

Designing the Two Wearable Robots; study of extension of human body

Minkyung Kim

Name: Minkyung Kim

KU-username: kqd550

Telephone: 52683940

Course: Robots and Artificial life

Language: English

Topic: Designing two wearable robots, called “Crow-like robot” and “Funeral-istic” and studying the relationship between wearable robot and the concept of extension of human body.

Abstract

This paper proposes the design of two wearable robots called, “Funeralistic robot”, and “Crow robot”, which I and Raghav Bashyal made. By combining principles of aesthetic visualization, mechanic movements coded by computer programing (Arduino), and wearable robot as a fashion, this paper aims to allude three big themes. The first theme is theoretical studies. The paper aims to discuss theoretical researches that are related to the robots. In this part, I will talk about cyborg theory and robot as extension of human body. The second theme is “Designing”. The paper will have reflections on designing process of the two robots our group made, showing from scratch sketches to the final robotic art works. It will describe designing path and implementation of mechanic movement. The last theme is about significance of the two robots, which aims to introduce the main purpose of making the robots. In this part, I will describe the interview that our group(Anna Willer, Minkyung Kim, Raghav Bashyal, Sara Ravn) had done with people wearing the two robots. By analyzing the interview, the paper aims compare people’s perception on the two robots and the two robots’ influence in communication.

Introduction

During the couple of decades, significant experiments and studies have been conducted over the wearable robotic field. As you can see from the production of Google glass and Smart watch, the demand to bring robots closer to our daily life has been increasing. The request from people who wish to have customized robots that they can carry or wear is engendering the special attention on wearable robots. This is the reason that it is very important to study about wearable robot not only from technological view point, but also from humanistic viewpoint. The definition of human body has become very vague since the development of technology has blurred its boarder. The perception of the human body has been keep extending due to the attachment of machines on human body. Thus, this paper aims to understand our extended perception of body by analyzing theoretical researches relevant to wearable robot and human body.

Part 1: Theoretical approach

Donna Haraway’s cyborg theory has been credited for the revolutionary insights and made significant contribution over many fields such as feminism, politic, history, art and literature, and so on. Her theory worked as a stimulant to many scholars and evoked great amount of researches that are related to it. She was also the most influential person to discuss this concept in terms of bringing

out oppositional thought over the traditional approach of an organism. In this paper, among broad range of fields that Haraway made influence, I will focus on the theory's assertion over the expanded conception of human body.

With her insight of analyzing the world and creating theoretical framework, Donna Haraway came up with the idea of cyborg theory. She defined a cyborg as following; "A cyborg is a cybernetic organism, a hybrid of machine and organism, a creature of social reality as well as a creature of fiction." (Haraway, 1985). She asserted that a cyborg is a mixture of machine and body. Her opinion of a cyborg body is not a body to protests against traditional western thoughts -such as racist, male-dominant capitalism, rationalists- but the body as a constructive body that has limitless potential of progress, by exchanging and reassembling with other objects. The post human body represents the indefinite organ that can diversify and make a progress by itself with the implementation of machine or technology on its body. The following sentence is Haraways' viewpoint of cyborg body. "Beyond the figure's capacity for critique, Haraway envisioned the feminist cyborg as a constructive force, capable of generating accounts of the world that encompass complex and contradictory positions." (Lynes, 2016) "Bodies, objects, and spaces were all subject to disassembly and reassembly, to new control strategies, and to new boundary conditions and interface procedures." (Lynes, 2016). As you can see from the two quotes from Lynes, Haraways' point in a cyborg is an organ that is open to make a connection with its surroundings, creating new boundary conditions.

Haraway asserted technology and science as an important factor in making connection between human body and complex surroundings. The following quote shows Haraway's vantage point in the technology and science. " Communications technologies and biotechnologies are the crucial tools re-crafting our bodies. These tools embody and enforce new social relations for women worldwide. Technologies and scientific discourses can be partially understood as formalizations, that is, as frozen moments, of the fluid social interactions constituting them, but they should also be viewed as instruments for enforcing meanings. The boundary is permeable between tool and myth, instrument and concept, historical systems of social relations and historical anatomies of possible bodies, including objects of knowledge." (Haraway, 1985) Haraway deemed the connection and implementation of technology as a positive factor that can give new positions for women. In the sentence, her assertion was from feminist viewpoint but we can apply the idea to all human. She continues her argument as follows, "Furthermore, communications sciences and modern biologies are constructed by a common move - the translation of the world into a problem of coding, a search for a common language in which all resistance to instrumental control disappears and all

