than an avatar fabricated by the game designers. The personal changes and choices by the player give the player an identity. Your identity in the real world is something different than in the game and will not have any influence on the game. Fabricating an identity on the Internet or in games is encouraged at every turn (Montola 2009). It is not possible for every platform to fully show your identity. The player itself is already there in the real world and is the perfect canvas for a platform/avatar extended with clothing to show everything.

In digital games the player often has an avatar, a game character, that the player controls. The relation between the player and avatar is necessary to create a feeling of improvement during the game. Without this relation the actions in the game will not have any influence on the player, the player will not care about what happens in the game. When the player fails or wins and there is a relation, it results in a powerful emotion. Every game aims to provoke an emotion, either good or bad. But still the player will not have a lot to say about the avatar and the avatar defines the borders of what is possible. The game character must fit into the game and the game designers defined the boundaries (Klevjer 2007), taking away a huge part of the identity of the player. Of course the actions of the player will determine the identity that the player tries to express. The player must prove its identity. Games with objectives, choices and obstacles give the player at every point a chance to express itself in that game. There must be different outcomes when the player does something, otherwise every player will express their identity in the same manner. By playing the way you want you are proving your identity (Ventrice 2012).

But looking at the different traits that distinguish players from each other, games only use a small portion of them. Profile pictures show the taste of the player about who the user wants to be and achievements show how good the player is or how much time the player has spend playing this game. But humor, interests, intelligence, personality or real physical possibilities are not used in the game. An avatar will never have the ability to show everything that the player is. The body and personality of the player are already there, but games are not using them at their full potential.

Using the body of the player in the game, makes the game more accessible and more logical. The game does not need to explain to a player how to jump and which button the player must press, the player can just jump and (in the game) the player jumps. There is no need of an avatar or a profile that explains who the player should be. The player is the one who is playing the game. A golf game does not require an avatar when the player physically swings the golf club (Klevjer 2007). When the player finishes or accomplishes something he must accept its own success and the improvement of its competence in these games. The motivation of a player determines the reward. When the player is forced to do

something its motivation is low, but when the motivations are intrinsically, the reward is much stronger and will help the player in the long run to succeed further in the game. The player will be playing the game much longer to make the person better by their own standards. This mechanic is hardly used in games because it must fit the story or context of the game, but when the avatar is the player the context is logical and the motivation can be created. The perception of your own performance is more important and stronger than the opinions of others (Blinka 2008). By using the appearance of the player in the game, you create a relation build from the own motivation of the player.

In pervasive games you are the avatar. The game world is your environment. By using this given fact the clothing of the player becomes a great platform for a game. The current pervasive games only use position or time of the player to create an identity. You have all the necessary elements to be a personalized avatar. The way you move, your appearance/clothing, your choices and how you act determine your identity and your identity in the game. The motivation behind these actions of the player fits in the context, because the player is the avatar. The player moves around in the real world, performing actions that fit with its lifestyle. The actions the player performs, determine what the player wants to do in the game. Clothing is part of the player. When we look at a person we do not see a naked person, we see someone in some type of clothing showing their identity. Clothing is part of a person, integration of electronics would make the platform part of the person. This makes clothing pervasive, it does not invade your personal space and without the player there will not be a game. Clothing with the extension of the user's body is theoretical the most complete game platform with all the necessary elements and much more to make a game truly pervasive and magical. To transform clothing in a platform we need a new technology and that is e-wearables.

E-wearables

E-wearables or e-textiles is a new kind of development in fashion that has been around for twenty years, but only the last few years has the technology become advanced enough to create affordable materials and machines to produce the necessary parts. The size of a powerful computer now literally fits in your pocket. E-wearables are clothing or wearable items combined with electronics. E-textiles are textiles with electrical circuits woven into the fabric or conductive fabrics/fibers that can be used for electrical circuits. The advantages of clothing with games is that the players are already accustomed to wearing clothing and it does not need an extra manual to explain how the user must use the clothing, only the specific interaction with clothing must be learned by the player as with every game that has specific rules. Gopalsamy et al (1999) explain in *The wearable motherboard: The first generation of adaptive and responsive textile structures* that in a modern society wearing clothes is part of everybody's whole life from the day they are born. We are already used to how to interact and use clothing. Changes or customization in clothing (trends and summer/winter clothing) is also something people are comfortable with and makes the entry level of this platform really low.

