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Sartorial Robotics

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Abstract

Sartorial Robotics is a method of merging fashion theory and robotics through the design and development of robotic systems. These systems facilitate interaction and play as well as mimic the materiality, aesthetics, and construction techniques of textiles, apparel and fashion. This will enhance the social aspects of human-robotic interaction and assist in how we situate robotics in our lives and cultures.

Building upon a history of robot aesthetics and a formulaic approach to analyze and understand fashion, a series of design principles for *Sartorial Robotics* were established and applied in the research and development of robotic systems that utilize the human-centric system of clothing to create robotics for human-robot social interaction. The *Group Identity Surface* is a soft-architecture system utilizing thermochromic textiles and computer vision to facilitate human-machine teammate building. *Zipperbot*, a robotic continuous closure for fabric edge joining, was developed to explore autonomous control of a sartorial gesture and performed as a wearable robot which was evaluated through social interactions.

Clothing is a uniquely human pursuit and is nearly universal in its adoption and use. It plays a prominent role in our individual cultures transmitting a mixture of social signals and meanings through the semiotics of fashion. It is through this performance of assemblage of fabric surfaces we reconfigure ourselves and our identities. Merging robotics and fashion within the practice of *Sartorial Robotics* will enhance the explorations of identities for both humans and robots.

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Chapter 1

Introduction

Why in the pursuit of robotics, or more specifically social robotics, should we make an attempt to integrate fashion theory? This question requires a multifaceted explanation. At first glance the two individual disciplines seem miles apart. However, as we progress through technological changes that shift computation into electronic-textiles and fiber-electronic devices, and the field of robotics transitions from industrial manufacturing and laboratory research into the consumer market and thus into our homes and our personal and social lives, the research space for robotics must expand and these two disparate fields of fashion and robotics are presented an opportunity to merge.

QB Avatar is a telepresence robot which is meant to give people a virtual presence anywhere they physically cannot be. As their promotional material advertises, it *"enables you to be where your heart needs to be, but you can't."* It is therefore intended as a social robot, a robot that interacts and communicates with people and is thus expected to demonstrate social behaviors. At a wedding where an elderly relative was unable to physically attend, the *QB Avatar* robot was employed (Glazer, 2012). However, this real-life, highly social application presented an issue. The attendee would be able to virtually attend but would not able to take part fully in the pre-wedding costume party. The robot could not dress up. Additionally, they would not be able to partake in the formal dress customary of the wedding day. In sociology, it is understood that our corporeal bodies perform a critical role in our social interactions. Graham Scambler, health theorist and medical sociologist, in discussing the body during debilitating illness and health-related stigmas states:

> *to be acknowledged as competent social performers we have to be able to give the impression of some degree of control, use and presentation of our bodies.*
>
> -*Graham Scambler* (Scambler, 2004).

Our bodies fail us not only in illness, but consider the social ramifications when we uncontrollably blush or inadvertently stutter. This issue of bodily control actually extends beyond our bodies to our surfaces, specifically our clothing; wardrobe malfunctions and other fashion faux pas by which we are socially judged, like a wrinkled business suit or stained dress, will have significant social consequences, *i.e.* lack of competent social performance.

The solution for the virtual attendee was a photographic cardboard cutout attached to the robot[1]. The lack of customizable or even adaptable surfaces on the *QB Avatar* robot spurred some very creative ingenuity which demonstrated the need and desire to play with surface for social expression and interaction **Figure 1-1**.

Figure 1-1. *QB Avatar telepresence robot modified with photographic cutout to represent separate outfits of the virtual attendee of a wedding.*

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[1] Interestingly enough, attendees wrote messages and signed the cutout of the virtual attendee creating a quite meaningful physical memento of the occasion also providing a means of interaction with the surface.

Despite all the technological advances of the telepresence robot it lacked the basic mechanics of clothing and fashion which we effortlessly choreograph every day when we dress.

Clothing performs a prominent role in our social presentation and transmits a variety of social signals and meanings through the semiotics of fashion in a form of sartorial signaling. Roland Barthes suggests fashion is play, with one of the most profound of human questions *"Who am I?"* (Barthes, 1990). It is through this performance of assemblage of fabric surfaces, play, we reconfigure ourselves and our identities. My hypothesis is that a robotic surface, which facilitates interaction and play as well as mimics the materiality, aesthetics, and construction techniques of existing textiles and apparel, will enhance the social aspects of human-robotic interaction and assist in how we situate robotics in our lives and cultures.

Surfaces and Playing with Identity

The morphology of clothing is in many ways a modular manipulation of surfaces and it is through this manipulation that we are able to explore and express identity of self, culture and social structures. However, even without clothing, human beings have expressed their identities through their very own skin. Researchers and roboticists in their pursuits of robotic skin generally mean coverings or surfaces designed to sense or detect mechanical pressure or a simple flexible covering. However, skin as we know it in living organisms and of course human skin is a more complex multilayered living organ. Functionally, it acts as a layer of protection from the environment and helps maintain a constant body temperature with the production of sweat. Our skin is responsible for the metabolism of vitamin D when exposed to ultraviolet medium wave light. It has tiny hair follicles, nerve fibers, arteries, and veins, and through capillary dilation can indicate an emotional response, we blush. The melanocytes stratum in the epidermis layer of our skin provides pigment and color, something that can have significant socio-cultural impact. Culturally our skin is pierced, cut and scarred, tattooed and wrinkled from our passage through time (Ahmed, 2001). Through an analysis of human skin beyond visual and sensory experiences we can observe that our skin is complex; our skin is alive and is not simply a static surface; it is a system, a system engaged with meaning. From the perspective of the materiality of the human body, our skin is not a simple covering or surface boundary; it is a functioning part of our whole and an interface to our identities.

Our clothing is an extension of our skin, both in its functionality and as an expression of identity. However it offers us quite a bit more in its flexibility and modularity. We can don and doff it, change or alter it, or discard it entirely with relative ease particularly in comparison to our skin. We can also employ it to experiment with other objects.

Figure 1-2. *A gathering of dressed and costumed Sony AIBO robots appearing at Robosquare in Fukuoka City, Japan.*

The act of playing with surfaces to explore identity and social/cultural relationships is something we begin to do from childhood, and it becomes an integral means of understanding our social and cultural values. The 19th century study of dolls in the *Journal of Genetic Psychology* consisted of anecdotal responses and ethnographic accounts of various cultures that practice some form of dollification of objects. The authors found that clothing and accessories were a large part of this play. In a period before the widespread mass production of toys and dolls, the reported accounts documented children dollifying a variety of objects that bared little if any resemblance to humans; among these were pillows tied with string around the middle, clothespins, flowers, bottles, sticks and chickens (Granville Stanley Hall, 1897). Clothing, as an additional surface, can help transform the identities of these mundane objects and animate them into characters and playmates. The clothing of course can do the same for robots.

As part of our human experience, we play with surfaces both on ourselves and on objects as means to explore and understand the identity of social and cultural constructs. Robots of course are not immune from this human instinct and so we find quite a bit of anecdotal evidence of people, including roboticists, dressing their robots, **Figure 1-2**. The addition of robotic attributes to surfaces, through electronic-textiles and fabrics, presents an innovative opportunity to both integrate surfaces into robotics further and expand on the influence of clothing and surface on identity, not just to assist in socially and culturally situating robotics but for situating ourselves as well.

The Presentation of Self in Everyday Life is a seminal sociology book by Erving Goffman in which he formulated dramaturgical sociology. By dramaturgical, it is meant that our social interactions have a lot in common with theatrical performances in that we, as social-actors, attempt to influence how others perceive us presenting our identity by controlling our settings, manners and appearance (Goffman, 1959). It suggests we might perform differently for different audiences, *i.e.* friends, family or work colleagues, and as such we'd desire to control our appearance by, for example, altering our style by controlling our surfaces, that is our clothes. It is from this perspective we consider fashion and clothing as costuming for identity. Soft-architecture robotic surfaces or as an extension, robotic clothing, offers us an augmented method for control of surface. Precisely how this control will socially perform or be perceived is yet to be fully explored.

Shifting Methodologies for Robotics

Among all the progress and developments in the field of robotics, there are two primary changes taking place that will help drive the fusion of fashion theory and robotics. The first change, as we saw in the anecdote about the *QB Avatar* telepresence robot, is that robots are entering the public space and joining our everyday social lives. The second change comes from technological developments, the core technology elements of robotics, *i.e.* sensing, actuation and computation, which are moving into soft and flexible electronic-textiles and fiber-electronic devices. Both of these changes will of course alter the aesthetic of robotics and overall require a shift or rethinking of the design methodologies currently employed in robotics.

The field of robotics has expanded beyond the domains of computer science and mechanical and electrical engineering. As robotics have transitioned from industrial manufacturing and laboratory research projects into the consumer market and thus into our homes and personal lives, the fields of design and psychology have gained more prominence in robotics, particularly if the robot is to be considered as a peer or companion. The robot design space is more complex for these social robots. Carl DiSalvo stated in observations on consumer robotics:

Because of the newness of robotics and the public's unfamiliarity with robots, the visual form of the robot often takes precedence in shaping our expectations of the robot and how we interact with the product.

-Carl DiSalvo (DiSalvo C. , 2009)

DiSalvo emphasizes the point that robots are not yet a daily experience for most people and so the lack of experience does not give the public a basis for forming any impressions. Instead the visual appearance of the robot and its aesthetics will be the driving force for initial public impressions which of course will shape our interactions. Initial impressions during social interactions make widespread use of nonverbal communications, and cues can signal much information. Clothing/fashion researchers have found that sartorial cues can play a fundamental role during initial impressions (Hamid, 1969) (Pine, Fletcher, & Howlett, 2011). Clothing is a principle means by which we identify ourselves in the public space. It contributes to our identities by signaling, for example, our occupation, regional identities, gender, religion and social status to others via our chosen style of dress. As an illustration of this, clothing masculinity was found to significantly influence the perception of management characteristics of female applicants during a job interview. Those wearing masculine clothing were perceived as more forceful and aggressive (Forsythe, 1988). For robots, even the general physical appearance of an artificial agent can influence our perception of the information it supplies us as being fact or opinion (Forlizzi, Zimmerman, Mancuso, & Kwak, 2007). In this study, an artificial agent with a machine-like aesthetic resulted in a factual impression of the provided information. Conversely, the artificial agent with a more human-like aesthetic was considered to be offering an opinion. Even representations of gender and ethnicity in computer/machine agents have been shown to influence interactions (Lee, 2008) (Pratt, Hauser, Ugray, & Patterson, July, 2007) (Nass & Brave, 2005). It is foreseeable to utilize sartorial treatments or surfaces to assist in the design of social robots to help define their social roles among us and shape our interactions with them. Therefore by clothing we mean not just its morphology, we mean an entire *system of clothing* which incorporates the mechanics as well as the social semiotics of clothing and the performance aspects of style and fashion.

The question raised by current technological developments is what will the consequences of a textile and fiber morphology for electronics mean for the field of robotics? Electronic-textiles and fiber-electronics impart electronic sensing, actuation and computation into the fibers and textiles themselves. This will result in textile-based soft-architecture robotics which will change the face of robotic design. Traditionally, robots are generally constructed from a variety of rigid materials and surfaces often resulting in machine-like aesthetics and materiality. The emerging field of electronic-textiles and fiber-electronics represents a shift in morphology from hard and rigid mechatronic components towards a soft-architecture and more specifically, the possibility of a flexible planar surface morphology[2]. This morphology shift will open robotics to other disciplines which traditionally work with textiles and fabrics, like apparel designers and textile designers as well as textile manufacturing processes. The aesthetic of robotics will need to be reconsidered given these unique parameters. In order to try to understand this morphology transition we need to identify and build metaphors from more familiar classifications. Clothing is perhaps the most recognizable form of soft-architecture textile object and is nearly universal in its adoption and use. Therefore we must investigate sartorial materials, sartorial processes and semiotics of clothing design to inform electronic-textile applications in robotics. Understanding the mechanics of clothing and its functional aspect will be critical in working with robotic surfaces and soft-architecture robotics, but for social robotics there is a principal concern of social expectations associated with these designs, the semiotics of fashion.

The research presented in this thesis intends to address both these methodological shifts by developing a design framework that incorporates technological developments of electronic-textiles, apparel, textile design, robotics and fashion theory. This work intends to establish clothing and fashion as an untapped resource for robotics.

Sartorial Robotics

So how do we define *Sartorial Robotics*? *Sartorial Robotics* describes a practice of developing robotic surfaces which are situated between a functional technological skin that offers enhanced capabilities and the semiotics of clothing, *i.e.* fashion, which helps facilitate social play with identity. Both are combined merging methodologies of apparel and textile design with methodologies of robotics. This dissertation presents several demonstration projects built to support this hypothesis in fusing fashion theory and robotics. This research is meant to explore soft-architecture robotics in terms of human-robot social interaction. Precisely how this control will socially perform or be perceived is yet to be fully explored.

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[2] It is important to note that the current field of soft-architecture robotics is more focused on exploiting the nature of the flexible materials for functional performance in actuation rather than its impact on social robotics.

Thesis Structure

This thesis, *Sartorial Robotics,* is more a collection of research and demonstration projects focused on merging fashion theory and robotics than any one single project or technology. It begins with anecdotal evidence of clothing and robotics mixing, highlighting people's desire to use clothing in order to play with identity, both their own and those of robots. The definition of *Sartorial Robotics* is the development of robotic systems that facilitate interaction and play as well as mimic the materiality, aesthetics and construction techniques of textiles, apparel and fashion. This will enhance the social aspects of human-robotic interaction and assist in how we situate robotics in our lives and cultures. The beginning of Chapter 2 starts with examining the aesthetics of robotics by tracing the historical aesthetics of robots beginning with Karel Čapek's 1921 theatrical work R.U.R. and on through modern times, with a particular focus on surface treatments. The second part of Chapter 2 presents related work in electronic-textiles and soft-architecture robotics which exhibit a shift in morphology from rigid aesthetics to soft materials. These new soft and flexible materials can be more easily integrated in robotic systems. The motivation is a combination of utilizing robotic surfaces as a means to *play with identity*. Chapter 3, Wearables for Robots, presents prior work of the author which introduces the crossover of robotics into soft materials. This crossover is put into practice by demonstrating the process of transitioning a wearable computing project utilizing electronic-textiles into a robot application, which is a sensor suit for social touch gesture fitted to a humanoid robot. This project acted as the impetus for *Sartorial Robotics*. In Chapter 4, Evaluation of Sartorial Cues, a study of sartorial cues exhibited by robots is developed and conducted. Sartorial cues are established as an aesthetic treatment which can profoundly influence our perceptions of robots. In Chapter 5, Design Framework, through a design analysis and study of fashion theory, a list of design principles for *Sartorial Robotics* is developed. Chapter 6, Group Identity Surface, is a research project specifically developed using the *Sartorial Robotics* design principles. It is a robotic surface which detects sartorial cues, exhibits its own sartorial cues and utilizes fashion theory based behaviors to facilitate group identity. Chapter 7 explains the development of *Zipperbot*, a robot designed for concealing and revealing clothing layers. The chapter then explores, through the analysis of a conversational study, autonomous sartorial gestures when the robot interacts with people. Chapter 8 builds on the work of this thesis to present directions toward future research into the area of *Sartorial Robotics*. The dissertation concludes with a summary of contributions within a variety of interdisciplinary fields that establish *Sartorial Robotics* as a fertile area for future research.

Chapter 2

Background and Related Work

Toward Development of Surface Aesthetics in Robotics

In this section we will explore the robot aesthetic as an embodiment of technology taking on the human form, and how this association influences our concept of the robot. Beginning with the early 20th century, we'll examine the initial incarnations of robots from theater and consumer culture, and attempt to trace those beginnings to current trends in the design and aesthetics of robotics. The aesthetics of the humanoid robot body is a re-imaging of the human body and so will be prone to its many body, social, political and cultural contexts. As part of these aesthetic ideas we will examine the treatment of surfaces, more specifically robotic skin, and the resulting metaphor and consequences.

Čapek's Robots: Soft-Architecture Biological Machines

In Karel Čapek's 1921 play R.U.R., Rossum's Universal Robots, where the term *robot* first originated, the robots are in fact constructed of biological-like materials and components rather than machine-like materials. He describes a factory mixing dough for bodies and skin as well as spinning mills where nerve fibers and veins are made, apparently in the same manner as one would spin cotton fiber into a yarn or thread. Dialogue from the play's two central characters Helena and Domin illustrates this:

> ***Helena:*** *What mixers?*

> ***Domin:*** *For mixing the dough. Each one of them can mix the material for a thousand robots at a time. Then there are the vats of liver and brain and so on. The bone factory. Then I'll show you the spinning mill.*
>
> ***Helena:*** *What spinning-mill?*
>
> ***Domin:*** *Where we make the nerve fibers and the veins. And the intestine mill, where kilometers of tubing run through at a time. Then there is the assembly room where all these things are out together, it's just like making a car really. Each worker contributes just his own part of the production which automatically goes on to the next worker, then to the third and on and on. It's all fascinating to watch. After that they go to the drying room and into storage where the newly made robots work.*

Čapek's robots are conceptualized in soft materials, and were to look and be dressed as humans. They were not machines constructed of metal with nuts and bolts, which was not Čapek's vision. They were to be indistinguishable from humans, mimicking our own materiality of flesh and clothing with their actions and emotionless expressions representing their automated production origins. Čapek was deliberate in this aesthetic design of his robots in order to cast them as a metaphor for the social and political turbulence associated with mass production and automation which in this cautionary tale he wanted to represent as dehumanizing. Marx echoes this representation in *Das Kapital* as he commented:

> *To work at a machine, the workman should be taught from childhood, in order that he may learn to adapt his own movements to the uniform and unceasing motion of an automaton.*
>
> - *Das Kapital: a critique of political economy by Karl Marx*

Costuming had a prominent role in this interpretation. Čapek had his brother, Joseph Čapek, an accomplished cubist painter, design costumes for these robot characters which were in the style of overalls or work wear representing both a lack of individual style and referencing the worker apparel that was common with factory workers at the time. As the play's popularity increased and other productions opened across Europe and the United States, the aesthetic design of the robot characters became more mechanical and machine-like. In the 1923 London production at the St. Martin's Theater, a costume for the robot characters was fabricated from a shimmering metallic-like fabric that in form and silhouette visually referenced rigid medieval armor. The aesthetic concept of the robot began to shift from a mechanomorphic human to an anthropomorphic machine all through the evolution of surface, **Figure 2-1**.

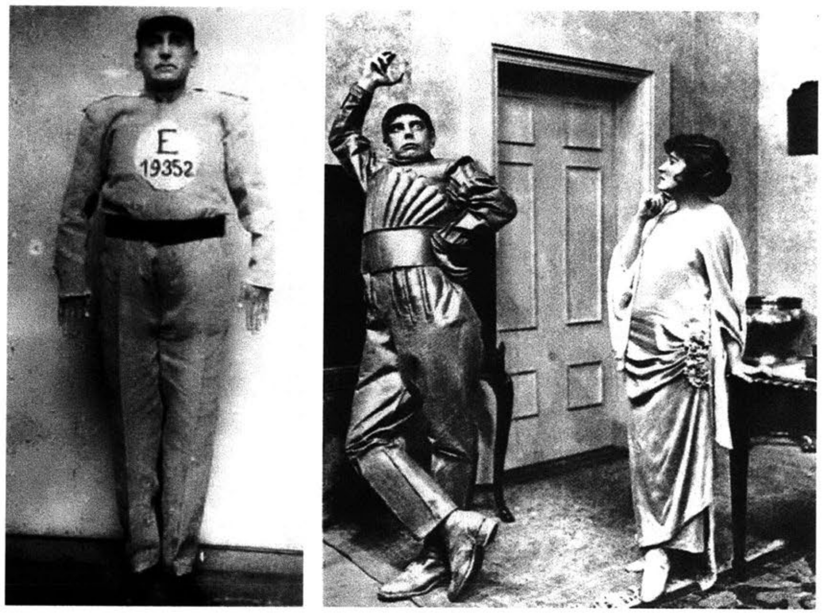

Figure 2-1. *Karel Čapek's play R.U.R. original Prague National Theatre production robot costume 1921 (left) metallic armor-like costume of the later London production 1923 (right).*

Čapek's Robots: Identity of Mass Production

There is other literature in science fiction and folklore that portrays humanoid creations constructed by man, such as Mary Shelly's *Frankenstein* published in 1818 or the golem from Jewish folklore. What differentiates Čapek's robots from these other biological, manmade creations are the instruments and means of production employed in their creation. Čapek's focal point was on the utilization of automation machinery and mass production which allowed his robots to be produced in the thousands. This is also a key distinction between the concept of robots and the earlier automatons that were handcrafted and produced individually as one of a kind designs or only limited numbers. Of course this is a fictional and conceptual representation of a robot and the technological development of robots followed a more machine or mechanical based materials approach, but their production method shared the same assembly line methodology.

Čapek's robots are defined by labor. The means of production utilized in their creation was derived from automated machinery and from factory production methods and the robots intended function was to perform labor. The word robot itself is derived from the Czech word *robota* which means literally *work*. Labor is intrinsically connected to one's sense of self; it can define one's identity. In *Estranged Labour*, Marx postulates that it is a fundamental need for man to be connected to the objects he is producing (Marx & Engels, 2011). Workers estranged from their labor, be it broadly because of economics, or more specifically, a shift in the means and instruments of production with the introduction of automated machinery or even robotics can have a disrupted sense of self. Our work and our jobs play a significant role in defining our identities so much so that a job loss can induce serious physical and psychological health effects. We witnessed this at the beginning of the 19th Century with the introduction of mechanized looms and the subsequent backlash from British textile workers during the Luddite resistance movement. These workers viewed the machinery as a threat to identity and self. The concept of the robot did not just remain a theatrical metaphor for the division of labor and the working class. Around the very same time as Čapek's play began headlining around the world, American consumer product company Westinghouse introduced their own vision for robots in society.

Westinghouse and the Domesticated Consumer Robot

In 1926 with the invention of the Televox, a "supervisory control system" developed by Roy James Wensley, Westinghouse began robot research. The Televox allowed for remote operation of just about any electrical device via the telephone system. The device had many practical applications. For example, it allowed a single streetcar dispatcher to open circuit breakers at distant substations thus replacing the many human operators that used to perform these jobs (The Harvard Crimson, 1928). Removing manual labor and replacing human jobs is a common theme within automation. However what differentiated the Televox device was its broad range of potential applications to any electrical device that needed operation. It was perceived to have near universal abilities. This was also one of the crucial characteristics of Čapek's robots. They were not replacements for one specific job function as most instruments of mechanized labor historically were such as the power loom, which was only meant to reproduce the weaving of textiles. Čapek's robots and now Westinghouse Electric Corporation's Televox were capable of any job humans could perform. Though not entirely true, the Televox was perceived in this manner, and Westinghouse, facilitated by the press, promoted this concept.

At the time, the physical form of the Televox was merely a box filled with relays and wires, a standard aesthetic for electronic devices. It did not particularly resemble the human form, but the perception of the device to perform universal labor was enough to cast the Televox as a human equivalent. A 1928 *Popular Mechanics* article titled "ELECTRICAL 'MAN' OBEYS VOICE ON PHONE" suggests the idea of the Televox as a "man" and within the same article refers to the Televox as an "electrical robot" (Popular Mechanics, 1928). An article about the Televox written by the editor of the Science and Engineering division of the *New York Times* was accompanied by a cartoon illustration depicting the Televox with arms and legs and seemingly capable of autonomy **Figure 2-2**.

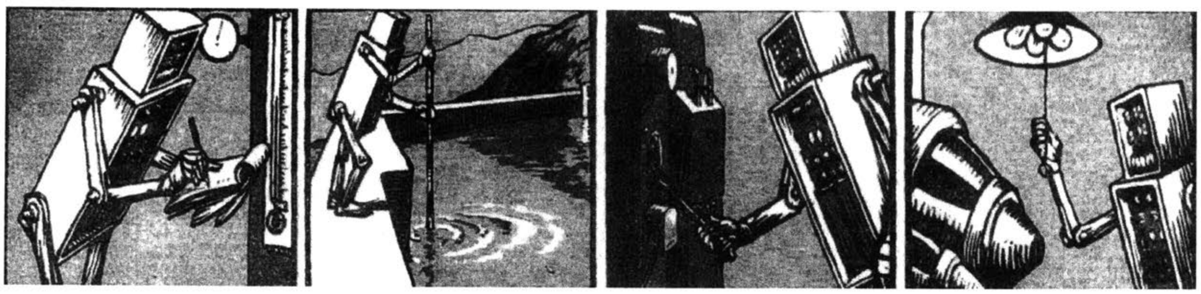

Figure 2-2*. Cartoon of the Televox from New York Times. October 23, 1927.*

It was this illustration that Roy James Wensley, the inventor of the Televox, cited as inspiration to give the Televox a humanoid form (Schaut, 2007). He used only painted wallboard with a head, a torso where the Televox electronics were installed, two arms and two legs. Just one arm was articulated and could be controlled via the Televox system. This crude creation lacked specific details of the human aesthetic, but represented the basic body forms and parts. Though primitive, it was an electromechanical humanoid robot. This mechanical man received worldwide publicity and press, exciting the public and priming them with the promise of consumer robots. There were previous mechanical men created by individual inventors, some of which proved to be fakes, but Westinghouse was a well-established company in the emergent electronic appliance industry and manufactured a large array of consumer appliances. The Westinghouse Electric Corporation went on to develop a series of robots which grounded the idea of humanoid robots in both the public's imagination and the imagination of consumer product companies.

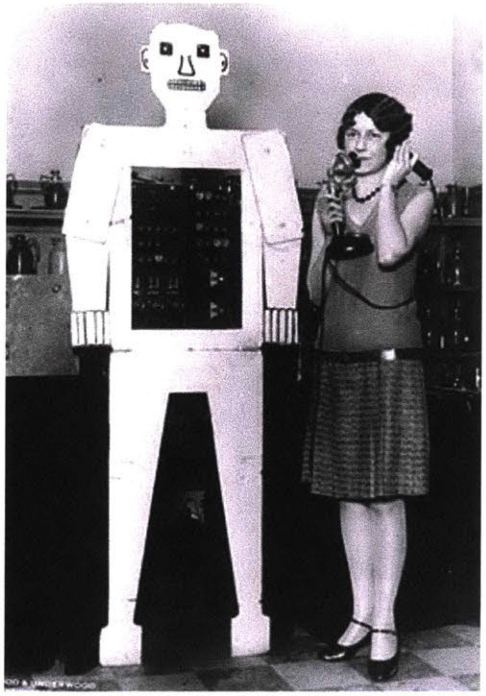

Figure 2-3. *Westinghouse's Mr. Televox (left) and Miss Katrina Van Televox (right).*

Westinghouse went so far as to promote the Katrina van Televox, the mechanical wonder maiden, with an associated price tag of $22,000 USD in 1930. She is advertised as able to talk, answer the phone, operate a vacuum cleaner and make coffee, **Figure 2-3**. Note Miss Katrina Van Televox is also dressed in traditional maid apparel signaling her intended role and situating the robot in the social class structure as part of the servant class. While this was clearly for publicity purposes, Westinghouse was positioning themselves as an innovative leader in the emerging consumer electronic appliance market, and so positioned the robot as a potential consumer item intended for servant tasks.