heterogeneity can be submitted to disassembly, reassembly, investment, and exchange.”(Haraway, 1985). The key point here is that application of science causes the breakdown for instrumental controls and creates limitless potential of complex combination. Furthermore, she asserted that the technology is a factor that blurs the boundary between machine and organism. The following quote shows her intention. “Microelectronics mediates the translations of labor into robotics and word processing, sex into genetic engineering and reproductive technologies, and mind into artificial intelligence and decision procedures. ... Communications sciences and biology are constructions of natural-technical objects of knowledge in which the difference between machine and organism is thoroughly blurred; mind, body, and tool are on very intimate terms.”(Haraway, 1985). As a conclusion, the technology, which defies the authority, hegemony and all the instrumental controls, grants an infinite possibility to human body, creating a mixture of complex, diverse, undefined identity, called a cyborg as well as post human body.

With the technological development of human and robot interface, the connection between robots and human is evidently becoming intimate and profound. An interface is a hardware and software link that connects two dissimilar systems, e.g. robot and human. Two devices are said to be interfaced when their operations are linked informationally, mechanically or electronically. (Calderon,L. Ceres,R. Pons,J,L. 2008). As Haraway pointed out the connection between human and robot, the human robot interface is granting extensive potential and empowerment of human body, creating post human body. The post human refers to the destabilization and unsettling of boundaries between human and machine, nature and culture, and mind and body that digital and biotechnologies are seen to be engendering. (Blackman,2008)

Anne Marie-Mol also asserted that our body is not a singular object, but that it is subject to the surroundings and is “assembled and made up from the diverse relays, connections and relationships between artifacts, technologies, practices and matter which temporarily form it as a particular kind of object.” (Blackman, 2008).

These concepts of ‘cyborg theory’ and ‘multiplicity in human body’ give an interesting connection point to the study of wearable robots. The relationship between cyborg theory and wearable robot is inextricable, since ‘attaching technology to the human body ’ is the key definition for the two concepts. The definition of wearable robot is ; “Wearable robots are person-oriented robots. They can be defined as those worn by human operators, whether to supplement the function of a limb or to replace it completely. Wearable robots may operate alongside human limbs, as in the case of orthotic robots or exoskeletons, or they may substitute for missing limbs, for instance following an amputation.” (Calderon,L. Ceres,R. Pons,J,L. , 2008), additional definition for

wearable robot is ; “Gemperle et al. defines wearability as the interaction that exists between the body and the wearable.” (Liu, Vega, Maes, Paradiso, 2016).

In current status quo, wearable robot is getting substantial attention over the field of technology, robotics, fashion, and so on. The interest on wearable robots brought technology and many field together and created innovative collaborations. The following quote allures the progress on technology and its potential contributions on the development of fashion and wearable robots. “Advances in electronics, material science and biotechnology make it possible to embed technologies into fabrics [10,35] as well as use implantable devices and biosensors [50]. Smaller and more powerful electronics and smart tags are distributed around the body and powered by new forms of energy such as thinner batteries, solar panels, thermoelectrics, and human motion [6,8,23,52].” (Liu, Vega, Maes, Paradiso, 2016). Specially, people’s growing interest in new technology and demand to understand their own body is triggering research on customized robots. The following quote shows the current phenomenon of people putting effort in developing wearable robots. “Once the rarefied pastime of alpha geeks who meticulously logged data about their bodies in spreadsheets and built graphs to glean trends about their inner workings from the numbers, self-tracking has become practically mainstream in recent years. The market for wearable fitness devices is projected to generate \$1.8 billion this year. There are commercial headbands to monitor brain waves and wristbands to track movement. Many smartwatches log their wearers’ heart rates, and a number of smartphones count their owners’ footsteps.” (Wortham, 2015). The phenomenon of increasing public’s attention on attaching robot into their body is both creating significant influence on study of technology and also requiring study of human body in humanistic viewpoint.

As a conclusion, there has been significant changes over the definition of human body, according to the development of technology during last few decades. The boarder between human and non human has became vague, and thus, importance in understanding human body has been largely emphasized. Considering importance of understanding concept of body and wearable robot, the paper illustrated Donna Haraway’s cyborg theory and the current trend on wearable robots.

