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Actuating movement in refined wearables

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Abstract.
Nowadays it is quite possible to deploy textiles as sensors and avoid traditional hard sensors. Actuation (movement) turns out more difficult. It is advantageous to combine sensing and actuation, similar to ecological perception theory. Although several actuators are known: SMA, voice coil, motors, they all have significant disadvantages. *Materials:* we explored new ways of using electric motors in feedback loops together with textile sensors (modified servos). *Approach:* together with Industrial Design (Eindhoven University of Technology, TU/e) and Fashion (Utrecht School of Arts, HKU) students we followed a hands-on approach to come to inspired innovative fashion: garments capable of mechanical change, showing dynamic forms or adapting to the person wearing it. *Findings:* we obtained six very different concepts, themes ranging from defence, attraction, using daylight, playfulness to breathing and dancing. The noise of the mechanism can strengthen the intended semantics – sometimes it is a problem. The conductive yarn sensors are useful, yet introduce calibration challenges. We have short video-clips of the results which we shall show during our presentation. *Implications and relevance:* our examples show the potential of actuation as a new semantic language, which will become even more important when new technologies will help us overcome the present-day actuator limitations. *Conclusions and recommendations:* our students enjoy this way of learning about electronics, programming and video making immensely while also learning about fashion and aesthetics. A new dynamic language is waiting to be discovered. We will share our findings and future propositions for activated fashion.

Keywords: Fashion, Technology, Smart Textile, Actuation, Innovation, Wearable Technology, Fashion Strategy

Introduction and motivation

In this paper we present work on actuating movements and new options for expressivity in wearables. As a part of our motivation, we present several lines of thought which are connected by the common themes of technological development, expressivity and ownership. The first line of thought, actually more an observation of facts, is that there is a lot of electronic technology being developed for embedding in garments. Yet, most of this technology provides sensor functionality. The main pushing forces behind this technology development comes from visions on the future of healthcare, well-being and sports in combination with the promises of ICT that will offer a multitude of ways to deliver, process and present the sensor data in useful or profitable ways. The second line of thought is that garments and fashion have not only practical functions, but also expressive functions, also called semantic functions. The practical functions include providing warmth, protection and comfort, and providing options for carrying things. The semantic functions include personal style, expression of moods and intentions, belonging to a group, constructing identity and so on. The semantic functions are what makes fashion such an important element of contemporary culture and what motivates the trillion dollars annually spent on it. There is an extensive literature on the semantic functions of fashion.

Putting these trends next to each other, we see a gap. The technological developments focus on sensing could in an extreme case lead to the situation that a garment becomes a platform for carrying the sensors that collect vast amounts of data that are fed into the data servers of parties such as medical specialists, health insurance companies, advertisement agencies, and so on. In a worst-case scenario, the expressive role of the garments would be neglected and the user could even loose ownership of the data. We think that there is an unbalance between the sensor developments and the actuator developments. Even in traditional engineering, sensor development and actuator development go hand in hand. This is because often feedback loops are deployed to guide an actuator moving to the right position, checking that it has the right speed etc. Conversely, actuators are used to calibrate sensors, adjust their position and adjust their reach. Besides personal fascination and interest in actuating movement in garments, the above considerations provide extra motivation for the work reported in this paper.

Whereas traditional fashion items are designed for their expressiveness, they usually have no active elements. Of course the garments are not static: they move when the wearer moves (making sure that this happens with an elegant or otherwise desired effect is one of the main issues in garment design). Therefore we like to explore the potential of active movements, which is what we did. There is a still an unfortunate mismatch between the specifications of the actuators we would like to have (more about that later) and the actuators which are available and affordable. We worked with servo motors and hacked servo motors and later in this paper we explain why. That is one of the things we could report on more: the technical explorations to deconstruct and subsequently reconstruct servos while using soft sensors instead of the conventional potentiometer encountered inside commercial sensors. Although the technology is really not perfect, it is what we have now. We believe it is worthwhile to experiment with actuators, even when they are not perfect so we develop understanding of dynamic form language and are better prepared when new, active materials become available.

Even more interesting than the technological questions, is the set of results we got when working with two groups of students during a module at TU/e and HKU. We shall describe the processes followed and the results, which are also available as online video clips. We begin with a very short introduction of the results, and add more explanation in subsequent sections.

Overview of realised garments

Two student activities were launched in parallel, each within a specific educational setting and with specific time constraints. There was an exchange of information between the two activities, but they were coupled only loosely and in overlapping, yet not equal time periods. The first five results in the following list come from the student teams at TU/e. The sixth is the result of a team of students at HKU supported and steered by HKU teacher and fashion designer/illustrator Wim Ewals and the authors.