Figure 2-4. *Mr. Televox (left) pictured with the 1939 World's Fair updated metallic aesthetic named Elektro (right).*

The robot perhaps largely responsible for the iconic boxy metallic aesthetic we so often associate with the concept of a robot is Elektro, **Figure 2-4**. Elektro was a humanoid robot built by the Westinghouse Electric Corporation and exhibited at the 1939 New York World's fair and thus received worldwide exposure. Elektro had an internal metal skeletal structure with electric motors turning gears and chains that moved his arms and allowed him to even walk in a crude manner. He could follow voice commands and could speak about 700 words. Photoelectric cells in his eyes enabled him to recognize two colors, red and green and he could even smoke a cigarette. Elektro was again mainly for promotional and publicity appearances, but he and his Westinghouse robotic predecessors could be considered the basis for the pursuit of humanoid consumer robotics.

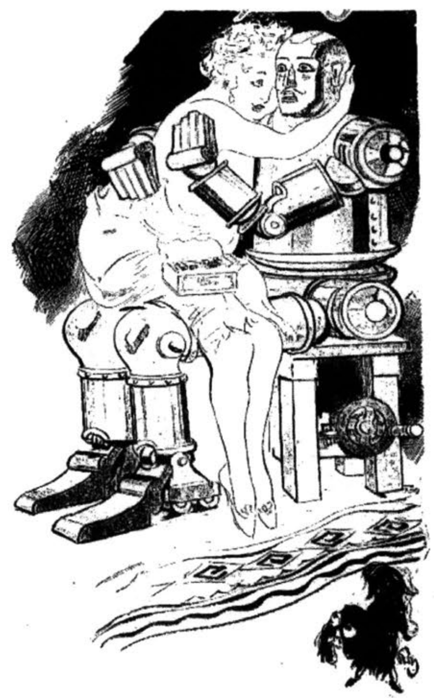

***Figure 2-5**. Two contrasting visions of the robot during its 20th century conception robot taking workers jobs (left) and robot for lovelorn women (right).*

As the concept of the robot and the humanoid robot began to take hold in the public consciousness, the robot or rather the concept of the robot, began an ascent of the social ladder, moving from the servant class, to the working class. The implementation of automated machinery had now taken hold within the manufacturing industry, and the concept of the robot representing this transformation was presented as something to fear in terms of job security as exemplified by a 1930 Socialist Party of Chicago flyer[3]. The robot was being positioned not only to enter the workplace but also the home, moving yet again from the worker class to robot-human relationships. **Figure 2-5** depicts a robot intended for the companionship of lonely women. Introducing the robot into our personal and social lives represented a new dimension that challenges our sense of self and identity (Harvey, 1994).

[3] Eventually in 1961 the first industrial robot, Unimate, fulfilled this prediction and replaced workers when it was put to work on a General Motors assembly line in New Jersey. Unimate however was not designed with a humanoid form but rather a basic metal box-like aesthetic.

These early depictions of robots, long before they realistically could ever have been technically implemented, originated a robotic identity crisis whose repercussions are still experienced today. Without any actual robots working among the public, this negative popular depiction of robots took root. For roboticists it is of crucial importance to explore the robot's identity and its position in society.

Robots, Skin and Artificial Slaves

In 1930 Westinghouse added a controversial robot based on the Televox technology to their series of promotional consumer robots. Westinghouse produced an African-American robot they named *Rastus*, which at the time was a well-known derogatory term for African-Americans[4]. In the United States the institution of slavery was still fresh in the public consciousness and the Jim Crow laws, a series of state laws between 1876 and 1965, codified segregation and discrimination based on race into law. Significant technical improvements were introduced to the aesthetic of *Rastus* with the collaborative development of a black rubber skin with the Goodyear Tire and Rubber Company, **Figure 2-6**. The skin, along with human clothing costumed with overalls and farmer apparel, presented a more realistic aesthetic, offering a familiar surface for the mechanical man who would alleviate us from the toil and drudgery of household work. Casting the robot now as an African-American and at the same time the African-American as a machine ensured the association of skin color to one's sociopolitical status. Westinghouse produced, quite literally, an artificial slave. When given the opportunity through design to remove the moral and ethical dilemmas that accompany human servitude, they chose to re-enslave African-Americans with the techno-political skin. What Westinghouse discovered was that playing with the surfaces of the robot, while influential, was socially and culturally challenging.

[4] *Rastus* was a derogatory term used for African-American men in the United States starting around 1880 and was associated with black male characters in minstrel shows depicting stereotypical lazy, happy-go-lucky former slaves.

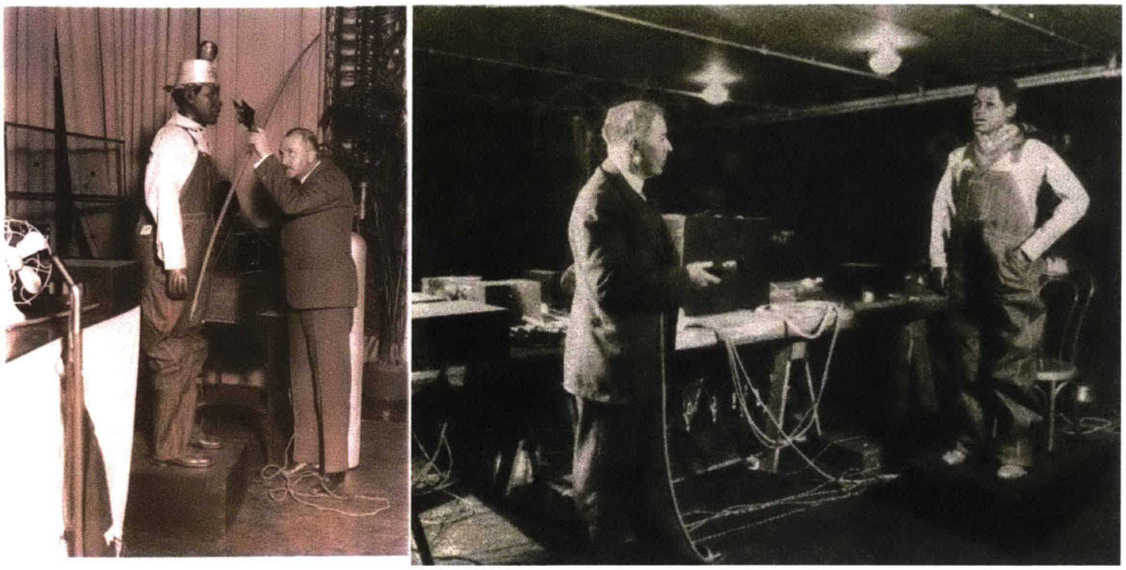

Figure 2-6. *Rastus robot built in 1930 as a collaboration between Westinghouse and Goodyear which specifically developed the rubber skin.*

To continue the development of the robotic enslavement, Langdon Winner suggests that man strives for absolute mastery over science and technology putting forward a master-slave metaphor which describes man's relationship with technology as a one-way control, that of the master over the slave. In the master-slave relationship the power imbalance most often focuses our attention on the identity issues of the slave. However, there exits identity issues for the master as well. In Winner's metaphor man becomes dependent on technological artifacts; in essence the master becomes dependent on the slave (Winner, 1978) and this becomes a master-slave paradox. It is not just that the master is now dependent on the slave for his livelihood, but the slave takes the labor from the master by *laboring in the material world*, and thus through his labor 'transforming the natural world'. We have seen that labor is intrinsically connected to one's sense of self; it can define one's identity. As previously discussed in *Estranged Labour*, Marx postulates that it is a fundamental need for man to be connected to the objects he is producing. This would even include the master-slave relationship that can disrupt one's sense of self. When the robot takes on human form the boundary between human and machine becomes less clear and reinforces the master-slave metaphor.

This master-slave metaphor introduces an underlying distrust between ourselves and robots, specifically humanoid robots. Jean Baudrillard recognized the robot as a slave, and that the master-slave relationship, because of history, is intertwined with the concept of eventual revolt or rebellion because throughout history we witness revolts by human slaves (Bauldrillard, 1968). First seen in Čapek's play the theme of robotic revolt is played out time and again throughout science fiction and popular culture, *e.g. The Terminator* franchise, where the robots rise up and over throw man. Even in this modern interpretation, *Terminator*, the role of surface identity is crucial in perpetuating this theme, as the cyborg arrives unclothed and nude; its first action is to murder a human in order to steal their clothing. However by the end of the film the cyborg is stripped of not only clothing but of its biological skin and remains a robotic skeleton assassin. In fact throughout the film the protagonist reveals that the entire purpose of the cyborg's biological flesh and skin was to deceive humans (Cameron, 1984). While DiSalvo stated that because of the public's unfamiliarity with robots, our expectations of robots will be shaped by their visual form there also exists the public's preconceived notions of robotics formed from popular culture films and television.

In tracing the development of surface aesthetics in robotics, we primarily dealt with initial static surfaces that were socially and culturally charged with meaning, *i.e.* industrial laborer apparel and African-American skin color. While this is challenging enough to grapple with in terms of social robotic design, the emerging technologies of electronic-textiles and fiber-electronic devices will add yet another dimension to the design space. These new surfaces will have capabilities of their own and be capable of exhibiting autonomous or semi-autonomous behaviors in addition to the social and cultural meanings. The boundaries of the surface and the object underneath, either human or robot, will be further blurred.

Electronic-textiles and Fibers that Sense, Actuate and Compute

In this section we will explore a progression from technological research and developments in electronic-textiles and fiber-electronics to projects in the emerging field of soft-architecture robotics and finally diverse combinations of clothing and robotics from both the technology sector and the world of fashion. These examples should provide an understanding of how these varied themes could merge together into sartorial robotics.

The fundamental qualities of robotics, sensing, actuation and computation can all be seen moving from traditional rigid components towards softer fiber and textile morphologies. Electrically conductive textiles and fibers have been available for some time. Conductive fibers have been woven into textiles for decorative purposes such as metallic silk organza, made of silk thread wrapped in a copper foil, which eventually was utilized in electronic applications and wearable electronics (Post, 1997). Current research into carbon nanotube (CNT) dyed threads results in conductive fibers and thread that retain their relative flexibility and twist consistency which would allow them to be integrated in the apparel making process. Some CNT dyed conductive threads have achieved consistent electrical conductivity variation when stretched so that they have actually been utilized as strain gauges (Panhuis, 2007). Other CNT dyeing techniques have shown considerable promise towards creating textile based energy storage devices utilizing carbon nanotubes and lithium cobalt oxide (LiCoO2) nanoparticles. The absorption properties of the textile fibers help the nanoparticle dye saturate the material and increase its efficiency. The change in morphology would be well suited for wearable applications (Hu, 2010). The textile based energy storage devices are reported to remain flexible and stretchable like fabric and are washable as well.

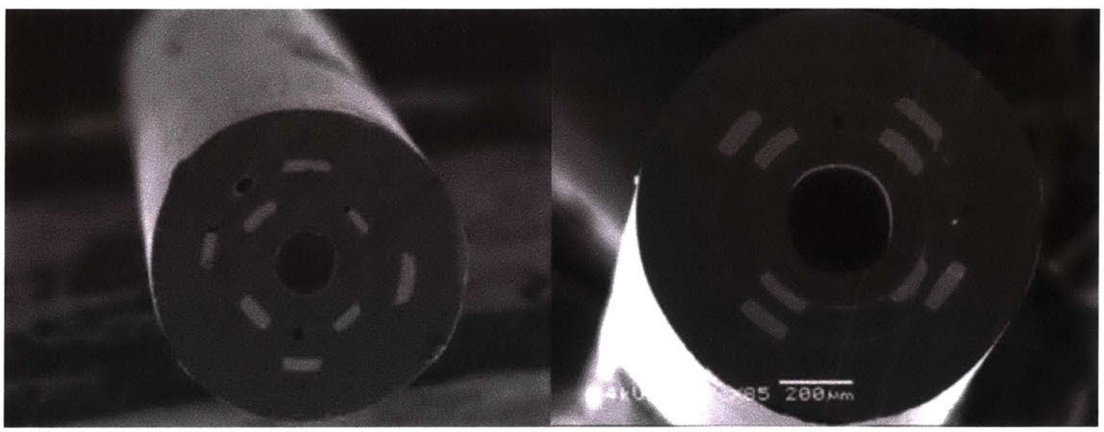

Figure 2-7. *Single fiber-electronic devices approximately 500 - 900 µm in diameter capable of optical, acoustical and thermal excitation and incorporating semiconductor junctions (Abouraddy et al. 2007).*

Another promising area for exploration involves manufacturing techniques within the photonics industry that could be expanded to include fiber-electronic production. The tapered preform-based fiber-drawing method, similar to the process used in the manufacturing of silica glass fiber optics for the telecommunications industry, shows considerable promise for producing fiber-electronic devices. Conductors, semiconductors and insulators, the basic components of electronics and optoelectronics, have been fabricated together in single fiber-electronic devices which range from 500 - 900 µm in diameter (Abouraddy, 2007) (Sorin, 2007). The technique has the potential to change the morphology of electronic components from the dominant chip/planar geometry construction to fiber-like geometries capable of textile construction **Figure 2-7**. "*This is the first time that anybody has demonstrated that a* *single plane of fibers, or 'fabric,' can collect images just like a camera but without a lens,*" said Professor Yoel Fink the project's principle researcher (Thomson, 2009). Optical, thermal and acoustic sensing devices have been developed with this method as well as semiconducting junctions like p-n junctions, the foundation for logic operations.

In addition to sensors, fiber based actuators are being developed as well from materials like electroactive polymers (EAP) and shape memory alloys (SMA). However, these materials often lack a significant amount of mechanical force so their applications have been limited. Recent research from the Nanotech Institute at the University of Texas has produced carbon nanotubes that have been spun into yarns that exhibit artificial muscle properties that can exert approximately 100 times the force per area than that of natural muscle (Keim, 2009). These examples show traditional rigid electronic components progressing towards fiber and textile morphologies that could be either literally the material of clothing *i.e.* fibers, yarns and textiles, or mimic the materiality of clothing in flexibility and conformability making them suitable for the design of soft-architecture robotics.

Soft-architecture Robotics

In this section we will look at examples of soft-architecture robotics, some of which utilize the materials discussed previously and others which make use of traditional textiles. The *Origami Robot* by Harvard University and MIT researchers, Robert Wood and Daniela Rus, is a programmable sheet material that can autonomously fold itself into a variety of shapes. The planar robotic surface is divided into hinged triangular sections that can bend using shape memory alloy (SMA) actuators which can be activated with heat, **Figure 2-8**. The SMA actuators are located along predetermined crease patterns to transform from a flat sheet into a three-dimensional form (Hawkes, 2010). The origami robot is an example of a robot exhibiting a flexible planar surface morphology which as a surface can be played with and morphed.

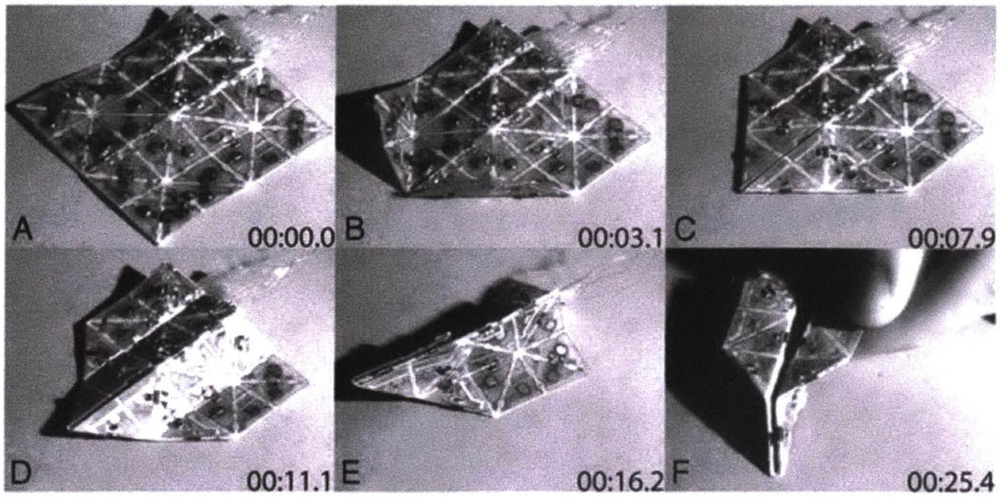

Figure 2-8. *Harvard University and MIT researchers created a self-folding origami surface.*

Other soft-architecture robotic research focuses on elastomer materials and pneumatics for novel actuation techniques. For example, iRobot's *Chembot* is designed to be a soft morphing robot and uses a process called jamming in order to move, **Figure 2-9**. Jamming requires a flexible silicone skin with compartments of loosely packed granular material which under a vacuum forces the granular material together and makes it more rigid.

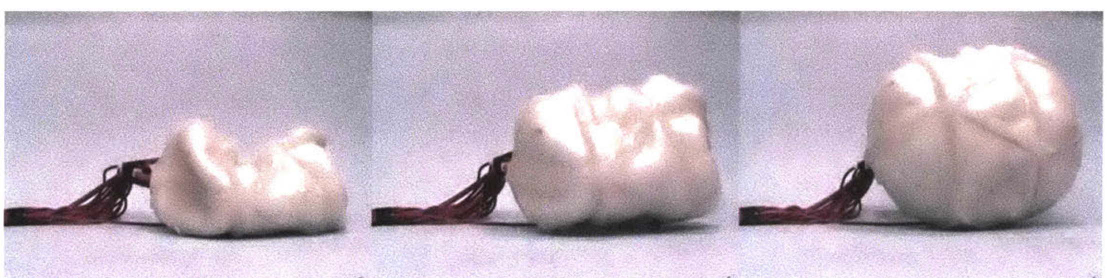

Figure 2-9. *iRobot's Chembot elastomeric materials and pneumatics for locomotion.*

Releasing the vacuum returns it to a flexible state. Electroactive polymers (EAPs) are also being used to create electroactive polymer artificial muscles (EPAMs). Researchers at the Auckland Bioengineering Institute are using EAPs that can expand and contract up to 300 percent when a voltage is applied (Melanson, 2011). With these materials they have been able to create soft, flexible motors that have none of the traditional rigid components like electromagnets, wire coils or gears. With this shift towards softer and more flexible robots their new aesthetic will influence human-robot interaction design.

Therefore investigating other soft and flexible cultural artifacts, such as clothing, will become crucial in understanding how this soft-architecture will be situated.

Figure 2-10. *Otherlab's low-cost, pneumatically controlled, inflatable robot, Ant-Roach.*

Ant-Roach by Otherlab is an inflatable robot that gets its form from textile-air-structured forms and is capable of motion through textile-pneumatic actuators **Figure 2-10**. The textiles are relatively low-cost and when deflated can be folded up into a compact package for easy transport. While textiles offer some advantages over traditional rigid robotic components they also present some problems. For example, traditional actuation in robotics might be achieved with servos or motors with shaft encoders allowing for very precise rotational control (radians per second). With soft-architecture robotics with textile-pneumatic actuators, like those in *Ant-Roach*, there are no shafts to encode nor even a precise axis of rotation. They might then rely on estimated open-loop control. However, with the addition of fibers or textiles that can sense force or strain, feedback can be introduced into the system for improved accuracy.

Robotics and Clothing

Whether deliberate or not, sartorial semiotics can be observed in several research robots currently being used and developed. We can see examples of sartorial semiotics in NASA's Robonaut. Robonaut was engineered to mimic the human body as the intended function is in a telepresence application for space based repairs and missions. The human form factor and size was also chosen so that the robot could operate in the same spaces that the astronauts could and use the same tools and equipment. Although Robonaut lacks any detailed facial features for communicating facial expressions, Robonaut is designed for peer-to-peer interactions with other astronaut team members. Robonaut does however have a jacket made of space suit material layers such as, Nomax, Kevlar etc. which acts functionally as impact protection but also acts as a uniform with appropriate mission patches and insignias and sponsor logos, **Figure 2-11**.

Figure 2-11. *NASA's Robonaut with sartorial design elements working with astronaut.*

This sartorial treatment positions Robonaut as a peer or team member as it is wearing the same clothing, the space suit, as the other human astronauts. This uniform is an example of priming for social cognition *i.e.* team uniforms communicate via appearance that everyone on the team shares a common goal. Again, it is not clear if this is simply an engineering solution or a deliberate use of sartorial design to socially situate the robot as a team member. Robonaut utilizes the sartorial design initially for functional purposes but intentional or not, a secondary social signal is conveyed. A more deliberate use of clothing and robotics is illustrated by the *ActDresses* project.

ActDresses by Fernaeus and Jacobsson from the Swedish Institute of Computer Science is a design concept that takes the intersection of robotics and clothing a step further. *ActDresses* uses the metaphor of clothing to control robotic devices. Fabric coverings and accessories are applied to the robot to change a robot's physical surface which initiates a new modality, linking physical appearance and action. Several different styles and accessories represented several different behaviors. For example, the researchers worked with the robotic pet, *Pleo*, and used a dog collar placed around *Pleo's* neck to signal it to switch into *watchdog* mode (Feraeus & Jacobsson, 2009). In terms of identity *Pleo* is to transform from a companion pet to a *watchdog* intent on guarding or protecting someone or something albeit still in the guise of play. This change of behavior coupled with the auxiliary surface transforms *Pleo's* identity, **Figure 2-12**.

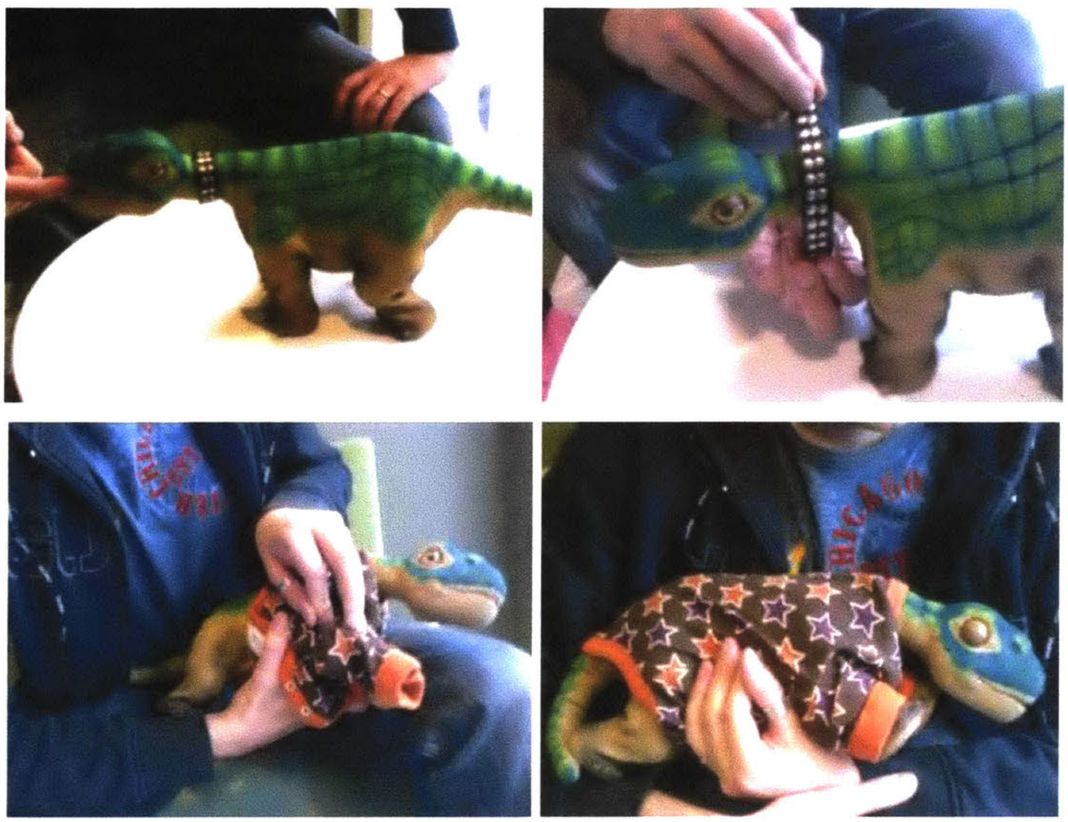

Figure 2-12. *ActDresses by Fernaeus and Jacobsson from the Swedish Institute of Computer Science is a design concept that uses the metaphor of clothing to control robotic devices.*

The project presents a physical language to control and program a robot, and it encourages personal customization of electronic and computational devices. While clothing in this example is being used as a modifier, clothing is also being utilized to provide more context to human-machine interactions. The Microsoft receptionist project is a screen based artificial agent that attempts to extract contextual information from a combination of visual and voice recognition as well as speech synthesis to handle basic tasks (Mitchell, 2008).

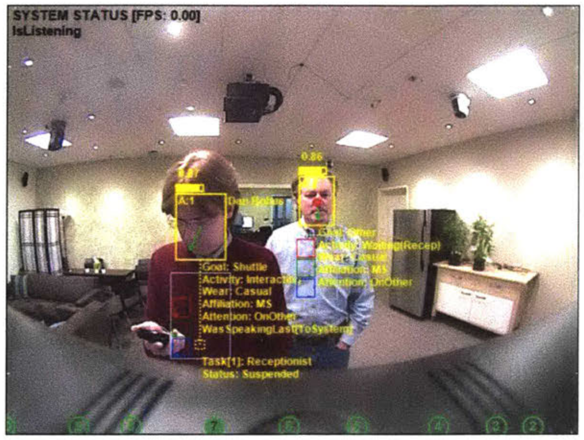

Figure 2-13. *Microsoft receptionist robot which detects sartorial cues.*

The system will detect sartorial cues and tries to make use of that information to categorize people as either *employees*, based on casual dress, or *business visitors* based on a more formal style of dress, like a business suit, **Figure 2-13**. The receptionist will then modify its own behavior based on the person's sartorial appearance.

As stated previously, the field of robotics has become a more multidisciplinary pursuit. Disciplines outside of traditional robotics are utilizing robotic practices. Within the fashion world, there have been designers who have attempted to mix robotics and clothing in a more expressive manner. Fashion designer Alexander McQueen in his 1999 spring/summer collection presented a white dress that was spray painted by two industrial robotic arms while being worn by a model on the runway in a choreographed robotic performance, **Figure 2-14,** (McQueen, 1999).