Part 2: Designing

The basic intention of making the two robots is to study about the concept of wearable robot in the current society and study about people’s conception on wearable robots. In this second part, the paper describes designing process of the two robots, “A Crow-like hat” and “Funeral-istic hat”. The paper will analyze the process by showing from very first prototype sketches to the final

robotic art work. It will consists of 4 parts, explaining motivations and designing approach, showing prototype sketches, describing electronic implementations, and at last, alluring some limitations we encountered during making the robots.

2.1 Motivations and design approach

There were three inspirations when brainstorming about the design of the robots. First inspiration was “hat” , the second inspiration was “nature”, and the last inspiration was “funeral”. When I first thought of making a wearable robot, the first concept was to make a wearable robot for the fashion, rather than for the medical enhancement, thus, deciding to make a robot accessory. The reasons for choosing hat were that it is easy to wear and take off, is big enough to make visible movements, and has enough space to hold mechanical devices.

After choosing to make a hat, I made few sketches as a prototype. While thinking about the possible arrange of movement that we can make, considering the servos that we had, we decided to have a part that opens and closes. This idea of open-close-movement brought us closer to get an inspiration from nature such as flower and bird because flower moves its leaves when it blooms and a bird opens and closes its wings when it fly. Considering that the design of a bird possibly gives the feeling of autonomy, we decided to choose a bird as our final design motivation. By attaching consecutive layers of feathers to the hat, we could succeed in making the hat that reminds of a bird. The last motivation for the hats were “funeral”. Timing is a very important factor in our life. There are some moments that you want to hide from others and also moments that you want to be a part of your surrounding. The purpose of the hats is to help people choose the timing by themselves, giving a private space when they want to hide from others, and also opening their space when they are ready to be present in front of others. To make it short, the main goal of making the two hats as funeral hat was the aim of giving private space to people and also helping them get over their situation when they need help to get along with their sadness.

2.2 Prototyping sketches and final work

The **figure 1** shows the first sketch of the hats. This is a scratch version of prototyping the hat. The **figure 2** shows the second sketch of the hat. It shows the change from the first sketch after considering the size of the servos we had and the possible movement the servos can make.

The **figure 3** shows the last sketch for the two hats, which became the final robotic art work.



Figure 1: first prototypes

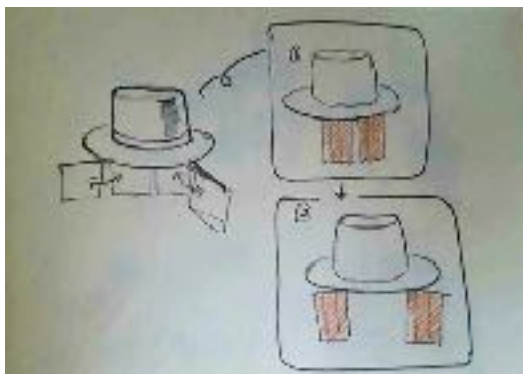


Figure 2: Second prototype



Figure 3: Final prototype

By developing from the sketches, I and Raghav made final works of the hats. The **figure 4** and **figure 5** are the final outlook of the “Funeral-istic hat” and “Crow-like hat” and the link below is the video that shows the movement of the robots. Hat video link: [<https://youtu.be/V83Chrk1Ps4>]



Figure 4: Funeral-istic hat



Figure 5: Crow-like hat

2.3 Form and Function; electronic implementation

As mentioned in above, our robot hats have a function of open-close movement of a veil. (**Figure 3** shows how it moves.) Those hats also have infrared sensor attached to them, making a reaction when the two infrared sensor detect the other one's signal. To make long sentence short, we made the two hats open its veil (wings), when each infrared sensors receive the other one's infrared signal.