E-wearables have one major advantage above all the other devices like smart phones, gadgets or handhelds. You will not forget your clothing. Nowadays your clothing is only used for covering and protecting your body, but it can be used for different actions you normally need other devices for. This is the best example for a pervasive platform, it does not disturb the user and the user is used to carrying it. Marculescu (2004, p2) agrees with this in his paper *Electronic Textiles: A Platform for Pervasive Computing*:

"Clothing is probably the only element that is "always there" (and, thus, pervasive) and in complete harmony with the individual (at least in a civilized society)."

But we must still consider some elements in the design of e-wearables. You cannot just stick some sensors or electronics on a piece of clothing to make it a perfect fit for pervasive computing. First of all the placement of sensors is crucial and because the human body is so dynamic and the garments are not

fixed on a certain position of the human body sensors cannot rely on distance between each other. It is important to place the sensors relative to the wearers body and use the changes of the body in your design (Martin 2005). It is also important to notice the biggest challenge with e-wearables and that is the change of clothing during a whole year. The change of seasons and weather makes the combination of clothes and type of clothing different every month. This makes it harder to design a platform that can be worn every day; it is only possible when the weather is constant during the whole year. With more fabric there is more space to implement hardware and there are more things you can measure, because you have access to more body parts. An e-wearable platform would not only be a single piece of clothing but the player with his complete clothing collection. In the future we see every piece of clothing with electronics. So when the user needs data of a certain body part or a specific game, the user changes the clothing depending on this body part or game.

When fashion designers talk about e-wearables the concepts and clothing are almost always based around a single material or technology. A great example is *Intimacy 2.0*³ by Studio Roosegaarde, a dress that becomes transparent when aroused. A really interesting concept, but this dress depends on one new material used as a fabric. Including circuits in fabrics, sewing conductive threads into fabrics, is an area which many companies and designers are looking into. The application and the use of these techniques are not designed for a bigger picture. I try to look further than only the use of one material or technique. The application of these techniques and the combination of these techniques to improve the interaction substantially is where the possibilities are.

The current status

Measuring body movement is a great way of determining the actions of the wearer of the clothing whenever and wherever the designer wants. A great example is using piezoelectric strips woven into the fabric to measure the bending on that location. Martin (2005) researched this technique and has positive results in using piezoelectric materials for wearable electronic textiles. The arrival of affective e-wearables also shows the possibility of sensing more of the user than the surface of his body. With

built in heart-rate monitors (for example the *Nuubo*⁸ shirt), body thermostats and breathing (for example *E392*) or galvanic skin response to measure physical reaction of a users body when their emotion changes. These affective e-wearables always focus on one element and are now only used for limited medical and sport purposes. Other directions of the current e-wearables are more focused on a gadget level. Philips developed *Lumalive*⁵, a technology that places RGB leds in a flexible package that can be integrated in fabrics and furniture. This technology is now also available on a bigger scale for t-shirts with one color lights that highlight certain elements on the users shirt, possibly on the rhythm of the sounds from the surroundings(*Tqualizer*¹⁰). A *Multimedia Jacket*⁶ by Infineon and Rosner integrates an earphone or phone wires and buttons in a sleeve of jacket to make it possible to change the song on the user's mp3 player. Other developments which have become popular are small wearable electronic devices like wristbands, that measure your activity with a accelerometer (*Jawbone UP*⁴) or a small chip that can be placed in a shoe (*Nike+*⁷). These devices would be great for pervasive games, but they all depend on digital devices for more information and interaction, making it a big hassle to use these devices, forcing the user from a real image of the user to a digital representation of themselves.

One of the more interesting work in progress videos is *tShirtOs*¹¹ by CuteCircuit. At first sight it looks similar, but the differences makes tShirtOs not a game platform, but an extension of a smart phone. It is interesting to see what other designers do with the upswing of e-wearables. There are always developments. Through the similar use of a screen on the belly of the user it looks the same. The technology of the screen is what sells this concept, the RGB leds are ultra thin and the screen has a high resolution. But keep in mind this is still a concept video, the rest of the platform should actually be more interesting. TshirtOs misses input, the camera, microphone and accelerometer are the only sensors. The camera and microphone is superfluous, it is already present in your phone. Some phones also already have an accelerometer, but this is just not enough input for interesting interactive experiences. The possible applications shown in the video are also less interesting. Twitter and Facebook feeds just work better on your phone. The user can only show wanted or unwanted personal information to

strangers. Software (applications or games) are necessary to show the full potential of a platform. The feedback on this video is really positive and people are intrigued by e-wearables, but it also shows the need of proper design and prototyping of a (game) platform.