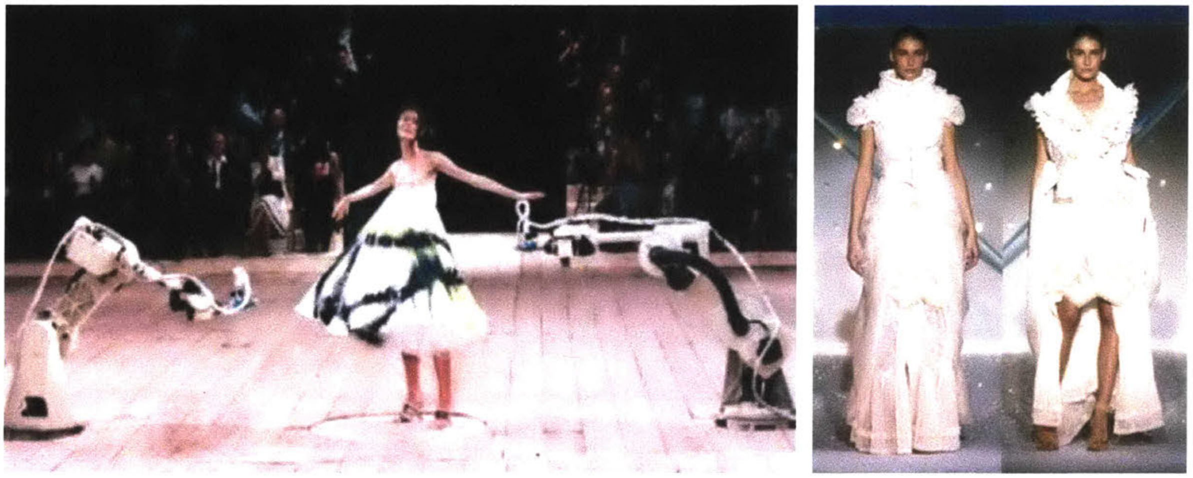

Figure 2-14. *Alexander McQueen Spring/Summer 1999 (left) and Hussein Chalayan Spring/Summer 2007 (right).*

Hussein Chalayan, in his 2007 spring/summer collection presented clothing that physically transformed itself. Using concealed servos and cables, the dresses automatically opened, folded and shortened themselves in length (Chalayan, 2007). Although specifically designed for the fashion runway, the clothing was able to physically transform and thus dynamically transform the image of the wearer affecting their presented identity through robotic facilitated performances of transformation, **Figure 2-14**.

Figure 2-15. *Boston Dynamic's Petman humanoid robot designed to wear and test chemical protection clothing under realistic conditions.*

Boston Dynamic's Petman humanoid robot is designed to wear and test chemical, biological, radiological and nuclear (CBRN) protection suits and clothing under realistic conditions which obviously wouldn't be safe for human subjects, **Figure 2-15.** Although intended for testing purposes the addition of clothing situates an otherwise ambiguous humanoid robot within the context of the military, bringing with it all the cultural and political authority or apprehension. The full outfit also transforms the machine aesthetic of the robot to a more human aesthetic with the simple addition of clothing.

Through examining the historical development of robot aesthetics beginning from early theatrical representations on through the transformation into actual technical inventions, we were able to observe the socio-political impact surface treatments like skin and clothing can have both in our social perceptions and acceptance of robotics. Approaching modern times, the many examples of robotics and clothing intersecting that were cited illustrate a trend toward adopting textiles and soft-architectures into robotics. The motivation for *Sartorial Robotics* as a discipline is to combine advances in electronic-textiles which bring robotic abilities into surface form factors with the ability to *play with identity* both for people and robots. Through *Sartorial Robotics* we can utilize robotic surfaces that mimic characteristics of clothing to *play with identity* and ground this work in fashion theory.

Chapter 3

Wearables for Robots Prior Work by Author

The field of wearables, which is the incorporation of electronics and computation into clothing or other body worn accessories, has been an emerging field of research since its inception during the 1960s with Claude Shannon and Edward Thorpe and their wearable roulette prediction computer (Thorpe, 1998)[5]. With the wide adoption of mobile smartphones, the research field has grown considerably and consumer products are beginning to emerge. The field of wearables is focused almost exclusively for human use and, as such, soft and flexible technologies such as electronic-textiles that can conform to the human body for comfort are continually pursued. These technologies and materials provide a point of intersection for researchers of wearables and soft-architecture roboticists. However this point of intersection should not be limited to technological advancements but should transcend and incorporate apparel design methodologies and practices. Sartorial robotics, as a practice, is meant as a bridge between the two fields and can be utilized in both the pursuit of robotics and the pursuit of wearables.

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[5] Thorpe and Shannon were working out a mathematical model to predict the results of a spinning roulette wheel. In order to test their algorithms in the field they constructed one of the first wearable computers. It consisted of a twelve transistor analog computer about the size of a cigarette-pack and four microswitches, one located in the wearer's shoe and operated with their big toe. The computer would send audio tones to an ear mounted speaker, like a hearing aid, indicating to the wearer how to bet. The device and their algorithms proved successful with the pair winning over $10,000 in their initial weekend testing. The physical form factor of the computer was transforming. The computer was battery powered and small enough to be portable. The wires to the ear piece were hair thin and painted to match the wearer's skin tone and hair color to be inconspicuous and the microswitch installed in the shoe was wired through the pant leg. The form of the computer had begun to break out of the traditional stationary box and began to be tailored to the wearer and their body.

In fact the impetus for developing sartorial robotics was the transition from my research work on wearables intended for people, to research on wearables intended for humanoid robots, specifically Honda's ASIMO[6] robot.

Honda's ASIMO humanoid robot platform began as an exploration of bipedal locomotion but has evolved into a potential domestic assistive humanoid robot which would be situated into our daily personal and social lives. The existing robotic platform is heavily dependent on computer vision for environmental sensing and has no pressure-based sensing on its surfaces for either collision detection or perhaps even more importantly social touch gesture recognition. Social touch gestures are touch interactions that contain social value, for example determining the difference between *tickling* and *poking,* and thus in turn interpreting its social meaning or perhaps simply recognizing a *pat on the back* to indicate a job well done (Knight, Toscano, Stiehl, Chang, Wang, & Breazeal, 2009). Understanding social touch gesture is critical once people begin to physically interact with robot bodies and vice versa. Embedding pressure-based sensors into the existing outer plastic shells is a common method for incorporating force sensing into robotics (Martin, Ambrose, Diftler, Platt, & Butzer, 2004) (Stiehl, Lieberman, Breazeal, Basel, Lalla, & Wolf, 2005). Since this would require a complete redesign of the shell housings and internal structures, which would be costly and time consuming, another solution was sought.

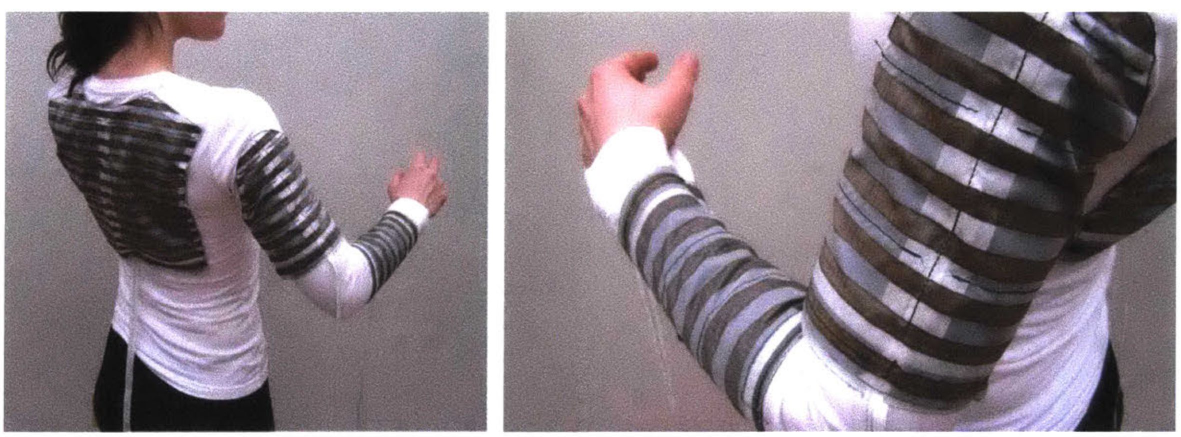


Figure 3-1. *Author's previous research into quantum tunneling composite textiles for wearable sensing and characterization of violent forces.*

[6] ASIMO is an acronym for ***A****dvanced* ***S****tep in* ***I****nnovative* ***MO****bility*

In collaboration with Honda Research Institute's robotics division, it was decided to build upon work previously done by the author in a wearable computing project which utilized electronic-textiles to detect and categorize violent forces on the human body, **Figure 3-1**. The project was to develop a similar electronic-textiles solution for ASIMO but with the intended purpose of social touch gesture recognition. Transitioning a wearable for human use to a wearable for robot use was the initial motivation for developing sartorial methodologies for the research of robotic surfaces and soft-architecture robotics. It was also an opportunity to rethink the often used metaphor of skin for robotic surfaces and instead focus on clothing. In terms of the metaphor, clothing is a modular removable and reconfigurable system while skin is a more permanently attached component.

It was decided to construct a clothing-type outfit for ASIMO. This resulted in a modular force sensing electronic-textile surface that could be donned and doffed from the main robot, adding or removing the sensing functionality easily. Thus in the same manner that a person might don or doff a raincoat for added functionality during stormy weather, sensing abilities could be donned or doffed on the robot depending on its required needs. The material is a composite textile of coated and layered conductive and quantum tunneling composite (QTC) pressure sensitive materials that allow the textile to vary its electrical conductivity in proportion to the amount of force applied to its surface. A variety of materials were used within the layered composite: electrically conductive silver/nickel coated nylon mesh, neoprene, electrically conductive nonwoven carbon cloth and a 4 oz. 100% cotton twill weave fabric for the outer covering layer, **Figure 3-2**. Building on the experience gained previously working with QTC material, the QTC material was selected because it can be easily coated onto other textile materials with a resulting composite textile that can be cut, sewn and worked on with many common apparel processes. Several mixtures of the quantum tunnel coating/film were experimented with until we achieved a force range ~10.0g to ~1000.0g and response time under 5.0μs which was suitable for our purposes. The size and geometry of the sensor affects its overall performance, but with proper electrode placement, performance can be adjusted and equalized to provide consistent measurements.

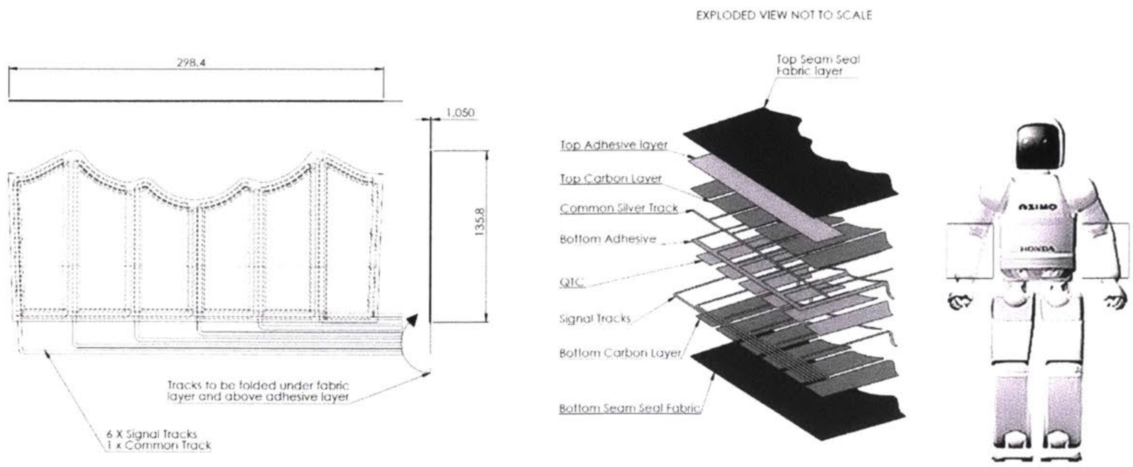


Figure 3-2. *Detail of QTC sensor construction layers for forearm location sensing of the ASIMO robot.*

One issue we encountered, despite having access to the ASIMO's 3D model data, was simulating full body motion of the robot and understanding the fabric kinematics to develop patterns with the proper fit and flexibility. The combination of fabric simulation with upper torso simulations did not provide enough information to design the full functioning suit system. We instead decided to employ traditional apparel methods of drape fitting[7] and pattern making. This process is quite unique to flexible fabric materials and with a skilled apparel engineer is relatively quick and simple. **Figure 3-3** shows the apparel draping process utilized in the design, development and construction of an electronic-textile force sensing surface developed for Honda's ASIMO humanoid robot. CAD/CAM software, like Rhinoceros which is a NURBS based 3D modeling software, can translate 3D forms to 2D surfaces using the *unrollsrf* (unroll surface) command. While the software was helpful in converting the basic forms into pattern pieces, adjustments and modifications still needed to be made once fit and motion were considered. This was more easily accomplished by fitting the textile directly to the robot's physical body form during the draping process.

[7] The process of drape fitting involves draping fabric, like muslin or even trace paper, onto the physical form being fit. Patterns are cut and shaped while on the form and can be tested and evaluated then readjusted until proper fit is achieved. This also allows the form to be put into motion to account for flexibility during movement.

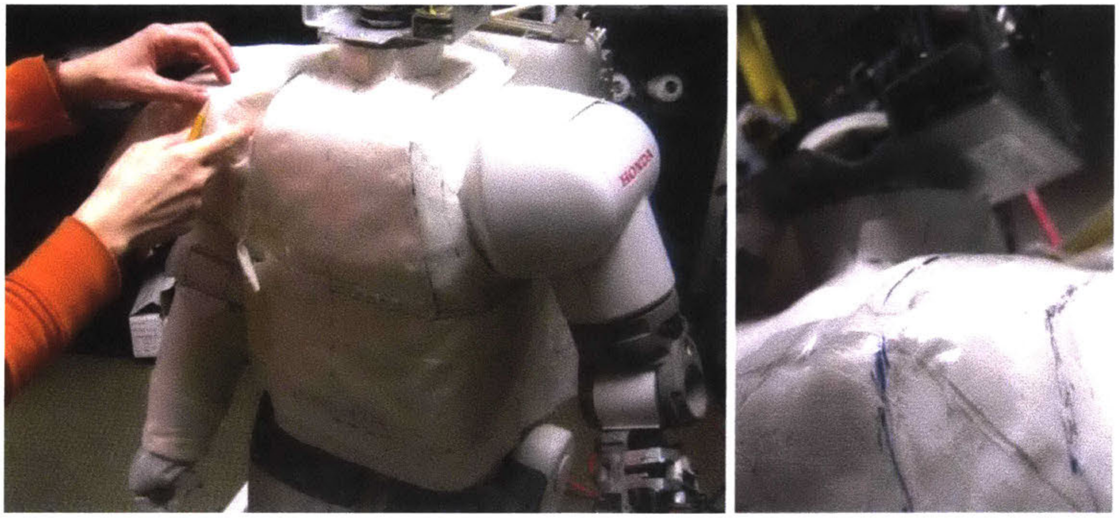


Figure 3-3. *Apparel draping process on humanoid robot for textile sensor design.*

Clothing is perhaps the most widely experienced form of textile object and is nearly universal in its adoption; as a result there are a variety of well-developed methods for design and construction. From a technical perspective, apparel designers are highly skilled in the art of tailoring textile materials, manipulating two dimensional patterns into zero Gaussian curvature forms that mesh with the biomechanics and kinematics of the human body, or in this case a humanoid robot body. This skill set should be incorporated into soft-architecture robotics that utilize electronic-textiles and fiber-electronics as the problem space is similar except instead of the human body a robot form is present. In addition to the engineering and mechanics of clothing, apparel and textile designers are highly fluent in the semiotics of clothing and the subtleties of the nonverbal communication of fashion. Apparel and textile designers/engineers understand both the mechanics of clothing as well as the semiotics of fashion. The semiotics of fashion as it relates to sartorial robotics will be discussed in more detail in later chapters.

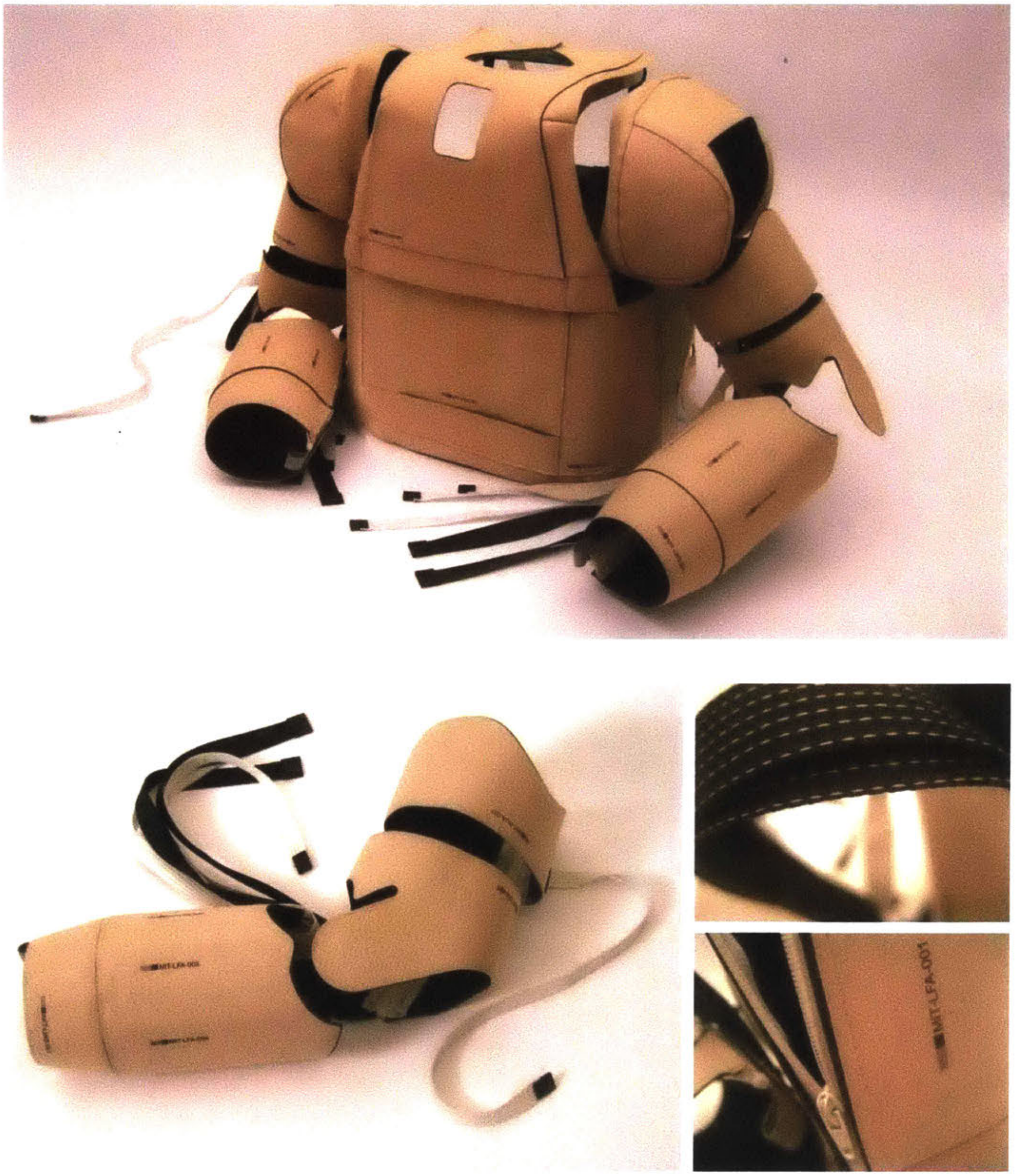


Figure 3-4. *Full suit arm components of quantum tunneling composite textile sensors for humanoid robot force sensing.*

Once the fit and patterns were established the sensor layout based on the modular design was finalized and developed. A total of 28 pattern pieces with 26 separate sensing locations were constructed including an X, Y and Z axis sensing surface on the stomach region similar to a 4-wire resistive touch screen but with the addition of force sensing in the Z direction and made entirely of textiles, **Figure 3-4**. The large area, full torso sensing system was derived from observing human-human touch interaction during instructional activities and casual social activities. We decided on less sensor density but more overall body area coverage in order to investigate regionally significant gestures. This meant a reduction in classifying some types of touch gestures but provided more full body coverage and awareness. Locational filtering and body mapping based on the specific form factor of the robot was utilized to extract touch gestures from the robot's surface.

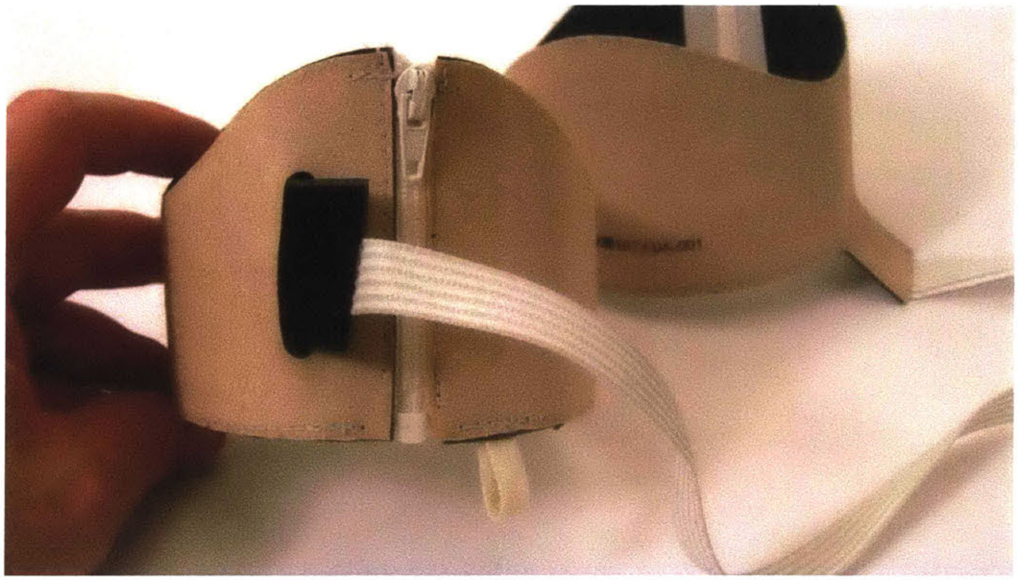


Figure 3-5. *Upper arm components of quantum tunneling composite textile sensors for humanoid robot force sensing showing zipper and conductive fabric ribbon details.*

For example, a high density sensor array may not be needed if an understanding of the body geometry is applied. With a radial layout of sensors around the forearm, grabbing the arm could be determined from simultaneous pressure on all the sensors, so *grabbing* would be distinguishable from a *tap*. Additionally a light touch combined with activation of a couple sensors could be categorized differently than a heavy touch on several sensors. However touch gestures like *patting* or a *tickle* may not be discernible (Stiehl, Lieberman, Breazeal, Basel, Lalla, & Wolf, 2005).

In order to make the modular components easily removable, apparel closers like zippers and adjustable fitting methods using woven elastic ribbons were employed, **Figure 3-5**. Material choice helped stabilize the modules once in place; the neoprene provided the proper friction with the robot's hard plastic case minimizing slippage and sensor movement. The outer cotton twill provided a slight texture and a warm to the touch feel which helped differentiate it from the plastic case. These details not only offered functional benefits, but also aesthetically identified the surface more as clothing than as a skin.

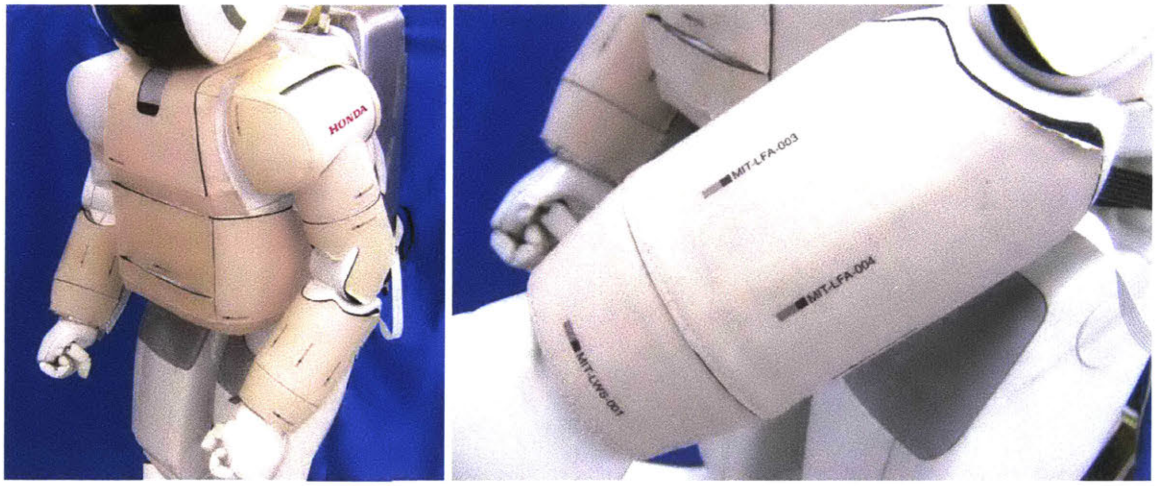


Figure 3-6. *Full suit arm components of quantum tunneling composite textile sensors for humanoid robot force sensing.*

By using electronic-textiles we shift from the metaphor of a sensing skin, often used in robotics, to the metaphor of sensing clothing. We incorporated apparel design and construction techniques to develop modular electronic-textile surfaces that can be easily attached to a robot and integrated into a robotic system. Adding new abilities to a robot system can become as simple as changing their clothes. The goal was to incorporate social touch interaction and communication between people and robots while exploring the benefits of a soft-architecture using textiles and the textile aesthetic, **Figure 3-6**. Honda researchers have reported successful testing and integration into the ASIMO system using the Phidgets USB sensing and control system, in preparation for touch gesture recognition work. This project, successfully demonstrated the combination of clothing and sensing technology on a robotic platform for human social touch interaction and formed the initial ground work for the practice of *Sartorial Robotics*. Textiles on robots, even electronic-textiles will imply clothing. This, in conjunction with our inclination to dress robots, means it is crucial then to better understand how cues from sartorial elements on robots would be perceived.

Chapter 4

Evaluation of Sartorial Cues and Robotics

We know from previous research into human- human communication via sartorial signals that one's fashion is a form of nonverbal communication that can influence our interactions. Clothing's nonverbal cues can have a profound impact on social perceptions such as trust, persuasiveness and competency to name a few. Sartorial cues can be challenging to evaluate given the cultural and social variety in attitudes towards fashion as well as the constantly changing landscape of fashion trends. However, as stated previously, several researchers have established the significance of sartorial cues as nonverbal communication in human-human social interactions (Forsythe, 1988) (Hamid, 1969) (Pine, Fletcher, & Howlett, 2011). Despite the many examples of anecdotal evidence of robotic researchers and operators utilizing sartorial treatments *i.e.* dressing robots, it has yet to be established that sartorial cues as a form of nonverbal communication can translate to human-robot interactions. As a result the effectiveness of sartorial cues as demonstrated by robots should be evaluated. Intuitively we seem to assume this would be the case but in order to understand the phenomenon more we should examine a real-world example, the play *I, Worker*.

Japanese playwright Oriza Hirata's one-act drama *I, Worker* is a robot-human play produced by the Seinendan Theater Company and Osaka University's Robot Theater Project in collaboration with Dr. Hiroshi Ishiguro (Hirata, 2011). The play includes two robot-actors whose characters are robots intended for household services. The robots eventually grow bored with the work and decide they no longer want to perform their services. The play stars two Wakamaru humanoid robots made by Mitsubishi Heavy

Industries. The robots which perform alongside human actors and are controlled off stage are also guided by sensors located on the stage. However, because the robots were manufactured they are aesthetically identical and so some method for differentiating them and defining their individual character was required. For this reason one robot was outfitted in an apron-like dress and one robot wore a bowtie. The sartorial treatments not only visually differentiate the two robots, but also additionally defines one as the female-character and one as the male-character, ***Figure 4-1***. The playwright's intention is that the inclusion of the sartorial elements, the dress and the bowtie, identifies the robot towards a gender identification more so than a robot without the sartorial elements. Again, intuitively this seems reasonable, but this hypothesis needs to be tested.