First we show the five TU/e projects and explain how the functional and esthetical issues are intertwined in the concepts. At several occasions, the non-functional properties of the actuators or sensors could be well-aligned with the essence of the design concepts. We discuss the activated items and their implications in each specific case.

Case 1) Moving Skirt by Jesse Meijers and Anne Spaa vimeo.com/87357718 is about extroverted and introverted movements. They took the natural drape of the fabric as starting point for the integration of the two servo motors. The servos are placed at the bottom of the skirt just above the ankles. The weight functioned as accelerator of the natural movement. A tiny thread is connected at specific folds in the hem and the servomotor. Straws guided the thread towards the bobbin that is built on the servo. Restricting the swing of the folds by winding up the thread proved to give and interesting dynamics for the dancer during a performance.

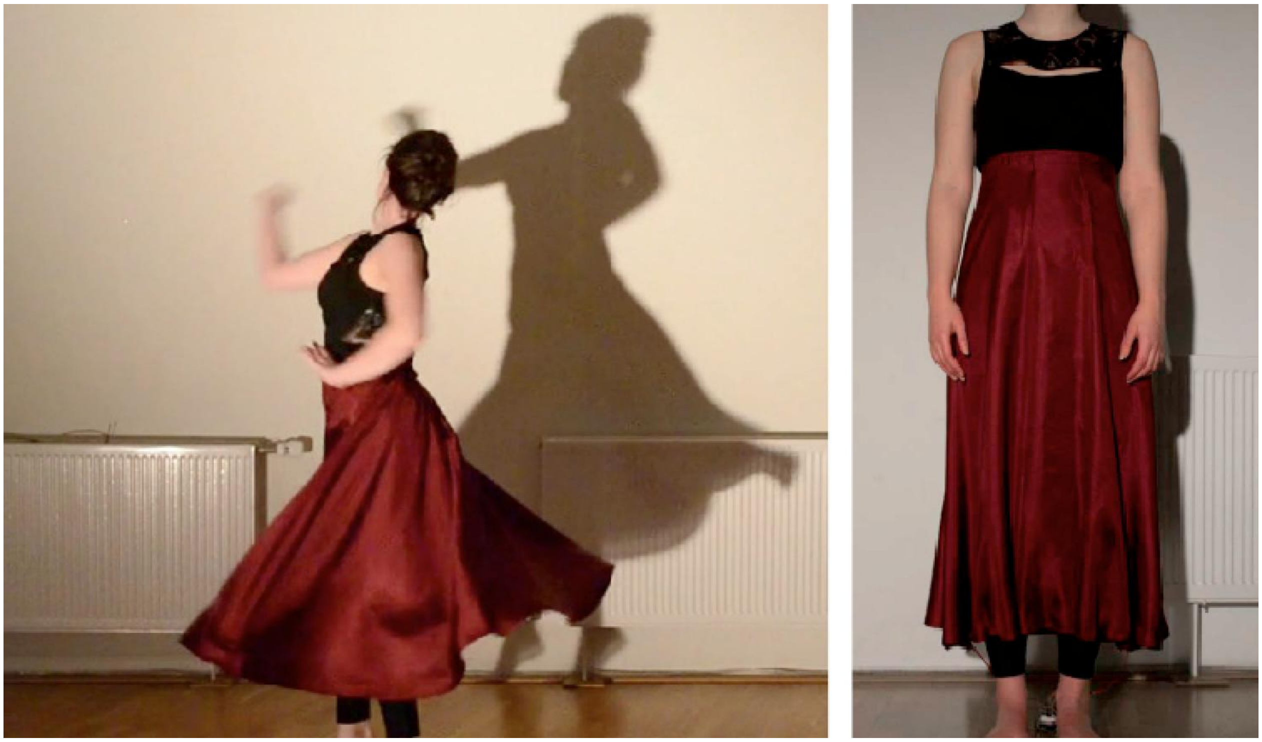

Fig. 1: *Moving Skirt* by Jesse Meijers and Anne Spaa. Right: *Moving Skirt* in its most restricted status.

Implications of technology in Case 1: In the concept of the *Moving Skirt*, the weight of the motors works as a centrifugal weight which helps the outward movement (in the extroverted state of the system). The positioning of the motors inside the lower seam of the skirt is essential (it wouldn't have worked if the motors would be elsewhere).

Case 2) Sédress by Ardjoen Mangre, Daphne Menheere and Nita Virtala is a dress that complements and enhances flirting. youtube.com/watch?v=OSF7hWM7wiQ&feature=youtu.be When the wearer touches her neck and plays with her hair (common signs of flirting), *Sédress* starts to slowly drape shorter.