These developments show that people are slowly accepting technology in their clothing and that it really has advantages. But still there is not a full game platform that can be used for more than one thing and this gives the opportunity to discover new territory in a game platform and e-wearables, bringing everything together. This is the first step to e-wearables as a part of a platform and eventually clothing as a game platform.

Building Woven and SPOOKY

With the results provided by this research Woven was born, a two-parted project existing of a set of e-wearables and a game. The game showcases the possibilities for this platform and the platform shows what is possible with a pervasive game. The e-wearable platform exists of a sweater and a pair of jeans. For this project we created two sets for back-up purposes and to test the social and multiplayer possibilities.

The platform

Woven started in separate parts to test every detail of the platform and on every part of the platform has been iterated. This shows that every part of this platform has challenges. By testing and research we managed to solve many of these challenges.

The first part of this platform was the processing power of the platform and the game. There were many options and we wanted to have as much technical freedom as possible with the platform. Using only an Arduino would not work because these prototype boards are too limited. Developing for a smart phone is easy and a smart phone already has many handy parts integrated like Internet, GPS and multiple sensors. A smart phone would be a good compromise for now. Using only a smart phone would be a challenge to connect everything with the available ports. It would still need an extra board to translate all the data from the sensors. We looked at multiple wireless possibilities: Wi-Fi, infrared or Bluetooth. We found a library, called *Amarino*¹, for Android using Bluetooth and Arduino supports Bluetooth modules. Bluetooth has one big advantage over other wireless technologies, it has a buffer. This guarantees that all the data we send arrives at the target device, it is really fast and the maximum amount of data is more than sufficient for a game platform. The radiation of Bluetooth is no danger at all for the health of the user (Wildstrom 2006). A combination of three Arduino Lilypad prototype boards and a smart phone became our choice. We started with one, but these boards have many limitations including ports, processing power and memory. Every time we added something substantial, like a screen or sensor, it required an extra Arduino. The advantages of these boards are that they are specially made for wearable applications; they are waterproof and can be sown

onto the clothing. The community is big and there are many accessories for this platform. With this in mind it was the perfect match for this project to quickly find out if things work or do not work. The boards are connected with a system called I²C and this makes it possible for the Lilypads to communicate with each other. Again this system has speed and data limitations and the amount of data had to be kept small. The basic set up was ready to go in a couple of minutes. But bringing everything together and the programming took much longer. The programming of every part had many challenges. First of all the code on the three Arduinos is different. Every Arduino has its own code and sends and receives the necessary data. The input is send to the phone and the phone processes this data. The app on the phone uses this data to control the game, play audio, send images to the screen and control the shaker motors.

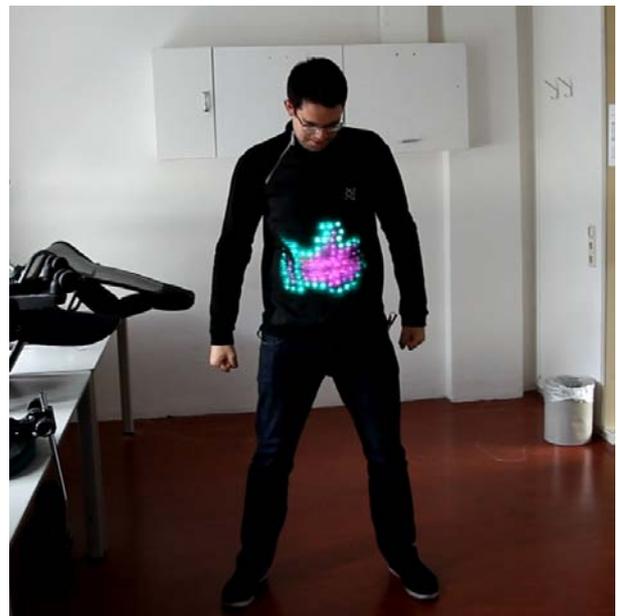


Figure 2: Complete platform in action.