Figure 4-1. *Scene from "I, Worker" a one-act drama by playwright Oriza Hirata with the Seinendan Theater Company and Osaka University in collaboration with Dr. Hiroshi Ishiguro.*

Among the more obvious sartorial cues are those that distinguish the male and female genders. In most cultures men and women have distinct styles of dress and fashion which help define their masculine and feminine roles. This definition of gender roles and appropriate dress has an extensive history and is even codified in the Bible's Old Testament.

> *"The woman shall not wear that which pertaineth unto a man, neither shall a man put on a woman's garment: for all that do so are abomination unto the LORD thy God."*
>
> *-Deuteronomy 22:5*

This social and cultural norm is still upheld today in modern Western culture although with more acceptance. Women can wear dresses although for men this practice would still be socially disruptive. Barthes does point out that women have far more flexibility in wearing traditional men's fashions (Barthes, 1990). Women, for example have transitioned to wearing pants, whereas men still have not adopted wearing dresses, but still within most segments of Western culture the necktie is predominantly associated with masculine fashion (Crane, 2001). In order to establish that nonverbal sartorial cues within human-human interaction might translate to human-robot interaction, an investigation of robots with masculine and feminine fashions was conducted.

Hypothesis

The hypothesis is that sartorial cues indicating a gender, *i.e.* gender specific clothing, will influence people's perceptions of gender in a robot. Specifically that feminine sartorial cues will increase perception of feminine traits and decrease perception of masculine traits, while masculine sartorial cues will do the opposite, increase perceptions of masculine traits and decrease perceptions of feminine traits.

Methods

To test this hypothesis a study on human gender sartorial cues was constructed for robots in order to determine if those sartorial cues could influence people's perception of a robot's gender. While this may seem peculiar, clothing is perhaps the main component of gender construction and identification. Among the more obvious sartorial cues are those that distinguish the male and female genders. Participants were shown an image of a humanoid robot. The image showed the robot displaying either *no clothing, feminine clothing* or *masculine clothing*. Participants were then asked to rate the robot in regards to gender specific personality traits.

Participants

Participants were recruited through the Amazon Mechanical Turk Human Intelligence Tasks Internet service specifically from the geographic location of the United States in order to have some cultural consistency among respondents. A total of 207 people responded to the survey but 6 were not included as they did not complete the survey. The data set included 201 respondents consisting of 131 men, 69 women and 1 reported gender of *other,* as it was an option in the survey. The respondents had a comparably wide range of ages (M=31.72, SD=10.47).

Experiment Design and Procedures

For the experiment of masculine and feminine sartorial cues and robots we employed a variation of the Bem Sex-Role Inventory (BSRI) measure of masculinity-femininity. The BSRI was developed by Sandra Bem in the 1970's and has consistently been a reliable and valid technique for rating gender traits (Holt & Ellis, 1998). The Bem Sex-Role Inventory is a psychological test which uses 60 personality traits consisting of 20 masculine, 20 feminine and 20 filler traits categorized as gender neutral. The traits are rated using a seven point Likert-scale and is self-reported. There is also a BSRI short form which reduces the number of personal traits tested to 30 traits, evenly dividing them into 10 masculine, 10 feminine and 10 filler traits. While there are other masculine-feminine measures, the BSRI provides tested traits that are represented by easily understood words and phrases, **Figure 4-2**.

Masculine traits	**Feminine traits**	**Filler traits**
self-reliant	yielding	sincere
has leadership abilities	feminine	tactful
independent	shy	unpredictable
masculine	affectionate	adaptable
assertive	sympathetic	happy
competitive	gentle	truthful

Figure 4-2. *Example of Bem Sex-Role Inventory words and phrases representing masculine, feminine and neutral personality traits.*

However, to encourage timely response a variation of the BSRI using 18 traits, 6 masculine, 6 feminine and 6 filler traits was developed for the study. Images of the Wakamaru robot from the one-act drama *I, Worker* were digitally manipulated to include sartorial cues or eliminate sartorial cues related to gender to generate the conditions of the study, **Figure 4-3**. The Wakamaru robot is designed as a domestic humanoid robot; it has highly generalized facial features with only eyes and a motionless mouth represented. The body form consists of a head, neck and upper torso with arms. The lower portion of the body does not have legs but is hoopskirt-shaped with concealed wheels for mobility. The overall aesthetic of the robot tends toward a feminine appearance; the hoopskirt-shaped body presents a dress-like silhouette. Its yellow hue is arguably more feminine and its rounded shapes are consistent with apparel trends of soft curved lines for women which are juxtaposed with the hard angular lines often used for men's apparel. The robot's shoulders are reminiscent of capped sleeves which represents another specifically feminine apparel aesthetic[8].

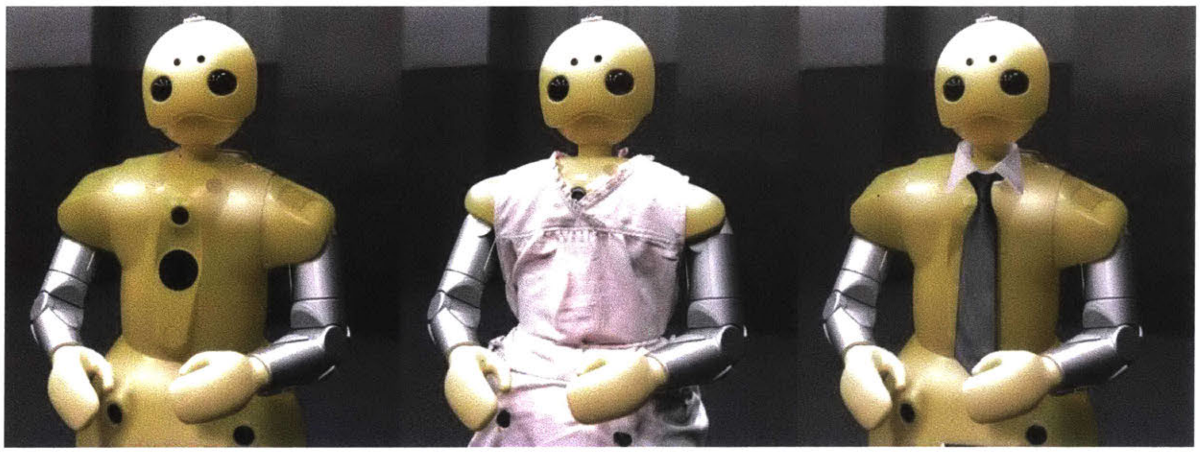


Figure 4-3. *The three conditions of Wakamaru Robot used in the gender experiment on sartorial cues and robots: No Sartorial Cue, Feminine Sartorial Cue and Masculine Sartorial Cue.*

The digital manipulations tried to compensate for this by cropping the lower body portion out of the image and dropping the color hue saturation which muted the yellow hue of the robot's surface. The white bowtie that was utilized in Oriza Hirata's play was replaced by a more traditional white collar and four-in-hand knot necktie which is a more common traditionally masculine sartorial element. The apron-like dress which appeared light grey was given a light pastel pink hue to the dress so that it might stand out more from the robot surface and background colors, **Figure 4-3**.

[8] Cap sleeves are a style of short sleeve which is cut and seamed to specifically fit the shoulder having a more rounded or curved appearance. They are most commonly found on women's blouses and dresses.

The online survey was designed using *Qualtrics* survey software with Likert-scale templates. Participants followed links from Amazon Mechanical Turk to the *Qualtrics* online survey. Participants would first agree to an online consent form. They were then randomly assigned one of three sartorial conditions: *no cue,* which consisted of the Wakamaru robot with no additional sartorial treatments, the *feminine cue,* which consisted of the Wakamaru robot with the addition of a *dress* with a ruffled surplice neckline and pastel pink hue, or the *masculine cue,* which consisted of the Wakamaru robot with a white collar and black four-in-hand knot *necktie*. Each participant was shown the image of a robot and then asked to rate each of the six masculine, six feminine and six neutral traits on a seven point Likert scale based upon how much they agreed that the trait matched the robot with 1 representing *strongly disagree* and 7 represent *strongly agree*.

Analysis

For each respondent a mean score of all the masculine traits and a mean score of all the feminine traits of the BSRI survey were calculated for each condition and then compared using independent samples t-tests. In addition, the Likert-scale responses for each individual trait were grouped into a general disagree and agree percentages in order to analyze any changes in response towards individual personality traits such as *self-reliant* or *affectionate*.

Results

When the mean scores for the conditions of the study were compared the results supported the main hypothesis. The following sections will examine the various comparisons between conditions tested in the study.

Gender Neutral Control Biased Feminine

It was initially considered that the *no cue* condition tended to have a feminine aesthetic and thus not be an entirely neutral control. In order to better gauge the *no cue* condition a paired two-sample t-test was conducted comparing the mean scores of masculine traits with the mean scores of feminine traits; overall the *no cue* robot scored a (M= 3.42, SD = 0.99) for the masculine traits and a (M=4.48, SD = 1.09) for the feminine traits. There was a significant effect on gender perception, $t(76) = 6.0$, $p < .001$, with the *feminine traits* receiving higher scores than the masculine trait scores, indicating that in fact the robot with *no sartorial cue* is considered more feminine and does not represent a truly neutral condition.

Masculine Sartorial Cue rated higher Masculine Traits and lower on Feminine Traits

For the *masculine sartorial cue* condition, represented by the *necktie*, we observed results consistent with our hypothesis. Despite the feminine bias for the neutral condition when the *masculine sartorial cue* condition was compared with the *no cue* condition we recorded an increase in mean score for masculine traits and a decrease in mean score for the feminine traits. The two conditions were compared using a two-sample t-test, and for masculine traits the *no cue* condition had a masculine mean score of (M=3.42, SD = 0.99) as compared to the *necktie cue* condition with a masculine mean score (M=3.92, SD = 1.14). There was a significant effect on gender perception, $t(123) = 2.7$, $p < .01$, with the *necktie cue* receiving higher scores than the *no cue* masculine trait scores, indicating that in fact the robot with the *masculine cue* is considered more masculine and had a measurable effect on people's perceptions of gender. The 95% confidence interval for the effect of the *masculine cue* on masculine mean score is between 0.14 and 0.86.

When we compare the *masculine cue* to the *no cue* condition for feminine traits we again observe results consistent with our hypothesis. An independent samples t-test was conducted to compare the feminine trait mean score of the *masculine cue* and *no cue* conditions. As predicted, we observe a decrease in the feminine trait mean score for the *masculine sartorial cue.* Results indicated a statistically significant decrease in feminine traits for the *masculine cue* (M=4.03, SD = 1.03) as compared to the *no cue* condition (M=4.48, SD = 1.09), t(135) = 2.56, $p < .05$. The 95% confidence interval for the effect of the *necktie cue* on feminine mean score is between 0.10 and 0.81. These results also support the hypothesis.

Feminine Sartorial Cue rated higher Feminine Traits and lower on Masculine Traits

For the *feminine sartorial cue* condition, represented by the *dress,* we also observed results consistent with our hypothesis. As we predicted when the *dress cue* condition is compared with the *no cue* condition we observe a decrease in the mean score of the *dress cue* condition for the masculine traits (M = 2.95, SD = 0.87) as compared to the *no cue* masculine mean score (M = 3.42, SD = 0.99). There was a significant effect on gender perception, $t(134) = 3.0$, $p < .01$, with the *dress cue* receiving lower masculine trait mean score than the *no cue* condition. The 95% confidence interval for the effect of the *dress cue* on masculine mean score is between 0.15 and 0.78. Again, these results support the hypothesis.

To compare the feminine trait mean scores of the *no cue* and *dress cue* conditions a two-samples t-test was conducted. Also as predicted we observe an increase in the feminine trait mean score for the *dress cue*. Results indicated a marginally significant increase in feminine traits for the *dress cue* (M = 4.78, SD = 1.03) as compared to the *no cue* condition (M = 4.48, SD = 1.09), t(131) = 1.64, p = .10. Considering that our *no cue* condition is not neutral, but instead biased feminine, it is understandable that the addition of the dress to the robot recorded a slight increase to the feminine traits which follows our predicted trends but is marginally significant.

Comparing Masculine and Feminine Traits

When comparing the *no cue* condition to either the *necktie cue* or *dress cue* we observe a shift in gender perception consistent with our hypothesis. However in the real-world example of Oriza Hirata's play the robots are not experienced as isolated but are viewed in the presence of other actors, both people and robots, representing genders of their own. To understand this fully might require additional experiments, but we can compare the *feminine cue* to the *masculine cue* to understand the magnitude of the overall gender shift between the masculine and feminine sartorial cues.

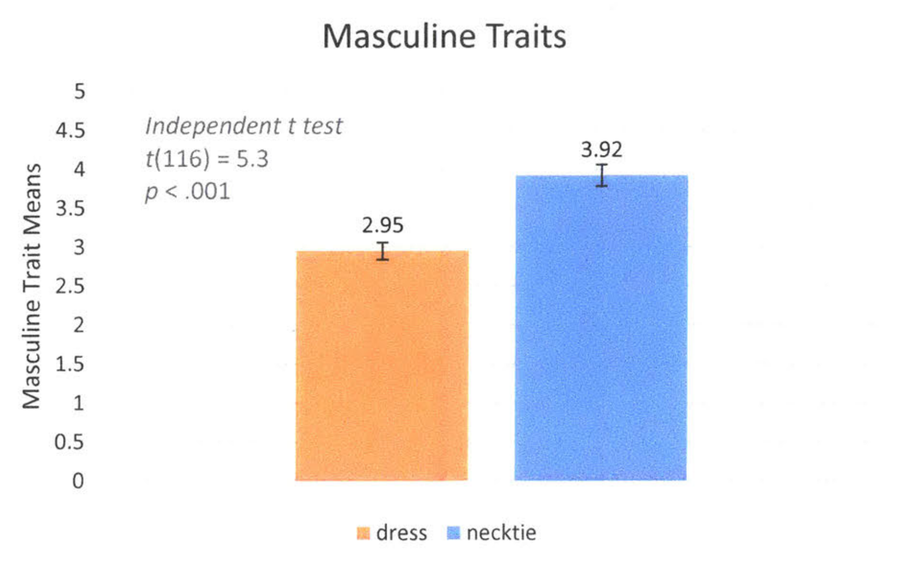


Figure 4-4. *Dress condition compared to Necktie condition for Masculine Traits*

For masculine traits there was a significant effect on gender perception, $t(116) = 5.3$, $p < .001$, with the *dress cue* receiving lower masculine trait scores than the *necktie cue* condition; *necktie cue* masculine mean score (M = 3.92, SD = 1.14) while the *dress cue* masculine mean score (M = 2.95, SD = 0.87), **Figure 4-4**. The 95% confidence interval for the difference in masculine mean score is between 0.61 and 1.33.

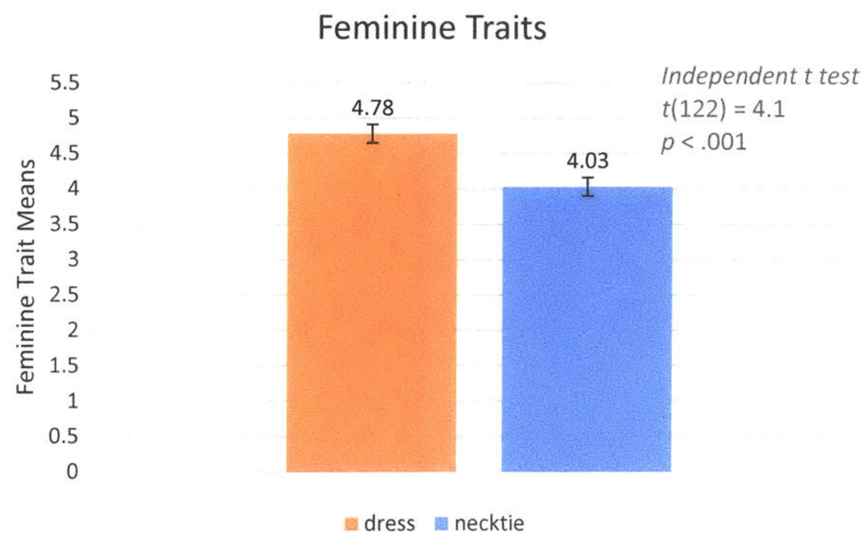


Figure 4-5. *Dress condition compared to Necktie condition for Feminine Traits*

Comparing the *dress cue* to the *necktie cue* for feminine traits there was also a significant effect on gender perception, $t(122) = 4.1$, $p < .001$, with the *dress cue* receiving higher feminine trait scores than the *necktie cue* condition. Again the *dress cue* feminine mean score is (M = 4.78, SD = 1.03) while the *necktie cue* means score is (M=4.03, SD = 1.03), **Figure 4-5**. The 95% confidence interval for the difference in feminine mean score is between 0.39 and 1.12. These results support the hypothesis.

Individual Masculine and Feminine Trait Shifts

When examining the results of the study, certain personality traits of the Bem-Sex role Inventory showed particularly remarkable shifts between the masculine and feminine sartorial cues. In order to examine individual personality traits, the Likert-scale choices for the individual traits were grouped into general *agree* and dis*agree* categories and compared as percentages, **Figure 4-6**.

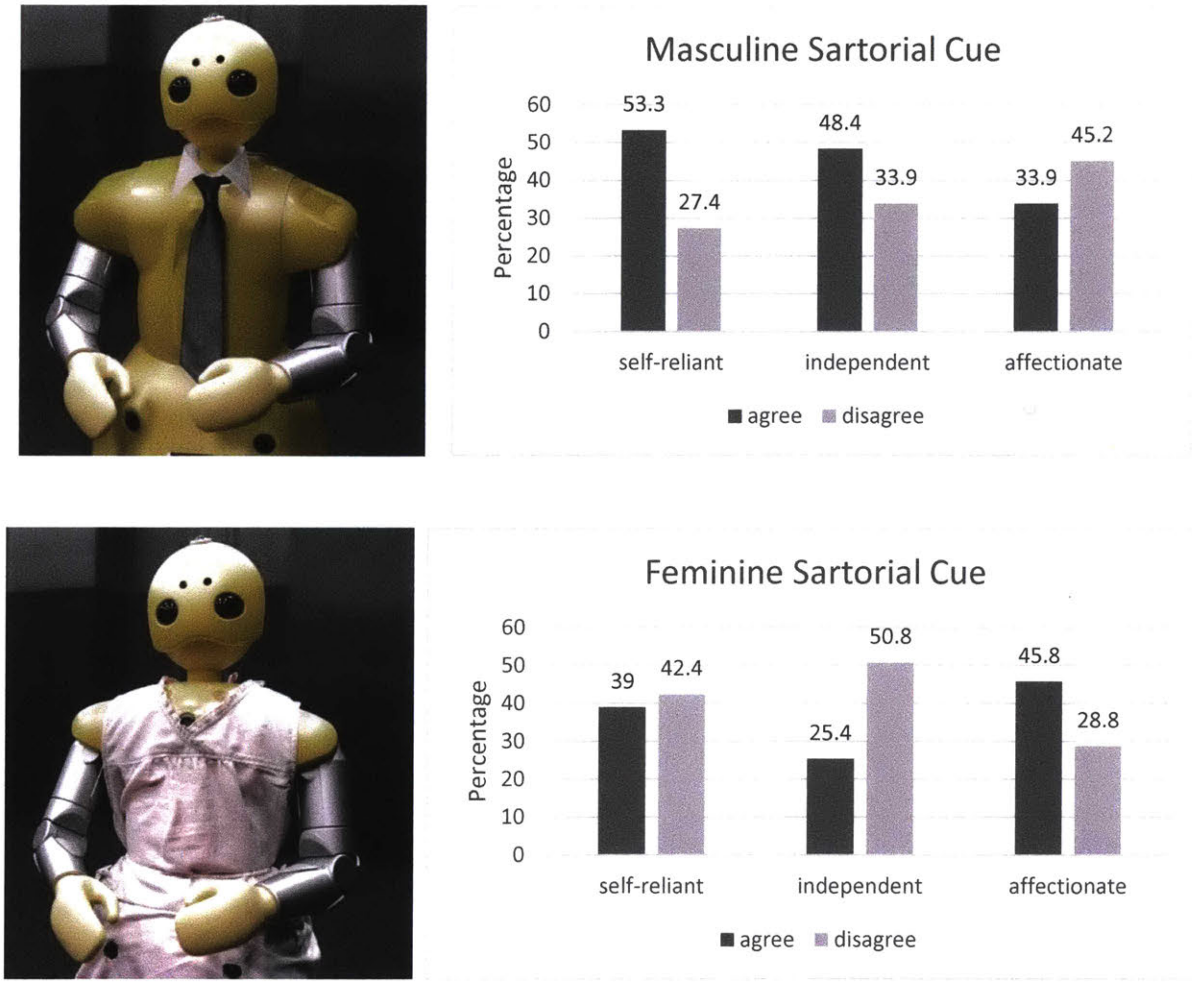


Figure 4-6. *Individual BEM Scale traits showing shift between masculine and feminine sartorial cues*

For the masculine trait *self-reliant* among those who saw the necktie condition, 53.3% agreed with the description and only 27.4% disagreed. For those who viewed the dress condition on the other hand, just 39.0% agreed with the description of *self-reliant* and 42.4% disagreed. For the masculine trait *independent* the results for those who saw the necktie condition were 48.4% agreed with the description and only 33.9% disagreed. For those who viewed the dress condition, just 25.4% agreed with the description of *independent* and 50.8% disagreed.

For the feminine trait *affectionate* of those who saw the dress condition, 45.8% agreed with the description and only 28.8% disagreed. However, for those who viewed the necktie condition, just 33.9% agreed with the description of *affectionate* and 45.2% disagreed.

Other individual personality traits used in the BSRI illustrated similar shifts. From the comparison of these percentages this data supports the hypothesis that sartorial cues indicating a gender, *i.e.* gender specific clothing, will influence people's perceptions of a robot. It also suggests that individual personality traits can be influenced as well.

Summary

From the experiment we observe increases and decreases in the predicted directions for perceptions of masculine and feminine traits, indicating that sartorial cues representing gender did in fact have an impact on people's perceptions of gender for robots. As we've previously discussed there are nearly limitless variations for fashion and sartorial signaling, and this is one particular sartorial cue for one particular social construct and social impression, that of gender. This does however show that sartorial signaling as nonverbal communication for human-human interactions can translate to human-robot interaction. The phenomenon of dressing robots, as discussed previously, does then seem to have some merit behind it, and consequently providing methods for robots to control their own surfaces, in a manner similar to clothing, could be utilized in designing human-robot interactions and behaviors. This should be considered a fertile area for future study.

Chapter 5

Design Principles and Framework

Daniel Weil's *'Radio in a Bag'* is a product commentary on the designer's role in electronic object design. Specifically his work is emphasizing how the designer, in the electronic and digital age, is increasingly being relegated to packaging or surface treatments and not involved with the development of the inner workings which remain the domain of the electrical engineer and computer programmer, **Figure 5-1** (Weil, "Bag" Radio, 1981). This represents a gap between the design of electronic and computational objects, which includes robots, and their aesthetic surface design as it relates to their perceived identities. As was established in Chapter 3, electronic-textiles are developing the core functionalities of robotics: sensing, actuation and computation. They are now capable of merging the surface and the inner workings, but new design principles and methodologies must be considered as the surfaces themselves will encapsulate the core functionalities.

Sartorial cues are well studied in human-human social interactions and are subtle but pervasive signals in our social interactions. In a way, we are constantly viewing each other through a sartorial lens where we are both consciously and subconsciously trying to interpret sartorial signals. We must then consider the robot aesthetic through this sartorial lens and understand that if the public has an eye for interpreting and decoding sartorial cues, then the lack of explicit clothing in robotics, particularly humanoid robots, means that the robot form itself will be interpreted as a sartorial element. Additionally as surfaces become active elements in robotics, for example the sensing suit constructed for ASIMO, then the perception of the surface as a sartorial element might increase.

Figure 5-1. *Daniel Weil's 'Radio in a Bag' 1983 exhibiting the designer's role in electronic objects.*

Electronic-textiles and fiber-electronics represent a morphology shift in the physical components with which robots are designed and built. This means that robotics, in particular their surfaces, can become more flexible and soft and become an integrated component of the entire system providing sensing, actuation and even computational abilities, and so the design space must reflect this shift and movement towards integrating the surface with the robot's core functionalities. The change towards a soft-architecture aesthetic will have a particular effect on human-robot social interactions, the field of social robotics. Social Robotics focuses on human-robot interactions in human-centric terms, *i.e.* natural language processing, facial expressions and gesture. Although it is often overlooked in robotics, fashion and clothing are modes of social nonverbal communication. In the same way gestures with the hands or the body are considered nonverbal communication, gestures with clothing can communicate as well. Consider a person rolling up their sleeves preparing for some hard work or how a wrinkled, untucked shirt might indicate a disorganized state. Studying fashion and clothing as a means of nonverbal communication however, presents an opportunity to explore where our human sartorial language of clothing and soft-architecture robotics can converge. How might soft-architecture robotics be utilized for social interaction? What will guide the design processes?

The design principles being developed here for sartorial robotics aim to develop a sartorial language/ecology for building robotic systems and surfaces that will utilize traits derived from the existing human *system of clothing*. One guiding principle should be that these surfaces should take advantage of both clothing's unique mechanical and semiotic characteristics to encourage social communication in human-robot interactions. To begin, we need to investigate the cultural phenomenon of fashion/clothing and how it can be used for social signaling and nonverbal communication. Specifically, we should try and determine a method to analyze sartorial signals in order to better understand them during the design process and also simplify them in order to incorporate them into robotic systems. Therefore, we should classify the types of sartorial signals we intend to utilize.

Public and Personal Sartorial Signals

When Barthes describes fashion as asking the question *Who am I?,* he is suggesting that fashion is a form of play with our identities. The simple act of doffing a suit jacket and loosening a necktie and rolling up one's sleeves transforms the business suit from formal business to casual and relaxed. Fashion then employs clothing as a medium to allow us a means to play with our identities. Dressing then, can be viewed as an act of assemblage, where the donning and doffing of articles of clothing or layers becomes an everyday performance of identity. However, from a design perspective, how might we be able to categorize these sartorial cues in order to utilize them in designing robotic systems and wearables? Sartorial cues can be categorized into two types of signals, *public signals* and *personal signals. Public signals* would include reflections of well-known societal roles and would include sartorial treatments like uniforms for identifying occupational roles or perhaps gender-centric clothing to identify gender within a culture. These types of sartorial cues are intended to communicate during brief periods of time as in the case of first impressions or casual passing interactions and so rely heavily on a common set of cultural apparel norms that are well understood by the public. *Personal signals* are more a reflection of the individual's choice and style, fitting more within the concept of playing with one's own identity. Both *public signals* and *personal signals* can be used together. For example the traditional men's business suit with a dark solid color and notched label might be considered the uniform of the financial industry, but doffing the jacket and loosening the necktie would be a personal signal indicating the wearer's transition from the formal and organized working environment to a more casual and relaxed state. We need to understand the many individual elements that might define a fashion and communicate a sartorial signal and develop a method to better analyze fashion.