But there are several factors that need to be considered to attach electronic devices. First question is where to attach the electronic devices, such as ardurino board, batteries, and servos. We had two options, whether to place the devices on the top of the hat or to place it around arm by making a strap that can hold the devices. The following sentence is from Rocon et al, telling that the best the part to applicate mechanical devices would be where human can possibly bear the loads of a robot. “pHRI[human–robot physical interaction] causes the transmission of loads to the human musculoskeletal system through soft tissues. This raises the question of the intensity, the mode and the areas on the human body where it is possible to apply loads.” (Rocon, E. et al. 2008) Furthermore, he suggests that we need to consider “ human tolerance of pressure ”. The following sentence states the guideline of human tolerance of pressure. “Regarding safety, the usual guideline is to avoid pressure above the ischemic level, i.e., the level at which the capillary vessels are unable to conduct blood, thus compromising the tissue. This level has been estimated at 30 mmHg (Landis, 1930).” (Rocon, E. et al. 2008). After considering the spot where human can easily bear the loads and pressure from robots , we decided to put the devices on a head because the electronic devices are light enough to be placed on a top of a head and the fabric of hats will de-concentrate the loads of devices . Also another reason for choosing to place them on the hat, instead of arm, was that it will give full range movement to people. According to Rocon et al., “pHRI[human–robot physical interaction] represents the most critical form of interaction between humans and machines. Any motion of the robot that occurs in contact with a human, and any force exerted by the robot, has to be soft and compliant and must never exceed the force exerted by the human to protect himself/ herself. In addressing this topic, the design of the robot structure, sensors, actuators and control architecture need to be considered all together, from the specific viewpoint of interaction with humans.” (Rocon, E. et al, 2008) it is important to consider from viewpoint of interaction with human and robot. There was some possibility that the sharpness of plastic and hardness of the ardurino board might cause a injury to human. Thus, considering that placing the devices on the arm by extending wires would also limit people's movement , we decided to place it on a top of the hat.

2.4 limitations

There were some limitations we encountered. The first limitation was on the mechanical part on infrared sensors. The radiation sensors also detect infrared that is emitted by the Sun. So the hat cannot be worn in a bright place, such as outside of building on a sunny day. Also the distance that radiation sensors can detect each other was not long enough. The two person wearing the hats have to be in approximately 20 cm close to each other to make robot reactions. Furthermore, the infrared sensor has to be right in front of each other to be connected. To solve these problems, we placed the infrared sensors at the very edge of the hats, lessening the distance between the infrared sensors of both hats as closest as we can.

The second limitation was vulnerability. The two robots require sensible handling, due to the unstable connection of wires. If people handle them without carefulness, the connected part between electronic board and the servos is so fragile that it was easily detachable. So we had to check the connection almost every time to make sure it is connected properly. To solve the problem we attached electronic tape on all the connection parts.

Part 3: Significance of the two robots.

The last part aims to introduce the main purpose of making the robots, by describing the three key characteristics of the robots. There are three important facts on “Crow-look-like-hat” and “Funeralistic hat”. Firstly, we designed two different robots that looks different. One reminds of a crow, and the other resembles just a normal funeral hat. By comparing the people’s interview who experienced the two different kinds of robots, this paper aims to study the concepts of “Robot as a Thing v.s. Robot as a Creature”. The second key characteristic of the robots is that the two robots have infrared sensors, which require people’s interaction with their partner. The goal of putting infrared sensor is to study whether the two robots can help people’s communication or not. The last key feature of the robots is that it is made with the purpose of fashion accessory. It does not put emphasis on strengthening human body but aims to be regarded as an expression of oneself. As a summery, there are three main research purposes of making the robots; “Thing v.s. Creature”, “Communication”, and “Fashion”. And this paper used the method of interviewing people who participated in the experiments with the two robots to answer those concepts.

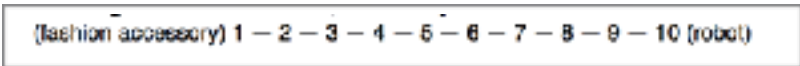
3.1 Describing the Interview

The interview was held in 26th of May, 2016 at IT University design lab. There were 8 participants, paired in 2 people, thus 4 groups. Only one of the groups consists of experts, who had background knowledge in IT or who are major in technology. Two groups were consists of friends who knew each other and the other two groups were paired randomly, who had never met each other before. Each pair of people had to answer questions before and after the experiments. For the the pre-question , people could answer it just by looking at the outlook of the two robots, without having any interaction .The interview consists of 4 questions on the both pre and after the experiment.

3.2 Result of the interview

Theoretically, there has been a lot of debate over the aliveness and un-aliveness of robots. The debate over what is the boarder between human perception on robot (as a creature v.s as a just a machine) has gained lot of interests. Our group conducted this experiment to find answer to the debate. Our hypothesis was that people might conceive the robot which resembles more like an animal as an autonomous robot and the robot which resembles a normal hat as un-alive robot. Thus, by making one hat more look like a creature, we intended people to imagine as more autonomous robot, and by making the other one look more like a normal hat, we intended people to conceive it as a un-alive robot.

The first focal point of the interview was to study people's perception on robots; how would they perceive the two robots; what point does it make people perceive a robot as a autonomous creature or just a garment that moves. To analyze people's conception, we asked them how would they perceive the two robots after having interaction with them. The following was the question on interview sheet. “ **After experiencing the hats in action, how do you now conceive of them?**”. The participants could choose the range from 1 to 10, 1 representing hat as a “fashion accessory” and 10 representing the hat as a robot . **The figure 4** shows the range from 1 to 10.