Portable power was the next step. With all the hardware in the blueprint we needed a lot of power, but still portable and rechargeable. A LiPo battery is a small battery with enough power to provide everything for a couple of hours. But LiPo batteries are 7.2V or higher with a high Amp-hour. All the small hardware normally used is 5V and to get the right voltage we added a small 5V converter with enough amps to safely convert everything to 5V. New connectors were added to connect everything fast and safely and a special charger was used to charge every battery. The charge time is around two

hours and the platform can be used for 6 hours when used intensively, enough for the prototype. In the future charging the platform by moving would be a really green option, but this would be a project on its own.

Input

There are many sensors available. Through the experience of previous projects using electronics we already had a good understanding of the available parts and the possibilities of sensors and small electronics. It is important to only pick the necessary sensors to keep the platform small and simple. Looking at a game, movement is one of the first elements used. So measuring body movement is needed. To give the platform something affective we chose to use the player's heart rate, because this changes pretty quickly and can be used in a game. Other affective data like galvanic skin response is slow and people do not have control over it. Also the heart rate sensor is a small sensor, we did not want to put for example multiple sensors on some ones head to measure brain waves. The sensors must be pervasive and not interfere with the user.

Body movement can be measured in different ways and we chose the cheapest and most integrated sensor, a fabric bend sensor. A fabric bend sensor is an analog sensor which changes its resistance when it bends. This makes it possible to determine the angle of that body part. Other possibilities are gyro sensors or accelerometers, but these are expensive and require a lot of processing power, also the Arduino platform cannot handle easily more than one gyro or accelerometers. They are also pretty big and are located on a PCB, making it a non-flexible surface. With fabric bend sensors users do not even feel they are there. Above all they are waterproof, washable and foolproof. I created my own bend sensor with a combination of conductive wire, a volume conductive material and a type of neoprene. The fabric bend sensors required 15+ iterations to get the right sensor. I experimented with different lengths, amount of material and patterns. This resulted in a sensor that is stable when bend and still has enough range to use in a game platform. These sensors only have one down side, when pressed they also respond. The placing of the sensors needed to be on the outside of the clothing and on locations where they are not already pressed. Each shoulder has three sensors. One on the top,

front and back of the shoulder. This makes it possible to measure 360 degrees of movement of your shoulder. A sensor is placed on the elbow to determine the angle. The placing of these sensors were chosen by experimenting with the position and looking at the proper bending of a sensor.



Figure 3: Integration of bend sensors inside jeans

Measuring a heart rate is pretty hard, because there are only a couple of techniques and places on a body to do this. It is also important to notice the difference between just a heart rate and an Electrocardiogram. For an ECG you need multiple sensitive sensors. A chest belt was tested, but this did not work with the rest of the platform. It was also something that only worked best when you are working out and sweating. The compromise was a heart rate sensor called the Pulse Sensor¹⁰. This is a plug and play piece of hardware for the Arduino platform. It only works on capillary tissue (earlobe, top of your finger or lip) and we chose for the earlobe, because it gave us the best results. We wanted to keep the user's hands free to do other things. It is like wearing an earring.

With this input we have enough to create gameplay. But this is not all; we can still add more sensors to this platform. More importantly we have a smart phone, a powerful computer, with options like the Internet, Facebook and GPS. With this we can roughly recreate every pervasive game and more.

Output

Three different kinds of output are used in this platform to implement every possible feedback: audio, haptics and visuals. The other possible two senses smell and taste are currently impossible to check with small and affordable sensors.

The first one we implemented was audio. The first experiment was with normal headphones connected with the smart phone. But the problem with headphones is that the volume is really soft. This does not work when the player is walking around in loud spaces. So we bought a small active speaker set and implemented this into the collar of the sweater. This location was chosen in collaboration with the fashion designer, because of the more social and open effect. Our first idea was to implement the speakers in a hood of a hoodie, but this locks the user away from the rest of the world. Other people cannot hear what is going on and this location gives it a more magical effect when music is played. It sounds like the audio comes from around the user. The player gets most of the information through audio and speech.



Figure 4: Close-up inside platform (sweater): screen, electronics and sensors.