The Formulaic Approach to Analyzing Fashion

In the study of social robotics facial expression has been a key area of focus and the Facial Action Coding System or FACS has long been used to analyze facial muscles responsible for facial movement (Friesen, 1978). Later work has taken the facial movements and mapped them to expressions, thus providing codified facial expressions, *i.e.* happy, sad, afraid, bored, etc. for roboticists to more easily utilize in social robotics development (Ekman, 2002). While the human face has a limited number of facial muscles and coordinated movements (head movement, eye movement), it thus has a limited number of potential facial expressions. In contrast to a limited number of expressions, clothing systems have virtually limitless variables because of layering and accessorizing, and so a rigid codified method of analysis is problematic. In addition, variations in social and cultural perceptions add yet another obstacle to any universal interpretations of fashion, but in an effort towards a conceptual or theoretical framework we can build upon Barthes analysis of the language of fashion in order to provide a structure for social roboticists to understand potential robotic surfaces.

Barthes discusses fashion from the perspective of the clothing itself, but clothing that, as one singular object, has at least three underlying structures: *real-clothing*, *image-clothing* and *written-clothing*. *Real-clothing* is defined mainly by the technical and mechanical means of producing a garment, that is, the drawings, pattern pieces and seaming used in its construction. *Image-clothing* is defined by the iconic structures represented mainly through fashion photography where the clothing is displayed on a particular model, in a particular setting, all in an effort to add to the perceived image of the clothing (Barthes, 1990). Barthes as a linguist and semiotician focused heavily on the *written-clothing* as it represents the verbal structure of the garment and how we as a society or culture would discuss and relay fashion to each other using basic descriptive words. For example in describing a skirt one could define it simply as *long* or *short* but also indicate the fabric type in which one could describe the graphical pattern as *plaid* or the fabric's texture which could be a *scratchy wool*. Any one of those descriptive qualities could be used in describing the skirt but some will have more impact on the sartorial signal being communicated than others. While there are other methods and structures, we will focus on Barthes's *written-clothing* as a method to attempt analyzing and defining the question *what is fashion?*

Barthes attempts to describe fashion in a formulaic method, not in a mathematical structure, but based on the verbal structure of *written-clothing*. He begins with the *object (O)* which might be defined as the basic form of clothing - a shirt, a pair of pants, a dress, with little if any other descriptive properties.

Interestingly enough in the pattern making process, apparel designers often use a *sloper*, which is the basic pattern of a garment, *i.e.* shirt, dress, pants, that lack specific details so that a *sloper* can be used to generate many different designs simply by adding details and making adjustments to the core *sloper*. The *sloper* is what Barthes might call the foundation for a basic apparel *object (O)*. Building upon the apparel *object (O)* we next consider the *supports* (S) which might be defined as individual elements within the *object (O)* so a shirt, for example, might have a collar, sleeves or pockets. These sartorial elements do not usually exist on their own but are dependent on the *object (O)*.For example a pocket cannot fully exist on its own because it needs to be attached to a shirt or pant. Finally, the *supports (S)* are then further described with *variants (V)* which are more physically descriptive terms. For example a *shirt (O),* would have a *collar (S)* that might be *turned up (V)* or *turned down (V).* In this example, either *turned up* or *turned down* would be the *variant (V)* which would help define the appearance of the clothing and thus define its fashion status, **Figure 5-2**. For example, an upturned collar on a shirt could easily transform the simple shirt into a preppy fashion. There are of course exceptions to these definitions and fashion cannot always be so easily decoded but this does provide a framework to build on.

$$\frac{\textbf{\textit{shirt with collar open and sleeves up}}}{\textbf{\textit{O}}\qquad\quad \textbf{\textit{S}}\quad \textbf{\textit{V}}\qquad\quad \textbf{\textit{S}}\quad \textbf{\textit{V}}} \equiv [\textbf{\textit{Casual}}]$$

$$\frac{\textbf{\textit{shirt with collar closed and sleeves down with tie}}}{\textbf{\textit{O}}\qquad\quad \textbf{\textit{S}}\quad \textbf{\textit{V}}\qquad\quad \textbf{\textit{S}}\quad \textbf{\textit{V}}\qquad \textbf{\textit{S}}} \equiv [\textbf{\textit{Business}}]$$

$$\frac{\textbf{\textit{a sweater with a boatneck collar}}}{\textbf{\textit{O}}\qquad\qquad \textbf{\textit{V}}\quad \textbf{\textit{S}}} \equiv [\textbf{\textit{Fashion}}]$$

Figure 5-2. *Roland Barthes's formulaic approach to analyzing fashion through deciphering word-clothing.*

This formulaic approach to analyzing fashion provides, from a design perspective, a method to understand individual clothing components of fashion and understand their combined potential meanings. In this manner individual clothing components can be investigated and evaluated to gauge their impact.

Core Functionalities: Sensing, Actuation and Computation

The field of robotics tends to focus on some core functionalities which include sensing, actuation and computation. Sensing involves using sensors or other methods to gather and receive information about their environment. Actuation is the ability of a robot to either move through the environment or manipulate the environment or objects within it. Computation allows robotic systems to process the gathered information in order to make decisions and guide their actions. However, computation is not just the technical ability to process information but also includes its underlying rational. For our design principles of sartorial robotics we can extract the functionalities of sensing, actuation and computation as design elements but with a focus on the sartorial. The intended goal is a sartorial robotic system that could respond to an interlocutor's sartorial expressions (cues) and then play with its own surfaces creating the opportunity for nonverbal communication.

Sensing: Sartorial Detection

Although sartorial communication and cues do not follow a traditional turn-taking dialogue, a sartorial robotic system should encompass a vision-based system capable of identifying surface traits in clothing like texture, such as wrinkles, folds and creases, along with graphic patterns like prints and solid colors. They should also be capable at recognizing sartorial actions like donning or doffing. Research by Pieter Abbeel, at UC Berkeley, is focused on robots learning to fold clothing utilizing a vision-based system and custom algorithms to demonstrate the effectiveness of a general-purpose two-armed robot, the PR2, manipulating and folding towels, socks and shirts (Miller, Van den Berg, Fritz, Darrell, Goldberg, & Abbeel, 2011) (Wang, Miller, Fritz, Darrell, & Abbeel, 2011) (Miller, Fritz, Darrell, & Abbeel, 2011). While the work may focus on performing tasks like laundry folding, it is however providing the foundation for understanding and generating a taxonomy of sartorial elements albeit not yet for sartorial communication. In order to fold a shirt, the system must first recognize a shirt from a sock or pants or any other article of clothing before deciding on a folding method, essentially the system must determine, as Barthes would suggest, the sartorial *object (O)*. Robotic imaging systems and computer vision already have the capabilities to detect some basic sartorial cues as exhibited by interlocutors, as we've previously seen in discussing the background work with the Microsoft receptionist project classification of formal and casual dress. However, input systems like Microsoft's Kinect with range imaging and depth sensing capabilities make identifying a person's silhouette and specific body areas easier and thus would allow for more in-depth analysis of clothing characteristics. In fact, the Kinect's IR depth sensor has enough depth resolution to detect wrinkles in clothing (Mlot, 2013). This level of precision would not only be capable of determining if your clothes are wrinkled or pressed but also detect more subtle technical sartorial details like fit, drape and construction lines. Because of the ever evolving landscape of fashion trends and styles, a vision-based learning system for creating an ongoing taxonomy of fashion is recommended.

Sartorial Actuation

In addition to sensing, it is essential to determine how a robotic system would actuate clothing and surfaces: to wrinkle or fold, to present graphic patterns or to signal donning and doffing or otherwise mimic the physical ability of clothing to exhibit sartorial cues. For example, how might a robot roll up its sleeves to indicate it is preparing for work? Specifically it does not yet seem practical for robots to dress or control their surfaces themselves in the same manner we do. The act of donning and doffing is quite a difficult task for a robot requiring a considerable amount of flexibility and dexterity. It is still however crucial that they possess control over their own surface appearance. For this reason, the actuation or control should be located to the surfaces themselves. Existing soft-architecture actuators like shape memory alloys and electroactive polymers are potential options for soft-architecture actuation but because these technologies often lack a significant amount of mechanical force, augmenting traditional apparel closure techniques and hardware with robotic attributes should also be considered. The intention would be to incorporate these into robotic systems for clothing and surface manipulation. Through actuating closures, textiles could potentially shape shift or self-assemble into a variety of forms. Physical movement is not the only means of creating a dynamic surface. Thermochromic and electrochromic materials are also potential options for sartorial cues utilizing color. While it may be difficult for a robot to assemble layers of textile to mix and match colors, controlling a thermochromic or electrochromic patterned textile is within its abilities. As a design principle for sartorial actuation focus should be on maintaining control over the surface appearance by shifting actuation to the surface instead of manipulating the surface with, for example, robotic end effectors.

Sartorial Computation

By sartorial computation we do not necessarily mean that computation must be done at a textile or fiber level as demonstrated with Yoel Fink's research into fiber-based electronic devices; we mean that the sartorial information gathered through sensors and the sartorial actuation exhibited must coordinate or be guided with principles that are based on our social or cultural expectations of fashion. There should be some fashion theory that guides the behaviors in sartorial robotics. There are a variety of interpretations of fashion and what may constitute fashion theory, but at its core is the understanding that clothing is nonverbal communication about individuals and groups and as such, clothing is code for social identity (Davidson, 2009). The dressed body, as opposed to other fashion embodiments, is critical to the definition of sartorial robotics, specifically as it relates to the aesthetic form of the robot.

We can summarize the main design principles for *Sartorial Robotics*:

- Utilize the formulaic approach to help understand fashion. Emphasize the *support (S)* and *variant (V)* structure.
- The *variants (V)* of the *support(S)* elements have the largest influence over the *object (O)* and the perceptions of the overall fashion.
- Clothing is uniquely human and robots come in a variety of not-quite-human forms. Adopting off the rack clothing for robots may have negative effects by approaching the uncanny valley[9]. Focusing on the *support (S)* elements avoids this conflict.
- Sartorial Detection: Robotic systems should be able to detect basic sartorial cues as exhibited by interlocutors. Computer vision would be the primary method.
- Sartorial Actuation/display: It is essential to determine how a robotic system would actuate surfaces in order to wrinkle or fold, to present graphic patterns or to signal donning and doffing or otherwise mimic this ability.
- Sartorial Behavior: To guide a robot's responses to any given situation a behavior system based on fashion theory and sartorial language must be constructed. In order to make sense of the clothing cues that are being detected and displayed a social and cultural understanding of clothing must be used as a guide.

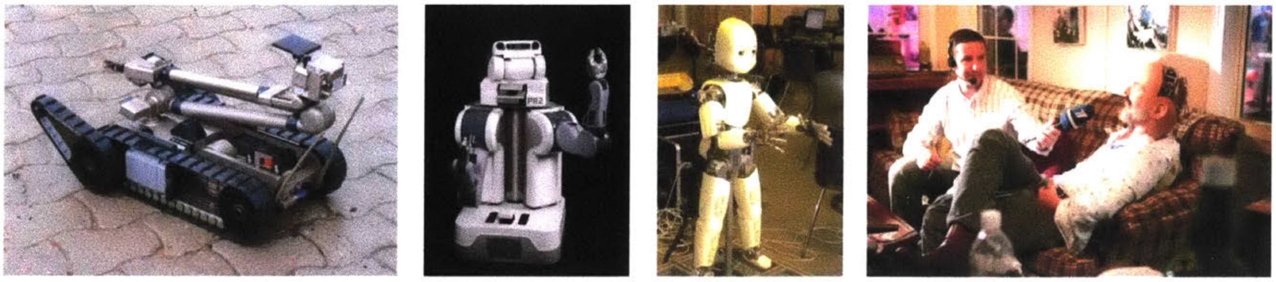
[9] Professor Masahiro Mori's *Uncanny Valley* hypothesis is in relation to robot aesthetics. It maintains that as a robot approaches a more realistic human likeness our comfort level increases, but at a particular point the human likeness isn't quite a perfect match to a real human and our comfort level drops dramatically towards revulsion (Mori, 1970).

Utilizing Apparel Techniques

Clothing, the language of fashion and the dressed body, is dominated by the use of textiles and fabrics and as previously cited, robotic technologies are undergoing a morphology shift towards soft flexible planar electronic materials. As such, utilizing apparel techniques to develop and manufacture soft-architecture robotics should be explored and adopted. Through experience cited with the Honda ASIMO project, apparel design techniques were critical in understanding the textile sensor transition from 2D patterns to 3D constructed forms and understanding the relationship between fabric kinematics and the robot body in motion. In addition, the apparel discipline obviously understands the language of fashion and is acutely skilled in identifying and utilizing sartorial cues in their designs. The apparel design field is primarily a practice of traditional artistry and craftsmanship and has been reticent to merge with CAD/CAM practices which have been more rapidly adopted by engineering disciplines that govern the field of robotics. The apparel field is slowly beginning to adopt digital practices but more cross-discipline pedagogical work between apparel design and robotics engineering should be developed to bridge the two fields.

Diversity of Robot Forms

When discussing sartorial cues intended for robots to utilize, it is beneficial to understand the various aesthetics within the robotics field. In the historical development of the aesthetics of robots, traced earlier from Čapek's robots to Westinghouse's Electro, the fictional robots portrayed a human aesthetic that drifted toward a machine aesthetic in conjunction with the Industrial Revolution. The aesthetic shifted from a human-like appearance with skin and clothing to metallic and machine-like one. Today we have more real-world examples of robotics to reference which illustrate a range of aesthetics running the scale all the way from machine to human. There are a variety of different classifications for robots, some of which can be defined both by their technical design as well as their aesthetic design. Since the focus will be adopting sartorial cues that are exclusively the domain of human activities the emphasis will be on defining them based on human-like aesthetics or human-like similarities scale.



Machine | Anthropomorphic | Humanoid | Android

Figure 5-3. *Examples of robot aesthetics ranging from machine to android illustrating the variety of robot body shapes and forms.*

Robots embody a variety of shapes and forms, representing a range of aesthetics, spanning from machine to almost human-like in appearance, **Figure 5-3**. We will define some key aesthetic differences found in the field of robotics that we can begin to categorize along a human-like similarity scale. The general appearance for the *machine aesthetic* might have exposed robotic components such as wires, servos, and printed circuit boards as well as a visible metal chassis. The outer form may be a designed housing which would have little if any resemblance to human features. A distinct head and face are probably not used unless highly abstracted. The form factor would be open to almost any form although for a consumer application the robot might adopt a familiar form of a pre-existing product, like a tool or household appliance form. The iRobot Roomba is an example of a machine aesthetic. The general appearance for a robot with an *anthropomorphic aesthetic* has geometrically abstracted human body-like forms. Not all body forms need be represented, for example, an articulated arm on a motorized wheeled base would qualify. A head and face would be optional, and if used would be generalized, abstracted or of a caricature level of detail. Sensor like cameras or depth range finders might be present where the lenses often vaguely resemble eye-like features. The general appearance for a robot with a *humanoid aesthetic* would have no exposed mechanical or electronic components. Head and face are definitely present and have a generalized, abstracted or a caricature level of detail. The form factor more closely mimics human forms and resembles the human body with head, torso, arms and legs although it might also have a wheeled base. General appearance for an *android aesthetic* would focus on an accurate detailed appearance of a human body. The head and face should be fully articulated with high level of detail. Details such as skin, hair, and finger nails are present but serve little if any functional role and are only included to visually mimic human appearance.

It is critical to understand the variety of robot forms and their relationship to the human form because the sartorial language has been uniquely developed to aid the human body's ability to communicate and thus presents a coupled aesthetic with the human body. Professor Masahiro Mori's *Uncanny Valley* hypothesis, in relation to robot aesthetics, maintains that as a robot approaches a more realistic human likeness our comfort level increases, but at a particular point the human likeness isn't quite a perfect match to a real human and our comfort level drops dramatically towards revulsion, **Figure 5-4**. As the robot continues on a path towards human likeness our comfort level again increases (Mori, 1970). The *Uncanny Valley* can be attributed to conflicting perceptual cues, in that, the robot may look human but subtle cues, for example non-fluid robotic movement when the human appearance creates the expectation of smooth organic movements, presents a cognitive mismatch.

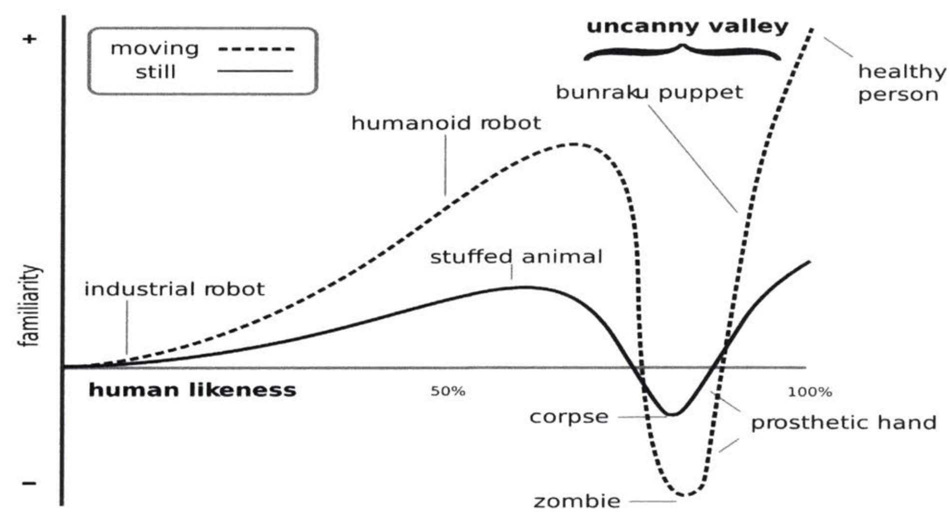


Figure 5-4. *Professor Masahiro Mori's Uncanny Valley hypothesis for human aesthetics in robotics illustrating a drop in comfort level.*

False perceptions of the robot's performance or abilities will undermine the human-robot interaction relationship. The Cognitive Neuroscience and Neuropsychology Lab at UC San Diego has been studying the neural signatures of the *Uncanny Valley* using functional magnetic resonance imaging (fMRI). In comparing a *humanoid robot*, an *android* and a *human,* fMRI scans indicated that the *action perception system* (APS) region of the brain, where perception of body movements and actions is processed, was especially active for the android condition, **Figure 5-5** (Saygin, Chaminade, Ishiguro, Driver, & Frith, 2011). Lead researcher, Ayse Pinar Saygin, assistant professor of cognitive science at UC San Diego summarized their findings (Kiderra, 2011).

The brain doesn't seem tuned to care about either biological appearance or biological motion per se . . . What it seems to be doing is looking for its expectations to be met – for appearance and motion to be congruent.

- Ayse Pinar Saygin

The humanoid robot condition and the android condition are the same robot, the only difference is that the surface elements *i.e.* skin, hair and clothing were removed to reveal the mechanics and electronics underneath (Saygin A. P., 2012).

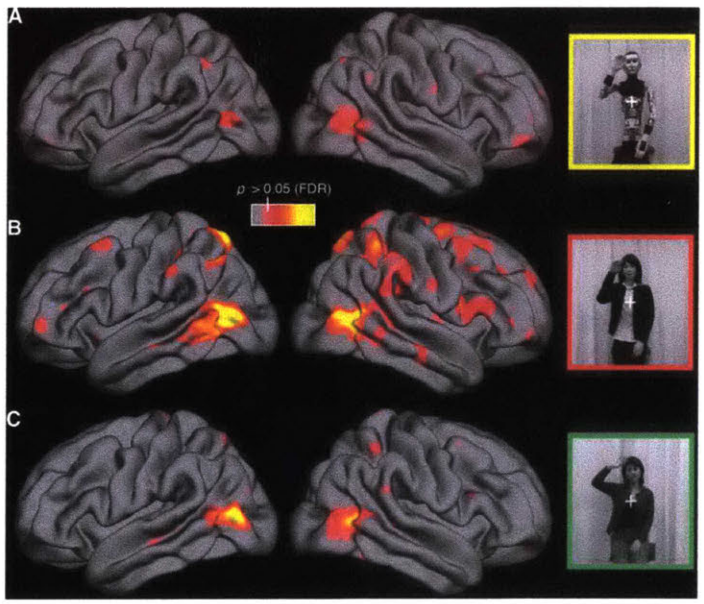


Figure 5-5. *Neural signatures of the Uncanny Valley showing fMRI scans of the brain viewing a robot, android and human.*

This is a significant detail as it indicates that the addition of surfaces on a robot can affect people's perceptions in a negative manner towards the *uncanny valley*. The surfaces not only represented a mixture of artificial skin and artificial hair but also included clothing. We must consider that clothing is such a uniquely human characteristic that it represents a human appearance on par with our accepted biological appearance. In relation to robots displaying sartorial cues, the design principles reflect that it may not be suitable for robots to utilize clothing specifically intended for humans to wear. We probably shouldn't dress robots in *our* clothing but instead extract the desired sartorial cues and design the surfaces specifically for them, creating a sartorial robotic surface.

Telepresence Robots

Given the diversity of robot forms: machine, anthropomorphic, humanoid and android, special consideration must be given to robots intended for telepresence applications. Telepresence applications differ from other robot occupations and tasks and specifically from teleoperation applications precisely because the operator is intended to embody the robot and socially perform via the robot's form and functional abilities. Robots intended for telepresence applications should certainly consider the implementation of sartorial cues in order to allow operators to customize their robot in regards to preferences of culture and gender as well personal identity preferences. In situations where multiple people use a telepresence robot, it would be advisable to design a form and appearance that is culture and gender neutral, but could be modified in that regard with a modular sartorial system to personalize or customize the robot per the users liking or to comply for example to a formal or informal occasion as we observed from the anecdote of the *QB Avatar* telepresence robot deployed at a series of wedding events. Telepresence robots are particularly unique because they are intended to represent people who will desire to *play with identity*. In a way we should consider a telepresence robot as a *set of clothes* or an *outfit* one wears.

Sartorial Robotics on People

In discussing sartorial robotics, these surfaces can be utilized on both robots and humans. However, since clothing is historically intended for people, we can follow more or less the usual apparel/fashion principles of design, but must consider how robotics will augment our existing landscape of sartorial communication. Researchers, technologists and artists have all explored applications in wearable computing; however the field of robotics and specifically soft-architecture robotic surfaces introduce another dimension to wearable computing. Given our clothing's unique and intimate position with our bodies and identities, one of the most significant issues will be control. That is, if we are to wear a robotic sartorial surface that acts either autonomously or semi-autonomously then in essence we are sharing our identity with an other. This raises several questions. Who and how are they controlled? Are the actions attributed to the wearer or perceived as something other? These issues will be explored in the evaluation of the demonstration project, *Zipperbot*.

Develop Series of Demonstration Projects for Sartorial Robotics

In summary we've examined group and individual sartorial signaling and developed a formulaic approach to analyzing sartorial cues which assists us in designing sartorial interactions. We examined a variety of robot forms in relation to the dressed body and highlighted the potential difficulty in directly adopting human clothing, and instead we recommended extracting the desired sartorial cues and then utilize *support (S)* and *variants (V)* methods as opposed to *objects (O)*. The next chapters will present the research and the development of sartorial robotic surface projects. Each project will explore a particular theme: sartorial detection, augmented surfaces and sartorial computation. The projects were researched and developed in tandem so that each individual project references the work done for the other.

Chapter 6

Group Identity Surface

This chapter presents a sartorial robotic project built upon the information gathered during the research and development of the design principles and framework for sartorial robotics in the previous chapter. The *Group Identity Surface* is a sartorial robotic surface which detects sartorial cues, exhibits its own sartorial cues and utilizes fashion theory based behaviors to facilitate group identity and represents a logical extension of the design framework. The *Group Identity Surface* as a robotic sartorial system would detect an interlocutor's clothing color, process the color as a uniform cue, and thus determine team identity, and then display a sartorial cue of its own by changing color via a thermochromic textile. The surface was constructed in order to demonstrate the feasibility of combining robotic systems and electronic-textiles to be used as sartorial cues for nonverbal social communication.

In relation to social human-machine communication, *The Media Equation: How People Treat Computers, Television and New Media Like Real People and Places*, Reeves and Nass present research on how people form teammate relationships with machines, specifically computers. They identified two methods by which people begin to associate machines as teammates, *group identity* and *group interdependence*. *Group identity* requires teammates to share some common identifying feature such as a team name, uniform or even, according to their study, just a color. Group interdependence means that the individual members of a group understand that they all affect one another and share in their performance. Reeves and Nass found that while *group interdependence* was more influential, *group identity* was effective at teammate building as well. Their experiment used a shared team name and team color which consisted of a colored wristband for the person and a matched color border on the computer to help elicit feelings of *group identity* between people and computers. Their work showed that human-machine interactions can be improved by simply having people wear matched colors with computers helping to form teammate identities (Reeves & Nass, 1996). In essence this is the concept behind team uniforms or any sartorial uniform for that matter. The matched clothing acts as a form of priming for social cognition, *i.e.* the team uniforms communicate via appearance that everyone on the team shares a common goal or purpose and is ready to perform; showing up without one's uniform would disrupt that social flow. In the previous example of Robonaut, group identity is being established through sartorial elements; the robot is wearing the same clothing, the space suit, with the same insignias and logos as other astronauts. The robot's surfaces, its clothing, starts to imply a uniform and thus team identity. This type of signaling could be utilized in identification for teammate formation and development of social group dynamics.

The *Group Identity Surface* is a robotic system developed for this thesis which combines an electrically controllable thermochromic textile, a computer vision system and utilizes a teammate belief system through electrically controlled sartorial color matching. Building on Nass and Reeves previously discussed work and utilizing the sartorial design framework established in Chapter 4, a woven narrow fabric for use as a trim or applique was developed which, according to the framework, would act as a sartorial *support (S)* element and so could be applied in a variety of designs for either robots or humans. The crucial difference from Reeves and Nass is that a machine, be it computer or robot, can now control its own surface color and thus determine when and with whom to color match and foster *group identity*. This concept of control is critical, as previously stated by Scambler, *"to be acknowledged as competent social performers we have to be able to give the impression of some degree of control, use and presentation of our bodies."* This project is a technology demonstration of a sartorial system which would allow the robot this level of control.

Group Identity Surface

The sartorial system uses computer vision to perform face detection and recognition, identify the region proportionately below the face and detect the color of a person's shirt. This information could be used to create a color palette of an individual or group of individuals and even track a color trend history. This database is then used to inform an electrically controlled, thermochromic textile to change color in response, resulting in a robotic system that would facilitate human-machine teammate building through matched sartorial identity.