(fashion accessory) 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10 (robot)

Figure 4

For the “Funeral-istic hat”, which resembles more like a normal hat than the other one, two people gave range of “5”, one person gave a range of “6”, and one person gave a range of “7”. The participant who gave a most lowest range, “5” ,explained the reason as follows, “While I don’t perceive it as a robot as such, I do look at it as an interactive adding to my body. Like an extra sense. ” The participant who gave the most highest range, a range of “7”, described the reason as

follows, “It did not function very well, and the veil did not move very much. On the other hand the electricity summed all the time, reminding me that it was more than just a hat.” Furthermore, for the “crow-like hat”, each person gave a range from “5” to “9”, and three people gave a range of “10”. The person who gave a range of “5” explained the reason as follows “Now that I saw the robots in action, I’m not so sure about them being fashion accessories. However, they are still hats, so I can’t say that they are entire robots. ” On the other hand, one of the participants who gave a range of “10” described the reason as follows “The sounds were a bit bird like. The hat shows an autonomy/ autonomous will/ behavior. Its movement gives the impressions of something bodily, arms/wings.” According to the interview, the “Funeral-istic hat” gained the average range of 5.75 and “Crow-like hat” gained the average range of 8.13. The difference between the average score shows that the outlook of robot affect people’s perception on aliveness of the robots. People perceive more like a robot when it resembles a living creature than just an object. Furthermore, from the interview answer, we can also conclude that the fact that it showing autonomous behavior (making random sounds, movements and so on) made participant perceive the hat as an alive robot.

The second characteristic of the robots is the infrared sensors. The two robots react by sensing the infrared signals emitted by the other hats, so the two people who are wearing the robots communicate by becoming closer to each other. The main goal of attaching infrared sensor on the hat is to conduct a research about robots’ influence on human’s communication.

To study about whether the robots can create positive atmosphere for human to have a better communication on a specific situation, our group made the following interview question, **Please describe the role of the hats in the social interaction with your testing partner. Did they create a barrier between you or did they bring you together? Can you describe what kind of social space/atmosphere was created during the interaction?** , The following quotes are from the participants’ answers from the interview question. “Really good eye contact, and a lot of laughter. We talked about wearing the hats at a party, walking around amongst all the guests, who were also wearing robot hats. We also talked about the hats influence on each other. ”(participant 1) , “They brought us together. The hats played a certain role in linking us to each other, and in breaking down the psychological boundaries, and create a common space for intimacy. A toy: Again through the play ground that the hats created that kind of space. You were acting more experimenting. Intuitively.”(participant 2) “We became so much closer with each other!! Very intense! It functioned well that we were forced to stay in so close physical distance to each other for such a long time. It created an intense, intimate and different atmosphere than normal social interaction. ”(participant 3) . As you can see from the reactions, overall participants felt joyfulness and excitement during experiments even though they encountered unknown partner who never met before. A development of a pleasant and personal wearable robot communication

device is an important step toward a new era of wearable computing in the future.(Kostov, Ozawa, Matsuura 2004) The result of the interview tells you that the goal of the robot , to help people get along with others has been achieved.

The last key feature of the robots is that it is made with the purpose of fashion accessory. It does not put emphasis on strengthening human body but aims to be regarded as a expression of one's identity. To analyze participant's reaction from the view point of fashion, we asked the following question: **Could you imagine buying/wearing the hat? Who would the wearer of the hats be?** . As a result, the 4 out of 8 participant answered they cannot imagine themselves buying the hats since the hats do not seem like normal hat that you can wear normally. The reason for the people who said they would not buy it was that it looks too special , reminding it as an outfit for “pop-star”, or “music video” . On the other hand, the other 4 people gave positive answer to the question. They said they would wear it for the special occasion such as theme party or recommend it to someone who like to stand out in his/her appearance on celebration day. Wearing fashionable accessories reveal personal aspects, such as one's mood or social status, to the outside world. (Hoinkis , Moere. 2006). The result of the interview tells that the robot hats looks too outstanding to wear casually in normal days. However the positive answers shows that it can be worn as an expression of oneself at special occasion.