The second was a screen of 144 RGB leds with a resolution of 12 x 12 pixels. This screen is for other players and outsiders to give them in-game feedback. This can be anything from a health bar to show who is the bad guy. The screen is also used for the player to show when something is happening, but it is not meant as a screen to show the user information. Watching your belly does not work. The only moment when the player checks the screen is in the mirror, it is possible to customize the clothing with different logos, images or colors. We looked at

many different materials to give the screen a more diffuse effect to integrate the light into the clothing, instead of just sticking a screen on the fabric. The biggest problem with this screen is the large amount of cables and the vulnerability. When a cable breaks by intensive use, a part of the screen stops working. This should be fixed in the next iteration in the future by using a different technique connecting pixels (flexible PCBs for example) or connectors making the connection stronger. Also the way the player puts the clothes on determines how easily things break. Currently it is a long-sleeve, but in the future a shirt with a zipper at the side puts less stress on the connections.

The last are three shaker motors to add haptic feedback. The positions of the three shaker motors were chosen after some experimentation: near the left and right arm at the front and one near the neck on the back. Shaker motors only work with a context, without a context they are experienced as hits or shakes. When a designer wants to create feedback, like discomfort, lightning or direction, it needs sound or visuals to communicate this with the player.

Platform Results

The first time the player wears this complete platform I saw that the magic is definitely there. There are so many different elements present in this game platform compared to a normal game platform, that it makes Woven a completely new and refreshing experience. The audio from the collar works beautifully. Stereo is still present and the openness makes it much better than a headphone. It is even easier to still hear everything around you. The screen on the player's belly is totally integrated with the fabrics. Many small icons are possible and customization is easy. A bigger screen would give more possibilities with images and video, but this will make the platform much more expensive. The sensors give enough data to use in a game and there are still enough possibilities to implement more. The combination of all these elements work as a whole and they are enough to create a platform. But still the latest version of this platform has some disadvantages: The connections of all the wires between the RGB leds are weak. Because of the thin and flexible wires we chose to use in combination with the flexibility of the shirt it regularly happens that a connection breaks. Luckily this is often

repaired in a few minutes, but in the future the connection between the hardware needs to be done in a different way. The bend sensors should not change resistance when pressed, because this can interfere with the input. Also all the hardware on the shirt needs to be brought together in just one piece of hardware. This should make it much stronger and much faster. The only connections would be the sensors. This project shows the concept of e-wearables as a platform and not as a finished product. For a finished product it still needs a couple of hardware iterations. Still this was not the biggest test. Software (in this case a game) needs to show what the platform is capable of.

The Game

SPOOKY never started as a ghost game, but as a Tamagotchi-like game. But I really wanted to create a game with a theme, because this reflects more of the possibilities of the platform. A Tamagotchi or a fitness game that only adds statistics to your world does not fully show the possibilities. The game needs to communicate to others what is possible on this platform and show how much fun a game on this platform can be.

The game is a smartly designed game with a fitting theme and a logical type of an invisible enemy. Your lifestyle and behavior determine when certain actions happen. Every ghost can be found on different locations, time of the day and during daily activities. If you are sitting still, it is possible to get attacked by a ghost. If you are walking, a different kind of ghost will find you. And with this kind of behavior we can implement enemies fitting the moment. During a more sporty activity, the ghost will be sporty and vice versa. For the prototype I designed five different enemies for different situations and a tutorial level. We implemented two of these enemies to test the game with different people. The tutorial level explains the game and how everything works. In the tutorial one enemy ghost, Ghosty, is present. The player must defeat this enemy by dodging (stepping away on the right moment) and punching Ghosty to stun him to finally capture the ghost with a hugging motion. The second ghost is Sporty, an old sporting coach. The player must perform different exercises and control its heart beat to weaken this ghost and capture it. By using the captured ghosts players can make other players outfits haunted, making it a funny social

multiplayer element. Through experimentation we found out that people like to annoy other players.



Figure 5: Playtest: battle with ghost

The Game Results

The game, with around ten minutes of gameplay, was tested with ten different people in our target audience: teens and young adults. The results of these playtests surprised us how well the platform works. An audio based game works perfectly for a pervasive game, people start using their fantasy. But the audio design must be flawless to make it work with every user. The balance of volume of all the music, sound effects and dialogue must be right. Because when people miss something, they miss crucial information, which is not depicted somewhere else. The tests gave us a lot of feedback about what worked and did not work with the audio. The dialogue must be accent free and without any effects. The sound effects must be louder than the music. After the game explains something to the user, it is better to downscale the information the next time the player will play the game. People see this as progress and the game would be more challenging and pervasive when only sound effects and shakes are used to play the game. We faked the multiplayer aspect of the game, but people really liked the fact you must scare people whenever they want.