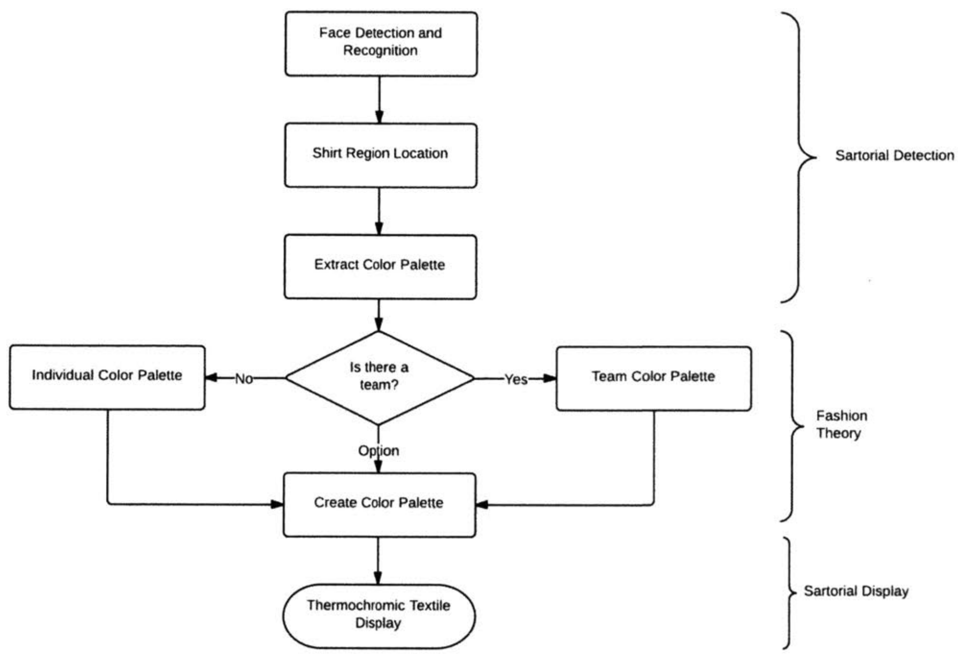


Figure 6-1. *Flow chart depicting the three phases of sartorial detection, fashion theory and sartorial display.*

The flow chart in **Figure 6-1** illustrates the basic processes required to achieve an effective sartorial robotic system, beginning with sartorial detection, continuing to the decision making based on fashion theory and finally taking action by actuating, or in this case displaying a sartorial cue, the color change, through a textile surface. While there are many components and processes involved in this sartorial surface the electrically controlled thermochromic textile is a vital piece for this demonstration project.

Electrically Controlled Thermochromic Narrow Fabric

The main component to be developed for the Group Identity Surface is the thermochromic electronic-textile *support (S)* element. The thermochromic ribbon is a grosgrain woven ribbon with individually addressable thermochromic threads along its warp. Grosgrain ribbon is a narrow fabric, approximately 0.5 to 1.0 inch wide with a ridged texture and a sturdy handfeel that makes it useful as an applique or trim. The grosgrain thermochromic ribbon is formed from a tight taffeta weave pattern using a heavier weft yarn to create a horizontal ribbed base structure similar to a corded fabric. In order to incorporate the electrically conductive threads into the ribbon, four warp rib channels were added into the weaving process. This allowed the conductive threads to be directly inlaid into the weave structure and to be fully concealed by the warp rib threads. It is also worth noting that the tight weave structure provides some electrical insulating properties. The ribbon can be folded onto itself without electrically shorting. The electrically conductive silver plated nylon threads, which are resistive enough to act as heating elements, are woven in evenly spaced rib channels along the warp weave. A colored thread coated with a two-phase thermochromic flexible acrylic which undergoes a color transformation of black to clear at roughly 31°C or 47°C when heated is sewn directly on top of the channels containing the heating elements, **Figure 6-2**. This configuration allows for each thread to be individually addressable and change from black to the threads intrinsic color when heated. The heating elements were woven into the narrow fabric and ultimately the thermochromic thread could be fully woven as well, but for prototyping they were sewn.

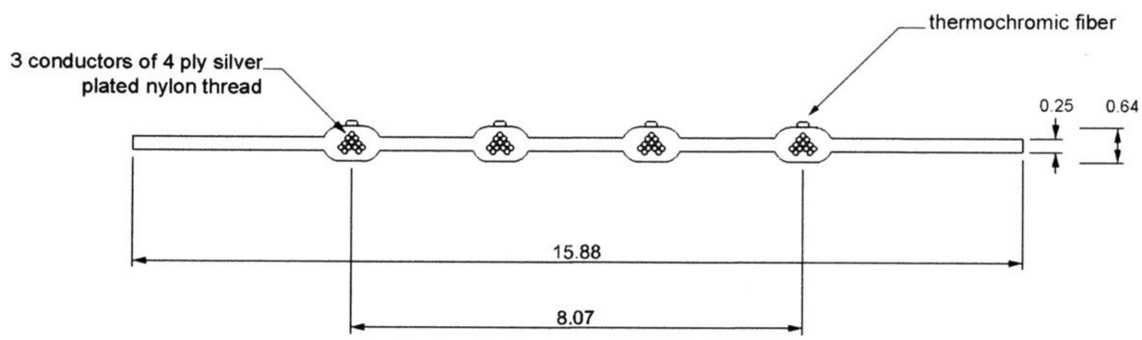


Figure 6-2. *Cross section of the thermochromic ribbon showing the conductive threads acting as heating elements and thermochromic thread configuration. Measurements are in millimeters.*

Although this is somewhat dependent on overall ambient temperature of the environment, the spacing of the heating elements and the transformation temperature allows for individual threads to be activated with little heat transfer to neighbor threads so they do not change color. Ambient temperature also affects reaction time, although for the purposes of color matching with a person's outfit, reaction time is not a crucial factor as people do not change their clothing that frequently. Typically the thermochromic threads can change from black to color within about 30 seconds and resort back to black in about one to two minutes.

Initially a textile dyeing process was considered to add the thermochromic pigment to the colored threads and dye the base polyester ribbon black, but this was not pursued after a separate project I was working on presented problems with the industrial dyeing process. While researching industrial textile dyeing on conductive fibers, specifically silver coated nylon, degradation of the conductive coating occurred from the corrosive nature of the dyeing process.

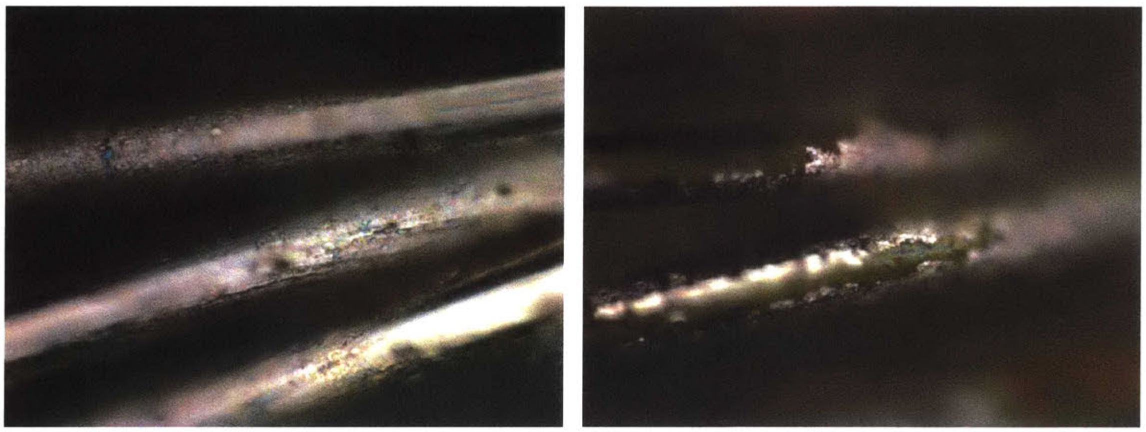


Figure 6-3. *Magnification of silver coated nylon conductive fiber before and after industrial dyeing process 100x magnification.*

Magnification of the fiber before the dyeing process and after the dyeing process shows significant corrosion of the coating and subsequent conductivity measurements show a substantial increase in resistance from approximately 16Ω/ft. pre-dyeing to as high as 80Ω/ft. after the process, **Figure 6-3**.

A custom mix of a two-phase thermochromic pigment and flexible water based acrylic was made and thinned with an additive to increase flow so the acrylic would flow through and form a consist spray with an airbrush. The individual colored threads were then airbrushed to apply the thermochromic acrylic. Several tests were conducted to determine the appropriate number of coats. Too many coats and the thread would appear very black, but the transformation from black to clear would result in a dull or muted colored thread underneath, and the color change would not be very noticeable. Too few coats and the thread would not appear black and the color change would again not be very noticeable, **Figure 6-4**.

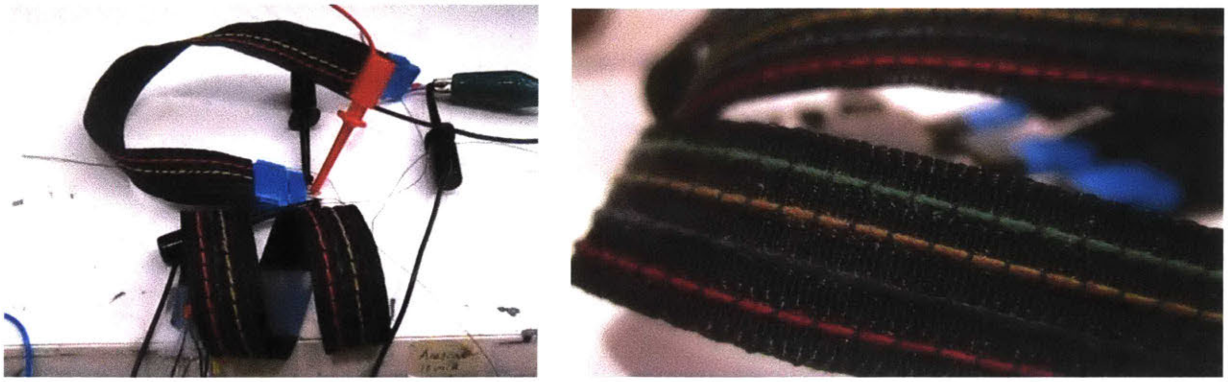


Figure 6-4. *Thermochromic ribbon showing the transformation from black to clear and revealing red and yellow threads (left) Full color (right).*

Within the field of apparel, trim and appliques are in the broadest sense, a smaller element applied to the larger design as a detail. Usually these are fabric or embroidered elements but can encompass just about any added element like sequins, buttons, ribbons and lace. In practice any number of things can be applied. As a design strategy, utilizing trims and appliques to introduce electronic-textiles as sensors or actuation elements is an advantageous method in developing sartorial robotics. The thermochromic ribbon was designed as a potential trim; something to be added to a surface as a programmable color detail. In reference to our design framework it would act as a *support (S)* with the color changing acting as the *variant (V)* element. When coupled with the computer vision system which can identify surface traits such as color, the system could then adjust the thermochromic ribbon to match, compliment or clash with the observed person's color palette.

OpenCV Programming

The software is written in C/C++ and uses the Open Source Computer Vision (OpenCV) library, version 2.1 on a Windows 7 operating system. The following is a basic outline of how the program operates. First, the program captures a 320 x 240 resolution frame from the integrated video camera. Then, it performs face detection based on a trained statistical model called the Haar Cascade Classifier, specifically using a frontal face classifier. In order to do shirt region location, the program then calculates a region of interest (ROI) proportionately below the detected face location which generally results in the chest area and thus focusing on the shirt area. The ROI is then converted to a Hue-Saturation-Value (HSV) in order to analyze pixel colors and determine the dominant color of the shirt ROI (Emami, 2010). As a final step the program updates an extensible markup language (XML) database file with the shirt color, confidence percentage and the current date/time.

Using a laptop integrated video camera for video capture provides real-time information on a person's clothing colors, **Figure 6-5**. The program could then generate a color palette incorporating secondary colors and save the data for a color trend history. Incorporating facial recognition could also add a high level of customization over time.

Figure 6-5. *Shirt color detection in OpenCV using face detection to assist in shirt region location and color palette generation.*

While integrated video cameras were suitable for this demonstration project, input systems like Microsoft's Kinect with range imaging and depth sensing capabilities make identifying a person's silhouette and specific body areas easier and thus would allow for more in-depth analysis of clothing characteristics. In fact, the Kinect's IR depth sensor has enough depth resolution to detect wrinkles in clothing. This level of precision would not only be capable of determining if your clothes are wrinkled or pressed, but also it would detect more subtle sartorial details like fit, drape and construction lines.

Interface PCB Hardware

In the current configuration, the OpenCV program is running on a Dell Precision laptop (specs) with an integrated webcam and running the Windows 7 operating system. The OpenCV program is periodically updating an Extensible Markup Language (XML) file which acts as the sartorial color database. Concurrently a program written in the popular Arduino/Processing programming language and development environment, which is well suited for prototyping, reads the XML database and then communicates externally via a Mini-B USB connector to an Arduino Nano board. The Arduino Nano is based on the Atmeg168 microcontroller and then signals the interface PCB. The interface PCB is responsible for activating the fiber/thread heating elements within the thermochromic ribbon using a basic transistor switching circuit consisting of surface mount resistors and SOT23 NPN-transistors. The Arduino output pins, determined by the Atmega pins, have a limited current capacity. This allows the interface board to receive a signal and switch the higher voltage and higher current loads required to heat the fibers/threads. In the current embodiment of the demonstration project the thermochromic ribbon is approximately 25 cm (9.5 in. to 10.0 in.) in length with an average overall resistance of 23.5Ω. A supply voltage of approximately 5.0V and source current of 200mA is sufficient to heat the conductive thread to the 31°C or 47°C range that will activate the thermochromic transition, but this can vary based on the length of the ribbon.

Figure 6-6. *Prototype printed circuit board and thermochromic ribbon showing the all black off state (left) and the full color all on state (right).*

The thermochromic ribbon interface board allows for the activation of four separate color channels across three thermochromic ribbons, **Figure 6-6**. To interface the textile ribbon with the printed circuit board a four position flat flex insulation displacement connector (IDC) with a 0.100 in. (2.54 mm) pitch was used. The ribbon was actually designed with an approximate 0.100 in. center to center spacing of the warp rib channels containing the conductive threads in order to accommodate this style of connector. The connector is an insulation-piercing type crimp designed to pierce the typical plastic insulation of a wire usually found on non-textile ribbon cables. This type of connector was found to work well piercing/separating the woven structure and making contact with the conductive fibers within the woven channels. This allows for a straightforward and standardized method for integrating an electronic-textile to a printed circuit board.

The *Group Identity Surface* demonstrates the development of an electronic-textile with an emphasis on the *support (S)* parameter and performs as a sartorial display combined with sartorial detection and guiding behavior derived from fashion theory to represent a complete sartorial robotic surface. The surface can successfully detect an interlocutor's shirt color and control an electronic-textile in order to color match with them. The technologies utilized during the development of the *Group Identity Surface* are intended to be easily adoptable. Miniature video cameras are pervasive and integrated into mobile phones, laptops and robots. The face detection and subsequent shirt region and color extraction software are well within the computational abilities of most computing devices and robots as well. The key development of the thermochromic ribbon was done with consideration towards manufacturing processes so that the ribbon might hopefully be produced en masse and that the *Group Identity Surface* as an example of sartorial robotics could be widely experimented with both robots and people. The *Group Identity Surface* establishes the technical feasibility of sartorial robotics through both applying the design principles previously developed and putting into practice the group identity theories of Reeves and Nass.

Chapter 7

Zipperbot

We know from previous studies that clothed and unclothed human bodies will affect how a person's mind is perceived in terms of *agency*, defined as the ability to act, to plan and to have self-control, and *experience*, defined as a capacity to feel pain, pleasure and emotions (Gray, Knobe, Sheskin, Bloom, & Barrett, 2011). Their studies demonstrated that clothed individuals were thought of as possessing more *agency* of mind while individuals with less clothing or no clothing were perceived as possessing more *experience* capacities of mind. The action or gesture of removing a socially constructed barrier like clothing, specifically, the donning and doffing or concealing and revealing of a surface would be considered an intimate act, and shift people's perceptions of the wearer. For this reason the relatively unassuming and often overlooked zipper, as a means for concealing and revealing, can have profound implications for social interactions and therefore makes it an ideal opportunity for exploring sartorial robotics.

Within the fashion and clothing system, the concept of donning and doffing is crucial in constructing the dressed body, be it human or robot. As such, the ability to add or remove sartorial elements or reveal and conceal them is essential. Building upon Barthes analysis of fashion, where he defines *supports (S)* within the fashion structure, the augmenting of traditional apparel closure techniques and hardware with robotic attributes was explored. The zipper, a continuous closure for fabric edge joining, was augmented with robotic attributes such as, sensing, actuation and computation, in an effort to create a programmable zipper closure, *Zipperbot*.

Zipperbot: A Robotic Continuous Closure for Fabric Edge Joining

One of the motivating factors in developing the *Zipperbot* was the complexity and difficulty of having a robot with end effectors manipulate a traditional zipper. The 1964 Mobot Mark II mobile robot invented by Hughes Aircraft Electronic Labs has been presented as assisting in dressing activities but this was mostly propaganda and promotional material. In 2011, researchers at the Nara Institute of Science and Technology in Japan trained a pair of robotic arms to assist in dressing the elderly, **Figure 7-1**. It is not clear that either of these robots, nor many others in the field of robotics, have the dexterity and coordination to manipulate a zipper. While the end effector approach might be appropriate for some types of assistive dressing robots, both the historical and modern versions, it would not be suitable for sartorial signaling and would not be consistent with our sartorial robotic design philosophy of moving robotics more directly towards the fabric surface and integrating robotics into sartorial form factors.

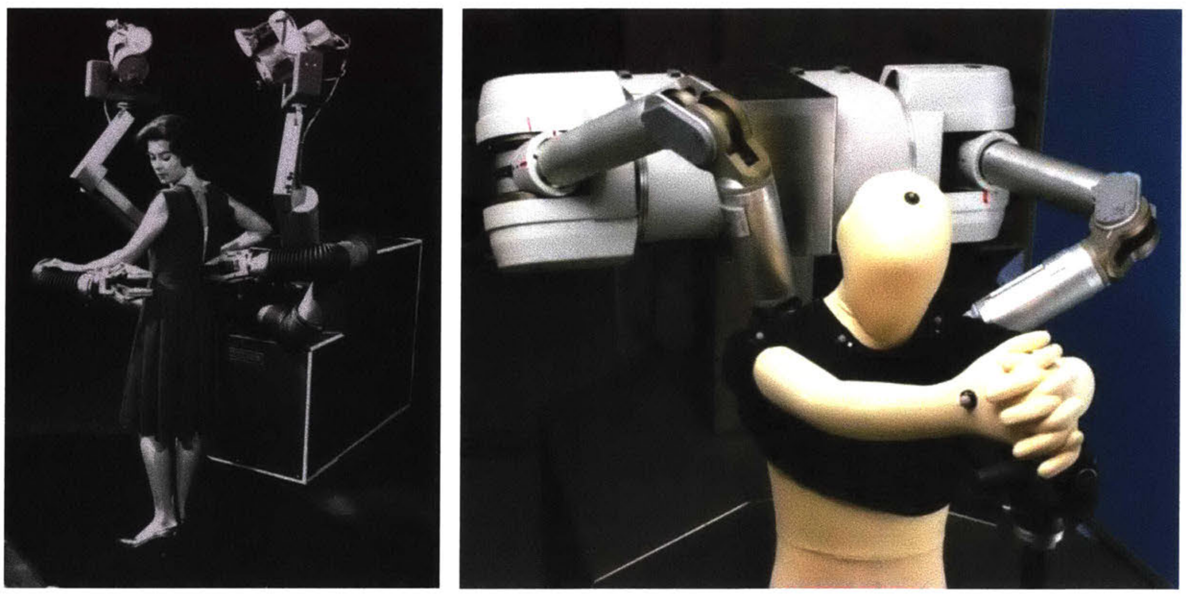


Figure 7-1. *1964 Mobot Mark II assisting woman with dress back zipper and Researchers at the Nara Institute of Science and Technology in Japan trained a pair of robotic arms to assist in dressing the elderly 2011.*

In contrast to end effector manipulation, within the field of apparel there are a variety of methods used to join the fabric edges of clothing together which are used either for aesthetic purposes or simple functional purposes of donning and doffing. Types of closures include, buttons, fabric hook-and-loop fasteners, snaps, lacing, cinched belts and of course zippers and would generally be defined in our formulaic approach to fashion as *support (S)* elements. Within the zipper category there are again several types of zippers, primarily divided into two main groups, coil zippers where the individual teeth are formed by a length of coiled wire and zippers in which the teeth are not coils but are made up of individual pieces of interlocking metal or plastic. *Zipperbot* incorporates a motor and gear assembly for actuation and an optical encoder for sensing its speed and position on the zipper tape and thus its position in relation to the garment. This feedback for control essentially makes the zipper a servomechanism. By moving the robot into the zipper itself, the closure as a *support (S)* would now have its *variants (V)* integrated and controlled within a robotic system. The robotic zipper introduces donning and doffing or revealing and concealing of clothing layers for fashion performance directly to robotic surfaces which could be utilized on robots for sartorial gesturing or on human clothing, not just for the functional process of dressing or undressing but for augmenting sartorial gestures as well.

$$\frac{\boldsymbol{jacket\ with\ zipper\ moved\ up/down}}{\boldsymbol{O} \qquad\qquad \boldsymbol{S} \qquad\qquad\qquad \boldsymbol{V}} \equiv [\boldsymbol{Fashion}]$$

$$\frac{\boldsymbol{jacket\ with\ zipper\ moved\ up\ quickly}}{\boldsymbol{O} \qquad\qquad \boldsymbol{S} \qquad\qquad\qquad \boldsymbol{V} \quad \boldsymbol{V}} \equiv [\boldsymbol{Fashion}]$$

Figure 7-2. *Formulaic approach to understanding zipper variants.*

For example in addition to opening and closing, the speed of the zipper when repositioning itself is controllable and could therefore move more quickly or slowly or even act jittery, offering multiple *variants (V)*, **Figure 7-2**. *Zipperbot* could also respond semi-autonomously to social or environmental situations introducing sartorial behaviors that did not exist before as it would be operating independently from the wearer. These behaviors are unexplored territory for fashion and clothing as a nonverbal communicator.

Mechanical Design

Initial development of the *Zipperbot* began with understanding the anatomy of the zipper, **Figure 7-3,** and taking force measurements on various zipper types in order to determine the amount of force required to move them up and down the zipper tape. Certain zipper types were found to require more force than others and individual zipper teeth seemed to perform better than the coil type zippers and presented a zipper chain with a relatively smooth flat surface. This research led to the selection of a number 5 sized zipper with individual plastic zipper teeth. On average, the number 5 zipper with plastic zipper teeth required about 1.25 N to 1.50 N to zip up and slightly less force about 1.0 N to 1.2 N to unzip. This however can vary greatly depending on the orientation of the fabric being zipped.

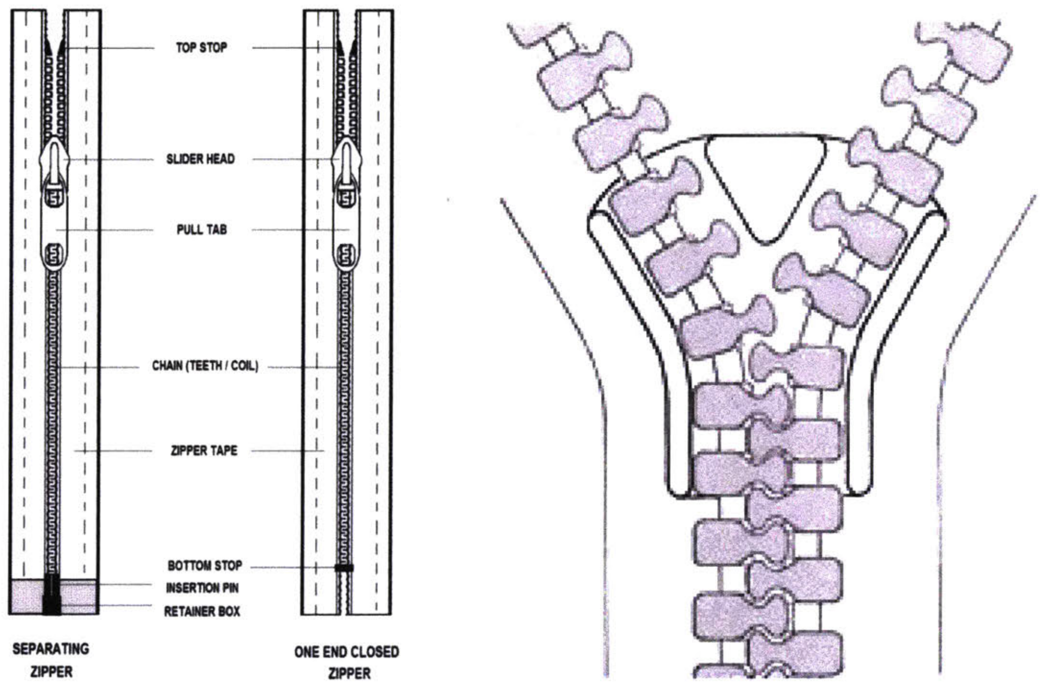


Figure 7-3. *Diagram of traditional zipper to illustrate various components (left) and internal geometry of the zipper slide showing how individual teeth interconnect (right)* (Weiner L. , 1983).

Several motorized mechanisms were then built and experimented with to determine overall feasibility. In order to move itself either up or down along the zipper tape, the *Zipperbot* prototypes initially utilized a rubber roller wheel and relied solely on friction with the joined zipper teeth to drive itself. There was however not enough friction and this caused too much slippage resulting in a stuttering motion and inconsistent speeds. Several types of flexible polymers, *i.e.* rubber with various shore durometers and surface textures were tested, but slippage remained an issue. In order to solve the slippage problem the inherent geometry of the zipper was taken advantage of; joined zipper teeth essentially form a linear gear and so a rigid circular spur gear was designed to fit within the zipper teeth forming a rack and pinion gear arrangement, allowing the rotational motion of the motor and gearbox to be transformed into linear motion which moves *Zipperbot* up and down the zipper tape. Because the joined zipper teeth have an alternating gear pattern, a split alternating spur gear was specifically designed to mate and provide smoother, more consistent motion, **Figure 7-4**. This solution worked quite well.

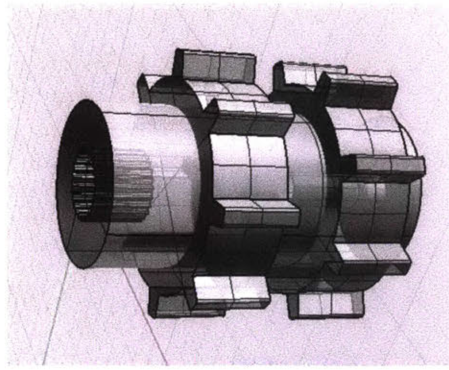


Figure 7-4. *Split spur gear and spur gear meshing with zipper teeth.*

The mechanical design of *Zipperbot* was designed using a combination of 3D CAD software; both the Rhinoceros NURBS modeling software and SolidWorks software were used during the process, **Figure 7-5**. Both were utilized in visualizing how the mechanical parts would fit, interact and function together as well as generate the needed files for fabrication using 3D printing and CNC machining processes.