Conclusion

Human body is not a solitary organ. We are far from unitary subjects but are multiple and defined by our capacity to be affected and affect others. As Anne Marie-Mol asserted, we are not molar and singular body but instead the body as an open system that connects with others, human and non-human. The body is extended to include how it becomes connected up to techniques, artifacts and practices which produce particular kinds of objects and entities. (Blackman, 2008) This is what Haraway believed of the concept of body in 21st century human. The cyborg body encompasses its surrounding objects and create new way of positioning human being in our society. As Blackman point out in his book, “ The emergence of the body as an important focus and object of study within the humanities has begun the important work of reformulating many concepts that have been integral to contemporary theories.” (Blackman, 2008) many concept over body has been developed.

By making our own wearable robots, we aims to understand the significance of wearable robot and implement the extension of body in a real life. One of the participants of the interview said, “ The sense, and experience of getting used to the prosthetic hat made you conceive it as

something that is a part of your body, but at the same time radical set apart from it. It influences our bodily style.” Accomplishing interview with participants helped understanding people’s conception on wearable robots.

The first part of the paper analyzed about the theoretical approach of relationship between multiplicity of human body and wearable robot. The second and the last part of the paper are based on the empirical research our group had done. The second section described the designing process of the two hats, “Crow-like-hat” and “Funeral-istic-hat”. By analyzing the process of design, the paper aims to describe mechanical implementation, design motivation, and the limitations we encountered while making it. Furthermore, the last section of the paper described interviews that was held with the participant who experienced the two hats. By analyzing the interview, the paper represented three experiment purposes of making the robots.

Future work.

It can be easily seen that the wearable robot has gained and also gain much more interest in the future. But at the same time many researches and experiments should be done. The experience during making the robots helped us to understand and think about the future studies on wearable robot. Technical development of making the sensors and actuators specialized for wearable robots would be need in the future. The servos and actuator that have been developed have many limitations for using it directly on human skin. More specialized and delicate actuators will make the human robot interface smooth and functional. Furthermore, as technology shrinks in size and becomes more powerful and more ubiquitous, these problems together with the social and cultural issues surrounding them become more important. Having most of the needed technologies available, the fundamental issue now is how to make a system that can combine all the communication and information retrieval functionality while still being attractive and unobtrusive to the user (Kostov. Ozawa. Matsuura. 2004). Going beyond technological problems, It is important to keep eye on safety rules specially with the empowerment of technology. The mass production of wearable robot by company creates social problems such as safety accidents. Thus, the study of law that can protect consumers from safety accident during using wearable robot is required. Government act such as putting limit on the electronic voltage or the laws that require certain amount of experiments before producing it to the market would be need in the future.

References

Blackman, Lisa. *The Key Concepts ; The Body*, 2008, Berg

Calderon, L. Ceres, R. Pons, J. L. "Introduction to wearable robotics", in *Wearable Robots: Biomechatronic Exoskeletons*, Edited by Jos'e L. Pons, 2008, John Wiley & Sons, Ltd.

Haraway, Donna. "A manifesto for cyborgs: Science, technology, and socialist feminism in the 1980s", in *The Postmodern Turn; New Perspectives on Social Theory*, Edited by Steven Seidman, pp. 82-116 , DOI: <http://dx.doi.org/10.1017/CBO9780511570940>

Hoinkis, Monika .Moere, Andrew V. "A Wearable Folding Display for Self-Expression", OZCHI 2006, November 20-24, 2006, Sydney, Australia

Kostov, Vlaho. Ozawa, Jun. Matsuura, Satoshi . "Wearable Accessory Robot for Context Aware Apprise of Personal Information", Proceedings of the 2004 IEEE International Workshop on Robot and Human Interactive Communication, Kurashiki, Okayama Japan September 20-22, 2004

Liu, Vega, Maes, Paradiso, "Wearability Factors for Skin Interfaces" , AH 2016, February 25–27, 2016, Geneva, Switzerland, DOI: <http://dx.doi.org/10.1145/2875194.2875248>

Lynes, Krista. "Cyborgs and Virtual Bodies", *The Oxford Handbook of Feminist Theory*, Edited by Lisa Disch and Mary Hawkesworth, Feb, 2016, DOI: 10.1093/oxfordhb/9780199328581.013.7

Rocon, E. et al. "Human–robot physical interaction", in *Wearable Robots: Biomechatronic Exoskeletons* , Edited by Jos'e L. P ons, 2008, John Wiley & Sons, Ltd

Wortham, Jenna. "You, Only Better" , The New York Times Magazine, NOV. 10, 2015

<https://youtu.be/V83ChrK1Ps4> : The video of the hats , 1min 8sec.