Players can continue their daily activities and play the game how they want. The feedback worked as designed, people notice the different shakes and

understand the use of the screen on their belly. We received interesting feedback about the shake motors. Players would love to see more shakers all around their body, because then it can be used for specific parts of your body. Shaker motors are cheap, small and require almost no processing power. The body gestures like punching and dodging work with the current set up. Players immediately ask for more gameplay. They want to fight more ghosts, perform more different kinds of attacks. This is interesting but also challenging, people nowadays expect a lot of gameplay from games.

The current game prototype needs some balancing and a little bit more gameplay to become a full game, but people see the potential of this platform and actually that is more important to us. The play testers immediately see the possibilities of our platform. A great reaction was when users start to think about the use of the clothing: "Everyone is wearing this platform in a disco and the movement of all the party people determine the music. When people are bored and not moving enough, the audio needs to change to pump up the audience". And this is just one of the possibilities. With this it becomes something more than a game platform, it is an engaging platform. Clothing as a platform. The user can do more than only play games, the platform is more personal and makes life much more interesting.

Conclusions

This supportive narrative made the first step to find the missing link in pervasive games to bring back the magic into current game design and started with the hypothesis: **an e-wearable platform is the most fully pervasive game platform**. This hypothesis produced many interesting results.

Current game definitions interfere with the definition of pervasive games. The new definition of a game gives a clear understanding of games and still leaves enough room to experiment with the borders of game design.

A game includes rules and a player who tries to reach a goal.

With this definition I could look closely to what defines pervasive.

A pervasive game is a game that tries to pervade the real world away, from the digital screen including, but not exclusively, elements like social connections, space and time using electronics or software to process the data and dynamics of the game.

It is a category of games. Looking at pervasive games the level of pervasiveness is different for every game. Alternate reality games are the weakest of the pervasive game genres. Augmented reality is half-way and the other six categories described by Montola (2005) are placed near the top. A new genre, called user focused pervasive games, is fully pervasive and looks at the player as a whole. A pervasive platform, in this case clothing through e-wearables, gives access to all this data. The player in a pervasive game is both the avatar and user. Everything the player does in its normal life is part of a pervasive game and determines its identity. The way the player is moving, communicating and its appearance, all determine the identity in a pervasive game. This changes the way pervasive games are placed in the world and adds to the information given by Montola (2005). To apply these lessons we must look at how to transform clothing into a game platform.

The application of clothing as a game platform has advantages: everything the player does, influences the player, when you exercise more, you get more fit and the active part of the game becomes easier. E-wearables is my answer on how to successfully transform clothing into a game platform. Clothing is part of the identity of the user, it is by all means pervasive and everyone learns from the day they are born how to use clothing. Above all, with clothing we, designers, have access to a lot of different data of the user. Body movement, affective data and daily routines can now be measured wherever the player is. Wearing and even not wearing (sleeping) the clothing gives useful information. With access to the internet and the body of the user, the sky is the limit. Woven is the first step in this direction. With Woven we created the first complete e-wearable game platform that measures data from the user in a pervasive way and uses this to play a game. The game SPOOKY shows the possibilities of this platform even in its limited form. The game can be played whenever, wherever and however the player wants it. It changes depending on the activity of the user. The social aspect of the game is very interesting and we are only scratching the surface of the social aspect of this platform. The results of Woven shows that e-wearables is one of the most interesting pervasive technologies usable as a game platform and it should be used more.

The two sets, consisting of sweater and a pair of jeans, work beautifully as prototypes, but we are far away of bringing this concept to the consumer. To fully use the possibilities of this platform everyone needs to wear this product and own multiple parts to make it possible to wear the platform during the whole year. The hardware needs multiple iterations to become reliable, cheap and flexible enough to be a truly pervasive game platform. With this project we took the first steps to hopefully see this concept in the future on the streets. This game platform can be used for more than only games, it is a whole new platform. It can change how people exercise, interact with others and objects in their surroundings. It weaves the possibilities of the user and their life to make the complete experience pervasive and fun.

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