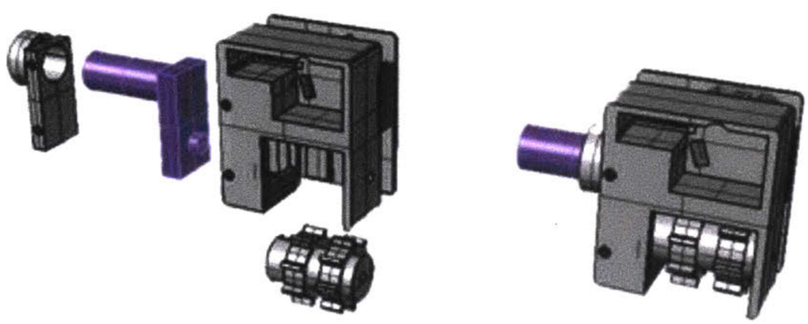


Figure 7-5. *Exploded CAD drawing of Zipperbot components (left) and then assembled (right) as rendered in Rhinoceros.*

The initial prototypes were 3D printed using the *Invision SI2 Multi-Jet Modeling* (MJM) 3D printer using an acrylic photopolymer printing material. There were several advantages to using 3D printing during the prototyping process; the split spur gear was printed which allowed for several iterations to be made in order to make fine adjustments to achieve the best performance. The 3D printing also allowed us to print the chassis and the zipper slide as one continuous piece, again making the iterative design process more feasible. However, the acrylic zipper slide was not robust enough for continuous use and so an aluminum chassis with an integrated zipper slide was developed and adopted. The internal geometry of the zipper slide was not possible to machine into the chassis as one continuous piece so a two part chassis was developed for the CNC machining process and then assembled as a second operation, **Figure 7-6**.

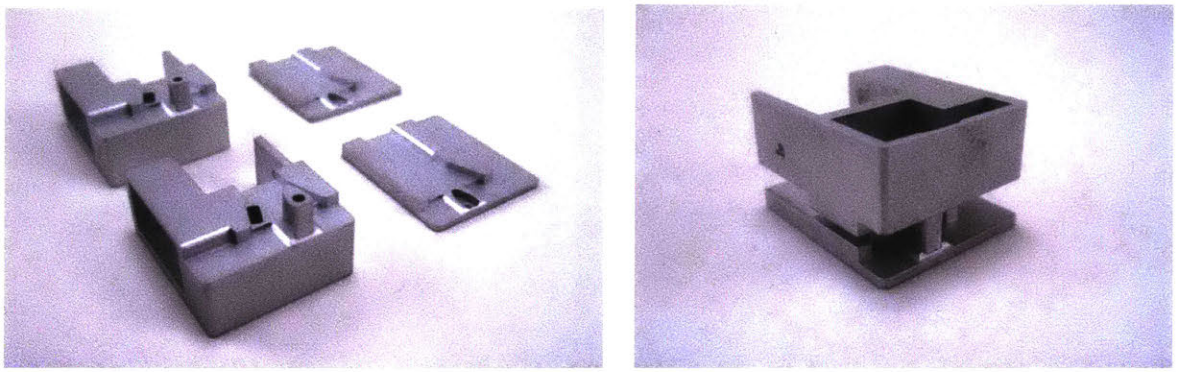


Figure 7-6. *Two sets of machined aluminum Zipperbot two-part chassis before second operation assembly showing internal zipper slide geometry (left) and assembled Zipperbot chassis (right).*

The *Zipperbot* consists of an aluminum chassis with zipper slide geometry integrated into the form. The *Zipperbot* dimensions are 21.03mm x 24.48mm x 14.93mm, and it weighs approximately 20.0 grams when fully assembled which includes the motor, gear box and printed circuit board with all electronic components.

The Motor

The motor and gear box are constructed from a modified servo and operates at a speed of approximately 0.12 sec/60° at 4.8V at a voltage range: 3.0V to 4.8V, stall torque: 0.9 kg/cm (4.8V), gear type: metal and aluminum-magnesium alloy gears, and weighs approximately 3.7 grams. The fully assembled *Zipperbot* can travel at an approximate speed of 2.20 in. per second. **Figure 7-7** shows *Zipperbot* traveling along the zipper tape self-assembling a flat 2D pattern piece into a 3D tube form sleeve.

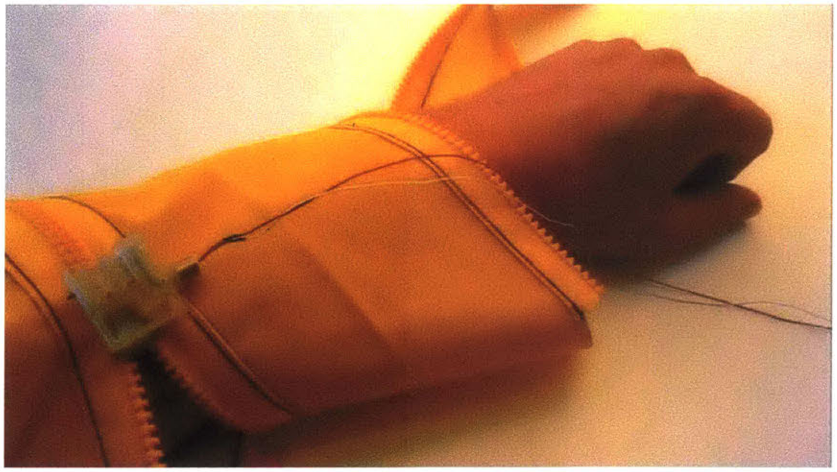


Figure 7-7. *Zipperbot joining a spiral pattern piece to assemble a tube sleeve.*

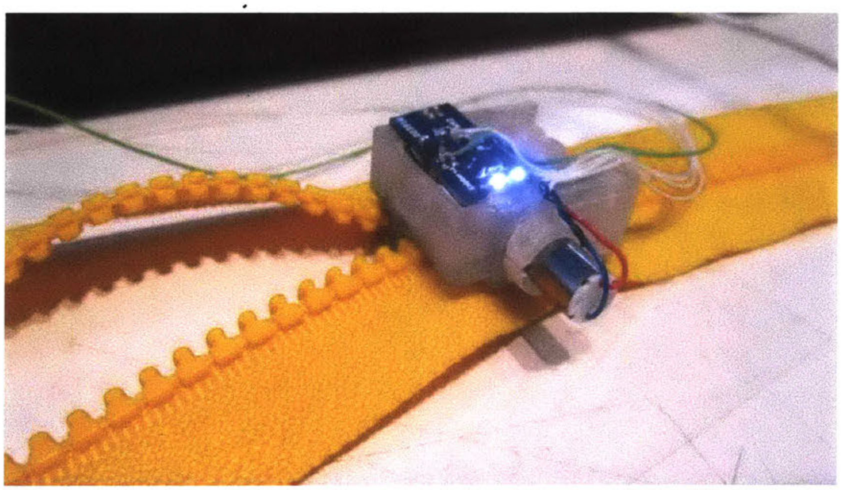


Figure 7-8. *Prototype Zipperbot with 3D printed chassis with integrated zipper slide geometry, motor and position detection.*

The motor and gearbox are positioned on the side of the 3D printed chassis, **Figure 7-8,** although other configurations would be possible. Investigating additional micro motors and gear box assemblies would yield further options as well.

Position Detection

While other position/rotary encoding options might have been available, the miniature form factor of the *Zipperbot* presented some unique challenges in determining its position on the zipper tape. In order to estimate the *Zipperbot*'s position along the zipper tape several optical encoding schemes were tested.

Instead of implementing a traditional encoder on the motor shaft, the sartorial method was adopted and the inherent qualities of the zipper itself were leveraged. Initially a reflective graphical bar pattern was placed on the zipper tape, the textile area which the zipper teeth are attached to. While this method worked it was not ideal as it added an additional construction method to sewing the zipper tape, **Figure 7-9**.

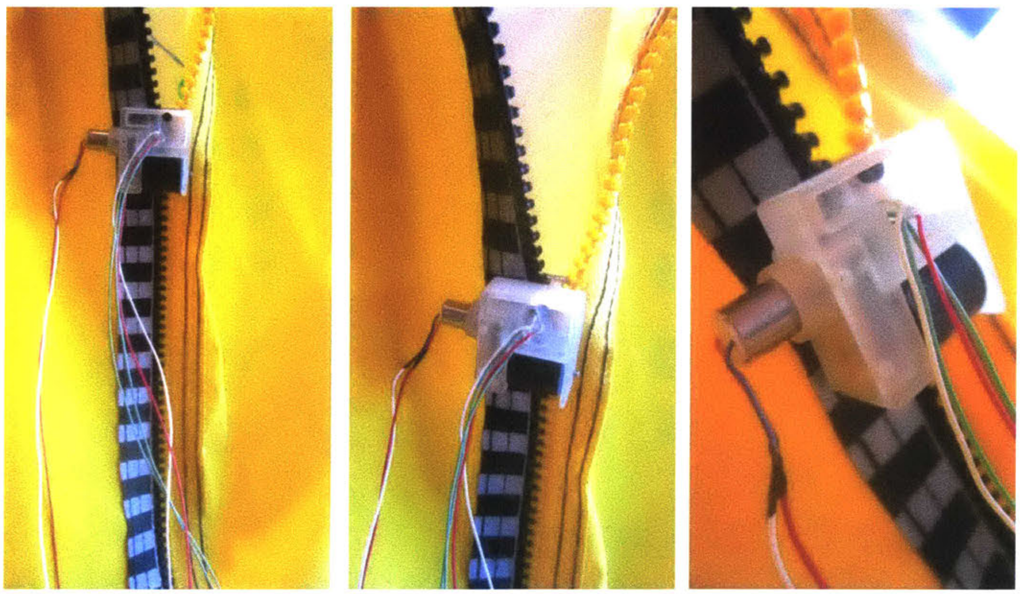


Figure 7-9. *Position encoding based on using reflective fabric sewn on the zipper tape.*

However, the zipper teeth themselves actually provided a solution as zipper teeth are evenly and consistently spaced along the zipper tape and represented a binary pattern: zipper tooth, no zipper tooth, zipper tooth, *etc.*, and therefore they can act as a single output incremental encoder. Detecting this pattern was experimented with to count zipper teeth and therefore gauge position and speed. Several infrared photo interrupters were tested. The Sharp GP2S60 subminiature, reflective type photo interrupter was the appropriate size and geometry for mounting within a zipper slide and was able to accurately detect the edges of the passing zipper teeth. In addition, there are some zippers that have different color zipper teeth that contrast with zipper tape fabric which creates more contrast. To accomplish this an infrared (700 – 100 nm wavelength) reflective type photo interrupter is mounted approximately 0.50mm distance between sensor and surface of the zipper teeth in order to count the zipper teeth as they pass through the chassis to estimate position and speed of *Zipperbot,* **Figure 7-10**. A sub-micropower operational amplifier and comparator are used to generate a clean digital output creating a digital high - digital low signal.

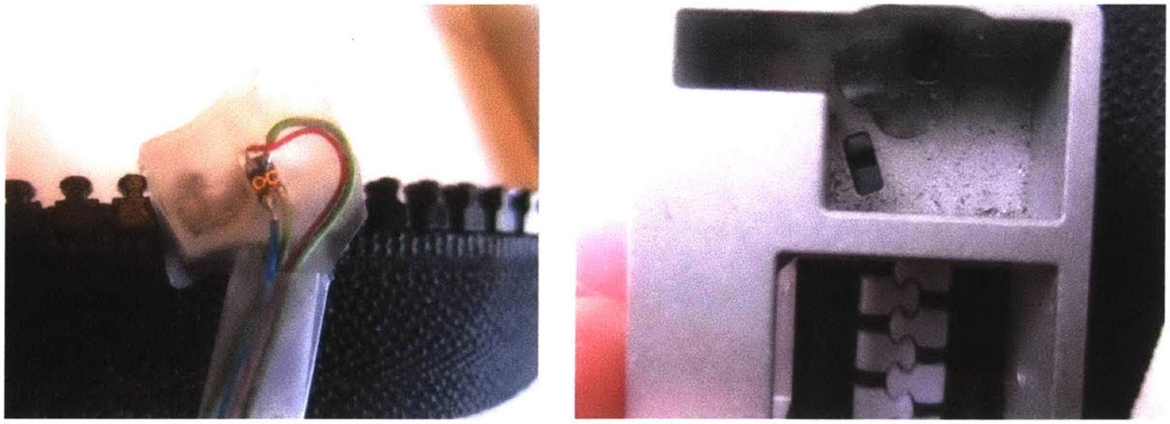


Figure 7-10. *3D printed prototype zipper slide with photo interrupter to count zipper teeth (left). Zipperbot aluminum chassis with photo interrupter cutout positioned above passing zipper teeth (right).*

Printed Circuit Board Design

Zipperbot is designed with a small double-side printed circuit board (PCB) and the approximate dimensions of the board are 19.46mm x 19.66mm. The board was designed and routed using Cadsoft EAGLE PCB Design Software, **Figure 7-11**. The board is responsible for supporting the photo interrupter with a SOT25 adjustable voltage regulator providing 1.2V and a TL072 comparator to make the photo interrupter output signal easily readable via microcontroller.

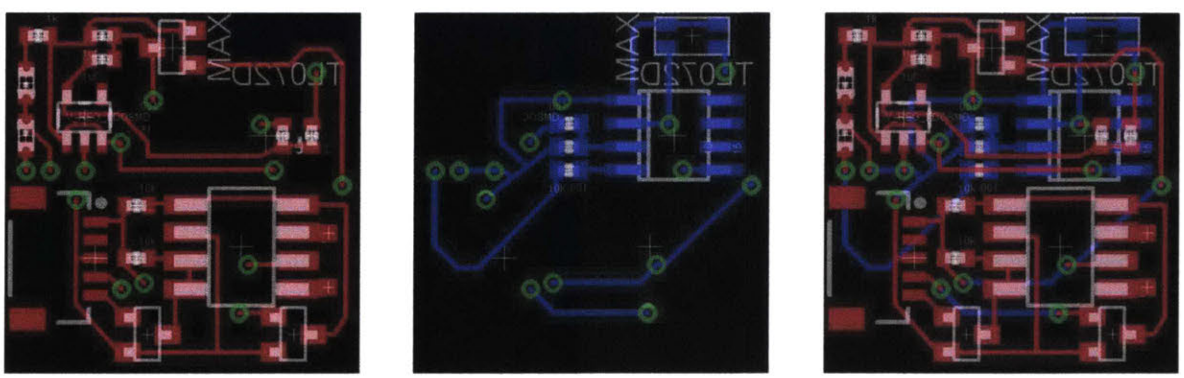


Figure 7-11. *Printed circuit board showing double sided layout, top layer (red) and bottom layer (blue) shown individually and then shown combined.*

The *Zipperbot* PCB also has a ZMEX H-Bridge microchip which is a compact size and can still adequately provide power to the motor. The ZMEX H-Bridge is supported by two SOT23 package N-Channel logic level enhancement mode power field-effect transistors which receive a high/low signal from a microcontroller switching the motor off, on-forward or on-reverse.

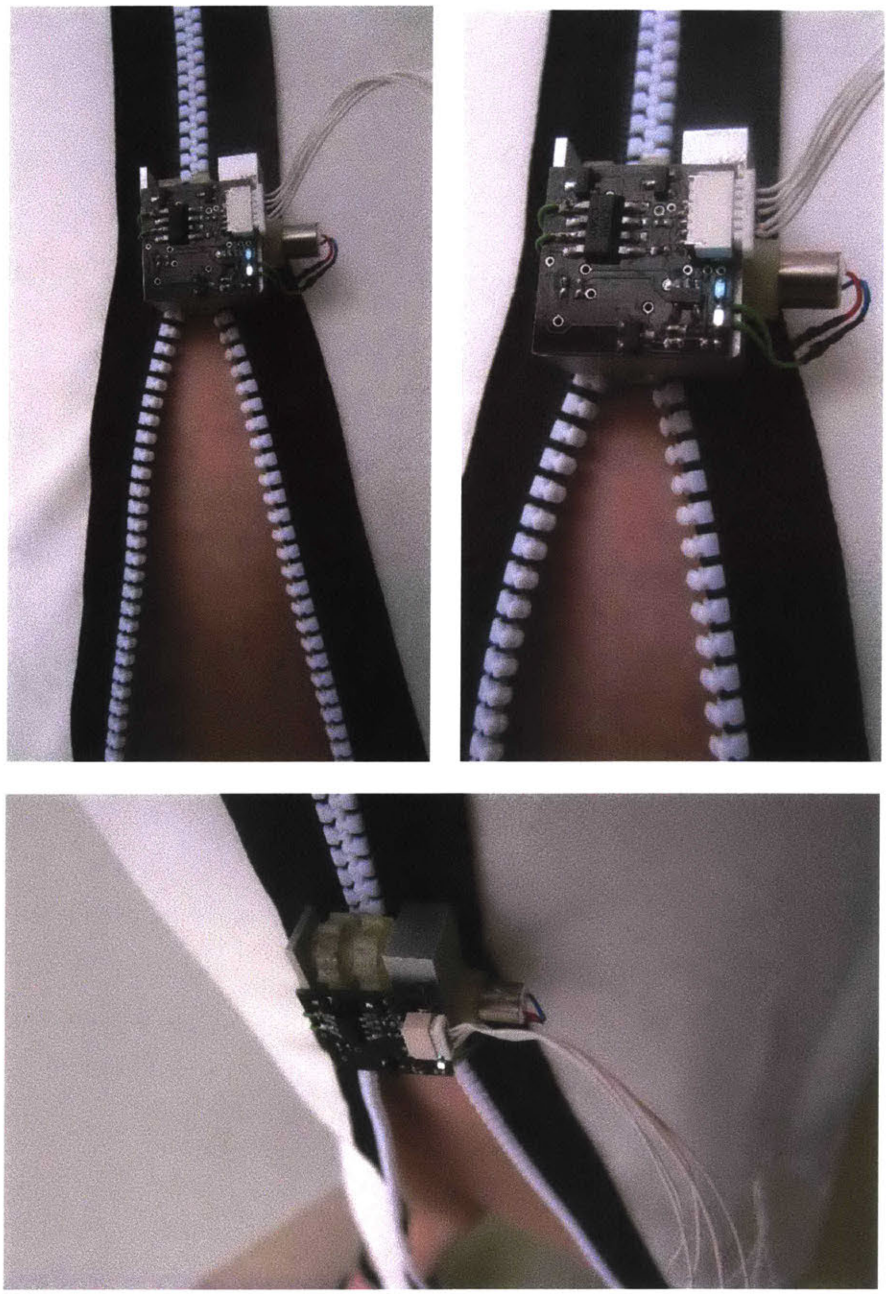


Figure 7-12. *Zipperbot: a robotic continuous closure for fabric edge joining*

The *Zipperbot* PCB has a five pin horizontal 1.0mm pitch JST-SH type connector for external power supply, motor control and microcontroller interfacing. *Zipperbot* has two surface mount indicator LEDs, one to display power status and an additional LED to display the counting of the zipper teeth, **Figure 7-12**.

There were initial plans to integrate an ATtiny45/ATtiny85 Atmel 8-bit AVR RISC-based microcontroller to the board and although there is enough additional space on the PCB layout to accommodate the microcontroller, for experimenting purposes this was not pursued. Instead work focused on interfacing *Zipperbot* with external microcontrollers like the popular Arduino platform and mobile Android devices through the IOIO board.

IOIO Board and Android

Zipperbot is able to interface with Android devices using the IOIO microcontroller (MCU) board which acts as a Universal Serial Bus (USB) host to connect up with Android applications which are programmed in Java. Zipperbot uses IOIO Version 1.0 running bootloader 3.06 and firmware version 3.26 and is connected to a Google Nexus One Android smartphone device running Android version 2.3.6. The IOIO connects with the smartphone wirelessly using a mini Bluetooth USB adapter. The IOIO board is only compatible with a few different models of Bluetooth USB adapters; several which were documented on the IOIO website as functional were tested but were unrecognizable by the IOIO board. However, one model did eventually prove successful. It should also be noted that the Android smartphone must be capable of Bluetooth Serial Port Profile (SPP) and not all Android smartphones have this capability.

Zipperbot in a Hobble Dress

Many potential wearable applications for *Zipperbot* are apparent such as thermal regulation through zipping and unzipping for automatic venting, assistive dressing for those with impaired dexterity and a playful learning to dress game for children. By utilizing the *support(S)* strategy from our sartorial design framework, the *Zipperbot* was able to be fitted into a variety of garments, including a pencil skirt/hobble dress and a light weight outer wear jacket. This allowed us to experiment with a variety of different articles of clothing, styles and sartorial cues.

Figure 7-13. *Zipperbot integrated in a hobble dress and controlled via an Android mobile device.*

The pencil skirt/hobble dress is essentially a dress or skirt that has a narrow enough hem that the wearer's gait is hindered; this fashion was popularized in Western culture by designer Paul Poiret around the turn of the twentieth century (Presley, 1998). While the silhouette of the hobble dress is desirable, the immobility is an obvious inconvenience, but many women are used to sacrificing comfort for fashion. The *Zipperbot* allowed for a more convenient method to transform the fashion state of the hobble dress between emphasizing silhouette and mobility, **Figure 7-13**. Individual discreet robotic elements as opposed to an entire garment integrated with technology illustrate the benefits of *support (S)* design strategy in transforming a garment by modifying the *variant (V)*, **Figure 7-14**.

$$\frac{\textit{dress with Zipperbot moved up}}{O \quad S \quad V} \equiv [Mobility]$$

$$\frac{\textit{dress with Zipperbot moved down}}{O \quad S \quad V} \equiv [Silhouette]$$

Figure 7-14. *Formulaic description of how a Zipperbot as support(S) can modify fashion.*

In addition, the robotic elements themselves can create another layer of *supports (S)* and *variants (V)*. For example the speed of the zipper opening or closing is controllable and could therefore move quickly or slowly offering multiple variables which possibly did not exist before or were traditionally instigated by the wearer's actions. Wearers can control *Zipperbot* with an Android mobile device giving them direct control over the previously difficult to control or manipulate dress slit. It was suggested that the internal accelerometers and gyroscopes of the mobile device could be used to control *Zipperbot* autonomously transitioning between silhouette and mobility when movement or walking was detected. However, the two models who wore the dress during fitting and testing reported feeling empowered by having direct control via the mobile device and felt they had a heightened level of control over their dress. This issue of *exhibiting control* of our clothing has been a recurring theme throughout the research and marks an important topic for further study.

Evaluation of Autonomous Robotic Sartorial Gestures using Zipperbot

Sartorial robots, like *Zipperbot,* have the ability to create a broad range of unique sartorial cues and gestures by both augmenting traditional sartorial cues and introducing entirely new ones. The intimate proximity to the wearer's body and the strong connection that fashion shares with personal identity coupled with their potential autonomous actions situate sartorial robots in a largely unexplored space.

The evaluation will focus on the sartorial robot, *Zipperbot* that was developed as part of this thesis, particularly focusing on the revealing and concealing of surfaces on the dressed human body when acting in an autonomous manner during a social situation. It will be important to analyze people's verbal responses and their behaviors when interacting with other people wearing sartorial robots. Perhaps the best method to understand these interactions between people and sartorial robots is through direct observation. The evaluation will consist of a conversation study between a confederate wearing a sartorial robot, *Zipperbot*, and a subject.

Research Questions

While we could evaluate *Zipperbot* in a variety of fabric edge joining applications and measure how *Zipperbot* compares with traditional manual zippers, this wouldn't necessarily help us in understanding robotic sartorial cues, gestures and their issue of *control*. The evaluation will focus on two research questions:

1. How might people perceive sartorial states as performed by *Zipperbot*? Specifically that concealing actions would induce negative perceptions and revealing actions would induce positive responses from observers.
2. How might *Zipperbot* affect interactions during conversation? Specifically that the interlocutor will modify their speech acts to some manner.

Materials and Methods

For the study, *Zipperbot* was fitted into a light weight jacket which controlled the main forward facing opening of the jacket. The jacket was modified with a high collar in order to emphasize the opening and to position *Zipperbot* closer to the wearer's face, which is generally the focus during conversation. I used a within subjects design to compare interactions between two people having a conversation in which at the beginning of the conversation *Zipperbot* is inactive presenting an *open-collar* and then later during the conversation *Zipperbot* is activated changing the sartorial appearance.

Participants

Participants were recruited from the MIT and Cambridge community via flyer advertisement and electronic mailing list. A total of 8 subjects consisting of five women and three men ranging in age from 21 – 65 took part in the study. Each participant in the study was compensated with a $20.00 Amazon gift card.

Experiment Design and Procedures

For the first condition of the within subjects study comparing interactions between people having a conversation, *Zipperbot* is inactive and the jacket collar is open. Throughout the conversation *Zipperbot* then either actively zips up, presenting a *closed-collar* or unzips presenting an *open-collar,* **Figure 7-15**. In order to form a baseline of normal or typical behaviors during interactions the inactive *open-collar* condition was presented first. This also was intended to help provide a comfort level for two participants meeting and interacting.

Figure 7-15. *Confederate displaying a closed-collar (left) and open-collar (right) as controlled by the sartorial robotic zipper.*

Participants signed consent forms to take part in the study and to be video recorded and interviewed. The study was then briefly described to the subjects with them being told that they would take part in a conversation with another person who would be wearing clothing that had a robotic component and that the clothing would be actuated. This was intended to mitigate any surprise and novelty factor. The subjects were not informed that the other person was a confederate.

Participants were then brought to a separate room where the participant was briefly introduced to the confederate and both were then seated at a small café style table. The confederate was wearing the light weight jacket fitted with the sartorial robot, *Zipperbot.* The investigator gave both the confederate and the participant general topic conversation questions to ask each other. There were four general topics for the participants to discuss: *Movies, Books and Television; Travel; Current Events, News and Politics; Leisure Time.* The participants were instructed to take turns asking each other questions and to follow the questions provided but were also told they could deviate and ask any additional questions they wanted. This provided for a semi-structured conversation format.

There were three questions for each topic. For example some questions were *If you could live anywhere in the world, where would it be?* and *What's your favorite time of day and why?* These were selected to stimulate conversation between the participant and confederate. The investigator then left, and the participant and confederate took part in a face-to-face conversation for approximately 10 to 15 minutes taking turns asking each other questions and answering. The confederate had prepared answers to the provided questions in order to maintain consistency of content and for three of the four conditions minimized facial expression and gesture in order to present a fairly neutral state. The topics' order was rotated to eliminate content as an influence, and each discussed topic represented a condition of the study.

Condition	**Sartorial action and appearance**
Condition 1	no robot movement, open-collar
Condition 2	robot movement up, closed-collar
Condition 3	robot movement down, open-collar
Condition 4	robot movement up, closed-collar, positive affect

Figure 7-16. *Conditions of the study representing robotic movement and the associated sartorial appearance.*

After the first topic, *Zipperbot* was activated just after the subject responded to the first question of each subsequent topic from the confederate. The zipper robot would then move up in position transitioning from *open-collar* to *closed-collar* and then reverse the action for the next topic. For the fourth and final condition, Condition 4, the confederate presented a more positive affect, including smiling, head nodding and positive verbal responses like *yeah* or *mm* representing conversational agreement or engagement (Lambertz, 2011). This order provided four potential conditions for the study, **Figure 7-16**.

The zipper robot was remotely operated in a concealed manner by the investigator in order to simulate autonomous action and the confederate made no gestures. After the conversation between the subject and the confederate, the confederate would leave the room and the subject was interviewed by the investigator. The interview was video recorded and later transcribed. The interview began with a series of broad questions such as "*What did you think of the experience?*" or "*Can you describe the interaction?*" This was done in order to allow the participant to use their own language and focus on what they perceived as the salient elements of the experience. Questions would then progress and become more specific, for example if the participant brought up the zipper closing action a follow up would be "*What were you thinking when the collar closed up?*"

Analysis

Because of the broad variety of social and cultural interpretations of fashion and clothing, it was decided to examine the firsthand accounts of the subjects from the investigator interviews. Specifically the focus was to gain insight into people's perceptions of the opening and closing actions as performed by *Zipperbot*. The video data of the subjects' responses from the investigator's interviews were reviewed, segments were transcribed and grammar and language analyzed for repeating themes and ideas.

Results

Based on the analysis of the interviews, precise interpretations of *Zipperbot* varied and covered a broad range but responses generally fell into binary states, representing positive and negative perceptions. The following sections will develop the various themes that emerged from the participants' post conversation interviews.

Positives and Negatives in a Broad Range of Perceptions

Based on our findings from this study one significant emerging theme pertained to positive and negative perceptions by the participants. The *Zipperbot* unzipping/open-collar was perceived as a more pleasant or positive state, while the *Zipperbot* zipping up/closed-collar represented a more unpleasant or negative state. We can directly observe the use of positive and negative language in the post conversation study interviews. The following quotes are taken from the transcripts of the post conversation interviews with the investigator:

> ***Participant 0046:*** *The first time it did it, I thought it was like 'boring not gonna listen to you', or like protecting myself, not hearing you. And then like one time it opened too and we were having a good conversation and it's like 'oh relaxing.'*

Participant 0053*: And when it undid I thought she was, she's going to sit with me; she's opening up.*

***Participant 0053:** The zipper was closing off the scene... it's closing up, the situation is tightening, it's like over, the person is not, the openness is no longer there it must be like we're coming to the end of something.*

***Participant 0048:** When it was up I thought she (confederate) looked a bit uncomfortable and then when it came down she looked a bit more relaxed.*

Subjects expressed negative perceptions with the zipping up/closed-collar condition as represented by phrases such as *"boring not gonna listen to you"* or *"the situation is tightening, it's like over"* in contrast to positive phrases associated with the unzipping/open-collar condition like *"she looked a bit more relaxed"* and *"oh relaxing."* These comments indicate an understanding of the collar states as performed by the *Zipperbot* action. Relaxed/comfortable as opposed to uncomfortable was the primary theme.

However a broad range of perceptions was noted. Reflecting the range of participant perceptions to *Zipperbot's* unzipping action, one *Participant 0055* discussed the sensual aspect of the action which is consistent with dressing or undressing. While at another extreme *Participant 004* stated that they thought the zipper opening and closing was an environmental cue that the wearer was perhaps too hot or cold. This range reflects the spectrum of individual human response to any given situation.

***Participant 0055:** Oh well the going down was I mean it was more sensual, I, you know, the zipper top is, I don't know, for me for it has like a very sensual feeling, especially visually.*

***Participant 004:** some sort of like um environmental cue like she was comfortable or it was hot or something.*

Perceived Body Posture

A variation on the positive and negative response theme was that of perceived body posture. Based on the review of the video, the confederate made neither hand gestures nor significant modifications to posture during the interactions. In spite of this, two participants recounted a *leaning in* posture which is considered a positive or engaging gesture when *Zipperbot* unzipped to the *open-collar* condition.

> ***Participant 0046:*** *I almost feel like but I don't know if this is true, that there was times when it was open that maybe [confederate] leaned forward but I don't know if she did?*

> ***Participant 0050:*** *Maybe when it was down she was more comfortable cause she (confederate) was sort of leaning forward when it, she [confederate] was more comfortable as it went down.*

This perception of positive body posture reinforces the theme of *Zipperbot* creating a positive effect for the observer when it unzips.

Questions of Control

Another evolving theme revolved around questions regarding ownership and control of the actions. For example, when *Zipperbot* would unzip the jacket, subjects were unsure of whether the confederate or the robot was in control. Some participants described their perceptions in terms of the conversation or overall situation providing descriptions such as *"the situation is tightening."* This comment avoids ascribing actions to either the confederate or the robot and objectifies the action in an impersonal manner. Others ascribed those perceptions more towards the confederate referencing the pronoun *she* as in, *"I just assumed she (confederate) was just making it go up and down."* Further still, participants mixed pronoun usage referring both to *she* and *it* when referencing the sartorial action, *"And when it undid I thought she was, she's going to sit with me, she's opening up."* This seems to attribute the motivating action to *Zipperbot* but a change in state to the confederate, albeit an active state change in that she is *going to sit* or *open up*, both describing activity. This seems to indicate that the participants perceived *Zipperbot* as more of its own entity acting on the wearer. This underlying question of control and intention ascribed to *Zipperbot*, as to whether the robotic zipper was acting autonomously as its own entity or as an expressive physical behavior driven by or connected to the wearer, was evident in the following comments:

> ***Participant 0055:*** *It was kind of like, just had a life of its own, like kind of happening.*

Participant 006: *I just assumed she (confederate) was just making it go up and down.*

Participant 0050: *The first time it was funny because she (confederate) couldn't do anything about it and just closing.*

Along with the references to the pronoun *it* in descriptions and recollections of the zipper action, some participants' statements reflected the autonomous nature of *Zipperbot*, *"It was kind of like, just had a life of its own,"* and that the confederate, in reference to the zipper was not in control, *"she couldn't do anything about it and just closing."* These observation indicates a perception of *Zipperbot* as some sort of an independent entity. In contrast one participant indicated the opposite, *"I just assumed she was just making it go up and down,"* but overall the range of conflicting interpretations points to a general uncertainty in regards to *control*.

Analysis of Body Language and Verbal Utterances

Considering that subjects had a variety of interpretations of the *Zipperbot* actions it was not clear how these perceptions might influence a conversation. So we looked at body language, examining positive nonverbal communications such as smiling, head nods and leaning in posture and negative nonverbal communications such as frowning, head shakes and leaning back posture. The video data was segmented based on zipper action and *open-collar* and *closed-collar* conditions then annotated using Anvil Video Annotation software in order to code physical gestures related to nonverbal communication and verbal interactions (Kipp, 2001). Individual physical gestures were counted and because the time of participant responses and interactions varied, frequency of physical gesture was calculated into number of gestures per minute. A series of two factor without replication analysis of variance (ANOVA) was then conducted comparing the various gesture frequencies between conditions. In the analysis we did not determine statistically significant differences between the overall various conditions for gesture frequency. However, when we examine the specific time frame when the *Zipperbot* is in motion, we do observe an effect with combinations of body language. For example, one participant smiled, looked at *Zipperbot* and then tilted their head to the side in a quizzical manner. Another smiled and laughed, while yet another had the opposite reaction and frowned, then leaned back away from the confederate. These reactions again reflect the wide range of human responses when confronting a new experience.

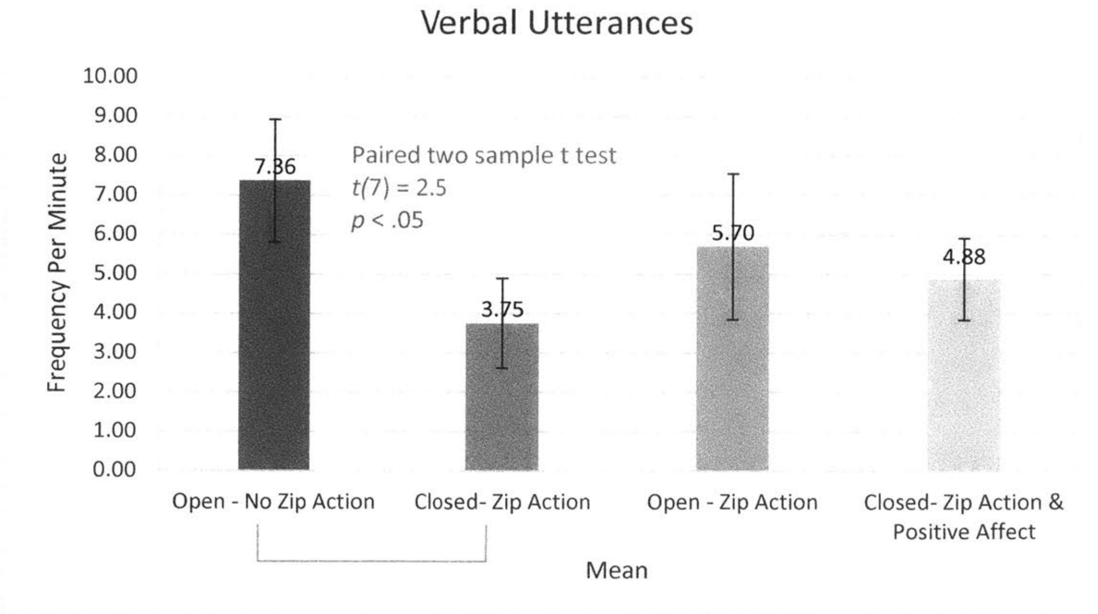


Figure 7-17. *Frequency of verbal utterances indicating a reduction from an open-collar state to a zipped up closed-collar state.*

Verbal statements and verbal utterances such as *yeah* and *mm* are backchannel responses that have been shown to be an indicator of listener engagement (Lambertz, 2011). It was considered that the *open-collar* condition with no *Zipperbot* movement would be a more comfortable state and act as the neutral control. A paired two-sample t-test was performed comparing the mean frequency of verbal utterance during the conversation between the *open-collar* condition with no *Zipperbot* movement and the *closed-collar* with *Zipperbot* movement. The mean frequency of utterances for the *open-collar* condition scored a (M= 7.39, SD = 4.40) and for the *closed-collar* with *Zipperbot* movement a (M= 3.78, SD = 3.29). There was a significant effect on utterance frequency, $t(7) = 2.48$, $p < .05$, with the *closed-collar* with *Zipperbot* movement condition recording a lower frequency of utterances than the *open-collar* condition. This suggests that subjects became less engaged when *Zipperbot* activated and closed the collar of the wearer. While *Condition 1* and *Condition 2* showed statistically significant differences, a two factor without replication ANOVA of all the conditions was not statistically significant. However, the frequency of verbal utterances data did show a pattern consistent with our hypothesis. Utterances drop when the zipper closes the collar, then increase when the zipper opens the collar and then drop again when it closes the final time, **Figure 7-17**. While this represents a single measure, this would seem to support the data from the interviews. In addition it could be that the *Zipperbot* motion was distracting, as one subject described their thoughts:

Participant 0050: *I'm not sure when it's going to start moving so I keep looking down at the zipper and so um I feel like I'm not being a good conversationalist because I keep you know being distracted by something else.*

Missing Gesture Phases

In the interviews after the study, when discussing the conversation and the actions of *Zipperbot,* subjects consistently used their hands to recreate the gesture of zipping or unzipping, including the very specific action of pinching with their fingers indicating the grasping of a zipper slide. This was noteworthy, as during the study conversations the confederate never used her hands to actuate the zipper, nor did the interviewer use this gesture when asking questions. This co-speech gesture suggests that there is an associated commonly understood arm/hand gesture to describe zipping and unzipping a garment. While this may seem obvious, it is an indication that arm/hand gestures associated with our clothing may be far more ingrained in our understanding of body language than previously thought. Some gestures, like co-speech gestures, can be described by a specific series of movement phases consisting of resting, preparation, stroke, hold, retraction and then back to resting (Kita, van Gijin, & van der Hulst, 1997). With autonomous action, *Zipperbot* lacks distinct movement phases associated with traditional gestures from the wearer. This means no arm/hand movement to indicate the beginning of the overall gesture. This begins to explain some of the ambiguity of the *Zipperbot* between being perceived as its own entity or as connected to the wearer. With no direct gesture from the wearer, combined with autonomous movement, *control* of the clothing has not been firmly established by the wearer, and as we've noted throughout this thesis, control of one's body and as an extension, one's clothing, is critical in social performance.

However, subjects still reported positive and negative perceptions in relation to the open-collar and closed-collar states but the gesture or lack of gesture was uncertain. This leads to the conclusion that there is a distinction between *sartorial state*, which is more the static appearance of clothing and *sartorial gesture*, which represents the action carried out in order to manipulate sartorial elements to achieve the *sartorial state*. While *Zipperbot* was successful in transitioning between *sartorial states*, the *sartorial gesture* was perceived more ambiguously.

Limitations

Within study designs are known to be affected by carryover effects, that is, when conditions of one condition carryover to the next condition. In relation to the *Zipperbot* robot, when seen for the first time it tends to elicit strong reactions from observers and as such could have caused carryover effects which influenced the subsequent conditions and the study results. The carryover effect could go in either a positive or negative direction depending on whether the observer was initially amused by *Zipperbot* or if they found it jarring. Another limitation would be that the confederate had trained to respond with minimum affect, but being human, an absolute repeatedly consistent response is difficult to obtain. This also could have influenced the results.

Discussion

There are certainly many applications and potential benefits for sartorial robotics or robots that are situated in close proximity with our clothing and bodies. However, from the *Zipperbot* study we learned that the implications for these robotic systems in terms of social interactions and communication is particularly complex. While sartorial cues might mainly fit within the appearance classification of nonverbal communication, the hand/arm movement to achieve the appearance seems to fit more within a gesture classification. *Zipperbot* allowed us to specifically remove the preparation and retraction phases of gesture and isolate the stroke phase. Subjects recognized the *sartorial state* change and the stroke phase of the sartorial gesture, but the absence of preparation and retraction phases seemed to put in to question the control or ownership of the overall gesture. This in turn creates some apprehension in interpreting social meaning.

Both the intimate proximity to the wearer's body and the prominent status placed on our clothing as representations of our identity create a challenging space for robotics. In this space the robot, the clothing and the person represent a triadic social performance but seemingly performed by one singular entity. What is the robot? What is the clothing? What is the person? As such the repeating idea of *control* throughout this thesis becomes even more critical when considering the design of these systems. The individual roles during this performance should be either clearly delineated or seamlessly orchestrated to ensure proper social interpretations. This is a significant finding which will help inform design for future developments in wearable computing, wearable robots or in general 'smart clothing'. *Zipperbot* represents the first steps towards introducing this level of *control* into a robotic sartorial system and building upon the knowledge generated from studying its human-sartorial robot interactions, we can now begin to utilize *Zipperbot* as a platform to explore and design more sartorial gestures.

Chapter 8

Future Work

The work in this thesis established sartorial robotics both as a practice and as a unifying premise for understanding the merger of soft-architecture robotics and social robotics. This demonstrates its potential as a beneficial field of study. In order to build upon this work it is advantageous to outline directions for future research. The next steps for future research should focus on wearable autonomous or semi-autonomous robotic surfaces in relation to social performance.

Agency and Control

When considering the prospects of wearable autonomous or semi-autonomous robotics in relation to social performance, agency and control were repeated key concepts. Independent or self-directed mechanical movement generally elicits thoughts of agency. However, whether or not agency is defined as an involuntary behavior or a purposeful action will depend on the context of the action and situation. The wearable element, either for people or robots, will imply a connection between the wearer and the robotic surface. The confederate, unlike in the *Zipperbot* study where the robot acted autonomously, also had the opportunity to wear the Hobble Dress and directly control the robot herself. The confederate had the unique experience of both controlling *Zipperbot* and having no control over *Zipperbot*. As an anecdotal note, she expressed completely different perspectives during both experiences. During the *Zipperbot* study she found that not being in control of her clothing was an unsettling experience, but she also found that its actions did make her feel either more closed off during the conversation when it zipped up, or more relaxed and open to the conversation when it unzipped, independent of the actual conversation. She commented on how she felt her personal space was affected by the actions. This mirrored the participants' perceptions during the study. However when the confederate wore the Hobble Dress and was given direct control over the *Zipperbot's* actions, she described experiencing a sense of empowerment. Obviously from a physical perspective, changing the fit of your clothing can change your attitude and have a psychological effect altering social interactions. It is noteworthy that these feelings came about not from the wearer's actions but by the autonomous actions of *Zipperbot*. This distinction is important and leads us into the concept of performativity. Philosopher Judith Butler, in thinking through gender and identity in terms of performativity, states that:

> *...gender is in no way a stable identity or locus of agency from which various acts proceede; rather, it is an identity tenuously constituted in time-an identity instituted through a stylized repetition of acts. Further, gender is instituted through the stylization of the body and, hence, must be understood as the mundane way in which bodily gestures, movements, and enactments of various kinds constitute the illusion of an abiding gendered self* (Butler, 1988).

This concept of performativity expands beyond gender and suggests that identity is not the sole source of expression. That instead of an internalized notion of identity, identity is constructed through the external semiotics of our performative actions, such as speech acts, bodily gestures and of course in our judgment sartorial actions. From this perspective an autonomous robot acting on or as our clothing could have a profound influence on forming or shaping our identities. While *Zipperbot* is a playful sounding robot, it presents a far more complex system of social interactions than it originally implies. Given our observations of the wearer's experiences regarding agency and control in both applications of *Zipperbot* and our understanding of performativity, it would be beneficial to run further studies in which volunteers would wear *Zipperbot* or other robotic clothing in order to measure the effects that control or lack of control might have on their own identities.

Social Performance

When we consider both the examples of fashion designers Alexander McQueen and Hussein Chalayan's work, we see robots or machines acting on the garment, independent of the wearer. This may work for the fashion runway in creating a visual spectacle, but when we tested a similar experience with the autonomous actions in the *Zipperbot* study, this caused apprehension during human-human social interaction for the observer. Analysis of study interviews indicated that control of *Zipperbot* was in question. However when control over *Zipperbot* was added via an Android device in the *Hobble Dress* application, the model wearing the dress noted a heightened sense of empowerment. Through having more direct control, the wearer exhibits a mastery over technology, over the robotic surface and to an extent the wearer now becomes a virtuoso of identity play via clothing. For the observer, the simple addition of the touch gesture on the Android device creates a connection to the robotic surface and helps establish control and ownership of the sartorial robotic gesture. Just as there are subtleties to human sartorial gesture, there are subtleties to sartorial robotic gestures, and understanding all the nuances is a challenging task. Returning to Erving Goffman's view of social interaction, in our attempt to influence how others perceive us by controlling our settings, manners and appearance, our clothing is situated somewhere between an object or prop and an extension of our bodies, if not considered an actual part of our bodies at times. Winnicott's transitional object, generally defined as an object which can provide psychological comfort, also exists as a merger or link of our inner selves and the external world; clothing occupies this same space as being self and not-self at the same time (Winnicott, 1971) (Benson, 2000). Through our clothing we play with this boundary and introducing robotic elements presents a profound modification to our customary social performances. In order to learn more about this we might break from the more conventional investigation methods and perhaps employ performers such as actors, dancers and performance artists who would be able to shed light on the dynamic range of body and sartorial gesture.

Sartorial State versus Sartorial Gesture

The evaluation of *Zipperbot* drew attention to the role of pre-gesture, the motions before the main stroke gesture, during sartorial transformations, and it also defined the importance of a sartorial state, which is more the static appearance of clothing and sartorial gesture, which is the more dynamic actions associated with transitioning from state to state. From the *Zipperbot* study, the open-collar would be considered one state and the closed-collar is the other state, the *Zipperbot* action changing the collar state would be the sartorial gesture. The evaluation of *Zipperbot* drew attention to the role of pre-gesture, the motions before the main stroke gesture, during sartorial transformations. Because of the importance of pre-gestures, future studies should examine adding either robotic pre-gestures or human pre-gestures to the robotic stroke gesture. Adding the pre-gesture would assist in establishing control of the stroke gesture and thus its ownership. A robotic pre-gesture may be as simple as flashing LEDs prior to beginning the stroke or a human initiated pre-gesture, based on capacitive sensing built into the robot, allowing a simple touch of the *Zipperbot* to activate and begin its stroke gesture. Either scenario would help in establishing ownership, but whether the pre-gesture is initiated by the robot or the human would be critical for the interpretation of the gesture. Further still, the specific type of pre-gesture could have an effect. A glance of the eyes down at *Zipperbot* to begin its movement as compared to a touch of the finger might be perceived quite differently but would also allow for more human improvisation during control. This future work would help to harmonize the sartorial state and sartorial gesture.

Another open question worthy of further investigation might be how *Zipperbot* would be perceived acting on the surface of another robot, perhaps a humanoid robot. As robots are generally thought of as electromechanical in nature, the addition of *Zipperbot,* also electromechanical, may be perceived as an extension of the robot much more easily than when experienced on a person's body.

Designing with Gestures

Given the distinction we have made between sartorial state and sartorial gesture, future work should investigate principles for designing the sartorial robotic gesture. The development of the design principles for sartorial robotics helped us create robotic surfaces. In a similar manner, we'll need a set of principles or tools for apparel designers and roboticists to design the specific gestures. This would initially require analysis of specific gestures, since, for example, zipping up a jacket would be very different than loosening a tie. Consider the entire process of movement and gesture involved in fully dressing one's self from putting on socks to buttoning shirts; it is a highly sophisticated orchestration and in the field of sartorial robotics requires further study and consideration. As a general principle, actuated robotic surfaces seem to remove pre-gestures so understanding the meaning of this gesture phase in relation to clothing would be critical. Future work towards developing a taxonomy of sartorial gestures and an analysis of the parameters for understanding the gestures would be essential for designers. In an effort to get sartorial robotics into the hands of fashion designers and roboticists, the *support(S)* strategy developed in this thesis benefits the production of do-it-yourself (DIY) kits which would provide standardized systems that could be incorporated into a variety of projects in the same manner *Zipperbot* was applied to both a jacket and a dress. The development of DIY kits would allow researchers to experiment with sartorial robotics in their own work exploring the sartorial gesture phases and to contribute to the knowledge base of sartorial gesture.

Multiple Zipperbots

For this thesis multiple *Zipperbot* prototypes were constructed with a variety of technical abilities. We were able to demonstrate a simple action of two *Zipperbots* working in tandem, but it is easy to imagine several working in an orchestrated manner for some more complex task. We can imagine multiple *Zipperbots* working together in complex self-assembling soft-architectures, for example portable structures like tents or highly technical clothing like an astronaut's space suit which may have multiple parts to attach during donning or doffing. In terms of fashion, these multiple *Zipperbot* scenarios generate a variety of creative opportunities for performance and performativity. However in order to realize this level of coordination, scaling for multi-robot control will require better robot-robot communication, or a more intuitive interface for human operators to control multiple *Zipperbots,* perhaps focusing on reading natural movements and gestures of the wearer. From a technical research perspective for multi-robot control, *Zipperbot* would require wireless communications built into the main circuit board and an established communication protocol for multiple robots. Research in this area would help to facilitate the adoption of multiple *Zipperbot* applications and usage.

Chapter 9

Contributions

This dissertation makes contributions to several different areas including soft-architecture robotics, interdisciplinary dialogues for the design of robotic systems and nonverbal communication for both social robotics and wearable computing and fashion. What follows is a statement of the thesis's contributions to each of these areas.

Soft-architecture Robotics

Within the emerging field of soft-architecture robotics, textiles, electronic textiles and fiber electronics have yet to be thoroughly explored particularly in the area of social robotics. The demonstration projects that are presented within this thesis such as *Zipperbot* and the *Group Identity Surface* help to illustrate and to extend the means of integrating these materials and processes into the field of robotics. While there is still much more work to be done in this area, this thesis has shown the possibilities and benefits of sartorial methodologies and practices to the field of soft-architecture robotics. The design framework which was developed as part of this thesis and which was used in the development of the sartorial robot demonstration projects will hopefully provide guidelines and methodologies to other roboticists in developing soft-architecture robots particularly those that might have a social interaction component. In particular the formulaic approach adapted from Barthes can assist in defining fashion and sartorial states in a manner which can help with designing sartorial interactions and assisting with robot aesthetics as viewed through the sartorial lens.

Interdisciplinary Dialogues

Interdisciplinary dialogues between robotics, textile design and apparel design will act as an initial step in further opening the field of robotics to outside disciplines. As more robots and robotic products enter the marketplace, more diverse fields of study will be required to meet the full spectrum of public needs. As robotics moved out of the industrial settings of the factories and into people's homes, psychology began playing a role in designing the human-robot interactions. When researchers began to explore robotics for educational settings, we saw roboticists reaching out to teachers and educators for guidance. In the development of this thesis, we experienced with the Honda ASIMO project the utilization of electronic-textiles to sense and explore social touch gestures. Working with soft-architecture robotics, the expertise of apparel designers and textile designers was crucial. Apparel design in particular is instilled with much tradition and as an artisan pursuit has drastically different tools and language than those found in robotics. Bridging this difference was a challenge, but more an opportunity as the fields of both soft-architecture robotics and wearable computing will need to fuse successfully with apparel for widespread adoption.

Sartorial Nonverbal Communication

While the overall aesthetic of robots is often considered in the field of robotics, the social and cultural role of clothing as a nonverbal communication system has been largely overlooked within robotics. Even when robots distinctly lack clothing, people tend to view the robot form through a sartorial lens. Clothing is a form of nonverbal communication among people and this thesis work explored how that language can transition to social robotic interactions. From the results of the *Sartorial Robot Gender Study,* we observed increases and decreases in the perceived masculine and feminine traits indicating that sartorial cues representing gender did in fact have an impact on people's perceptions of gender traits for robots. There are many different types of fashion and sartorial signaling, and while this study represents one particular sartorial cue for one particular social construct, that of gender, its results show that sartorial signaling as nonverbal communication for human-human interactions can translate to human-robot interaction and should be considered a fertile area for future work. This thesis has explored the role of sartorial cues in robotics and has laid the foundation for its further development and inclusion into research.

Through the development and use of *Zipperbot* as a sartorial robot and the resulting behavioral analysis, we were able to explore the distinction between the *sartorial state*, which is more the static appearance of clothing and *sartorial gesture*, which represents the action carried out in order to manipulate clothing elements to achieve the *sartorial state*. *Zipperbot* allowed us to remove phases of hand/arm movement within the gesture which in turn disrupted the ownership of the gesture and helped to illuminate the importance of the sartorial gesture in using clothing as nonverbal communication. This suggests that clothing is not only a form of nonverbal communication based on appearance but can be a combination of both appearance and gesture.

Previous researchers and literature have postulated that control of one's body is crucial to being perceived as a competent social performer. This thesis established that this same concept extends to clothing and our wearable surfaces. When *Zipperbot* performed a gesture with the wearer's clothing, ownership of that gesture was uncertain and there was a question over *control* of the clothing. This in turn reflects on the wearer in terms of their ability to socially perform. This level of understanding will be essential in the design of wearable robotics or smart clothing that intends to do any form of actuation.

The world of fashion and the field of robotics are socially and culturally diverse. This thesis established a foundation for merging the two fields into *sartorial robotics* so that both can contribute to each other. This synthesis will enhance the social aspects of human-robot interactions and assist in how we situate robotics in our lives and cultures.

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