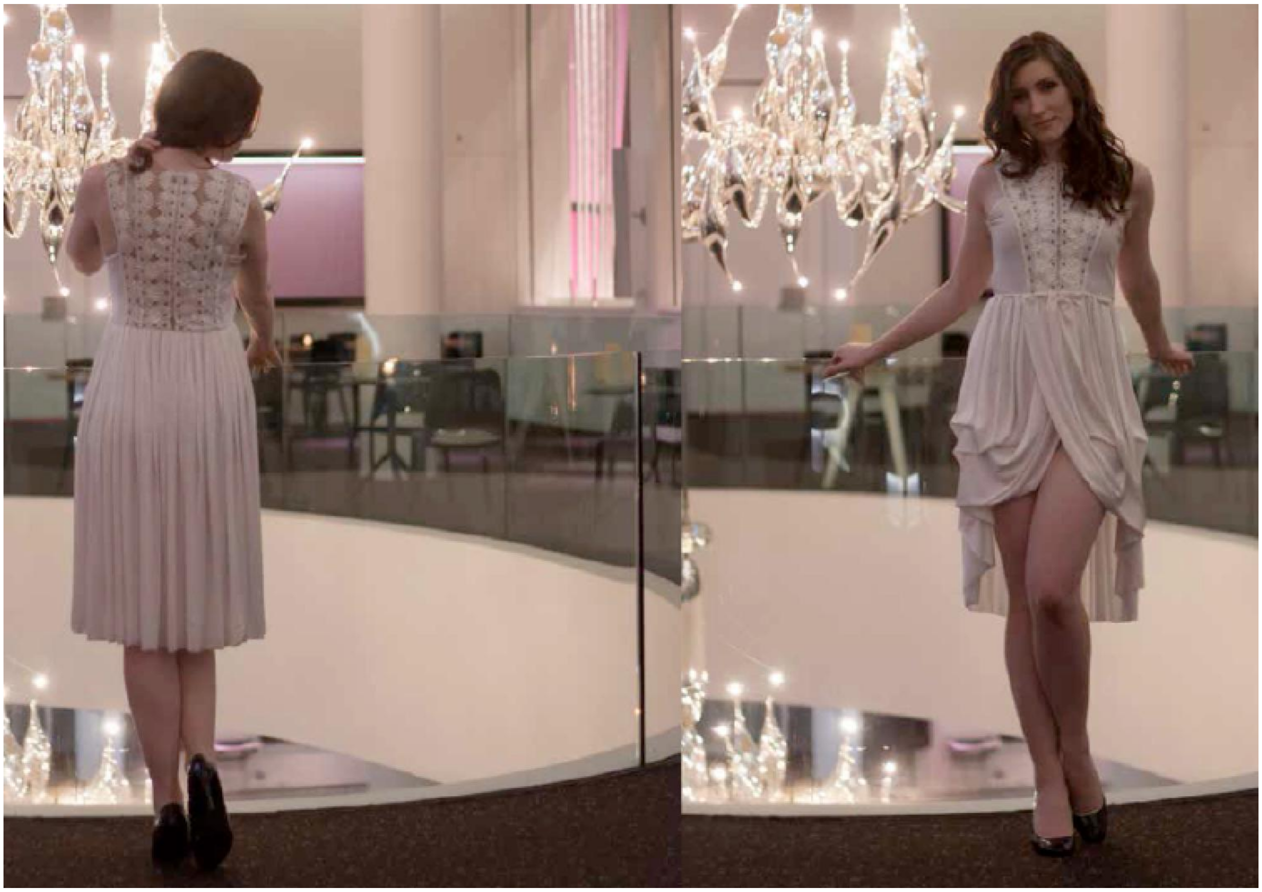

Fig. 2: *Sédress* by Ardjoen Mangre, Daphne Menheere and Nita Virtala.

Implications of technology in Case 2: For *Sédress,* the motors could be hidden inside the dress construction of the dress; though not perfect, this worked out not too bad because the embedding and testing of the pulling string was done already in a very early phase. The soft touch sensors are perfect, the flirting movement is picked-up by the sensor, which is made of textile, and the reverse movement is triggered by a software time-out.

Case 3) Shivrr by Theodora Kyrgia and Paul Klotz vimeo.com/88865783 embodies and visualizes shivers in a garment and provides the user with physical feedback. Often you can sense when someone is approaching you from behind. The wearable top is reflecting this concept by causing a small shivers sensation starting from the spine. The shiver motivates you to straighten your back and take a 'strong' posture. In the proposed scenario, there could be a proximity detector, "sensing someone approaching you from behind and how this could reflect on a wearable piece", as Kyrgia and Klotz put it. This was also the basis for the storyboard of the video made in an industrial environment that enhances the "dangerous" feeling.

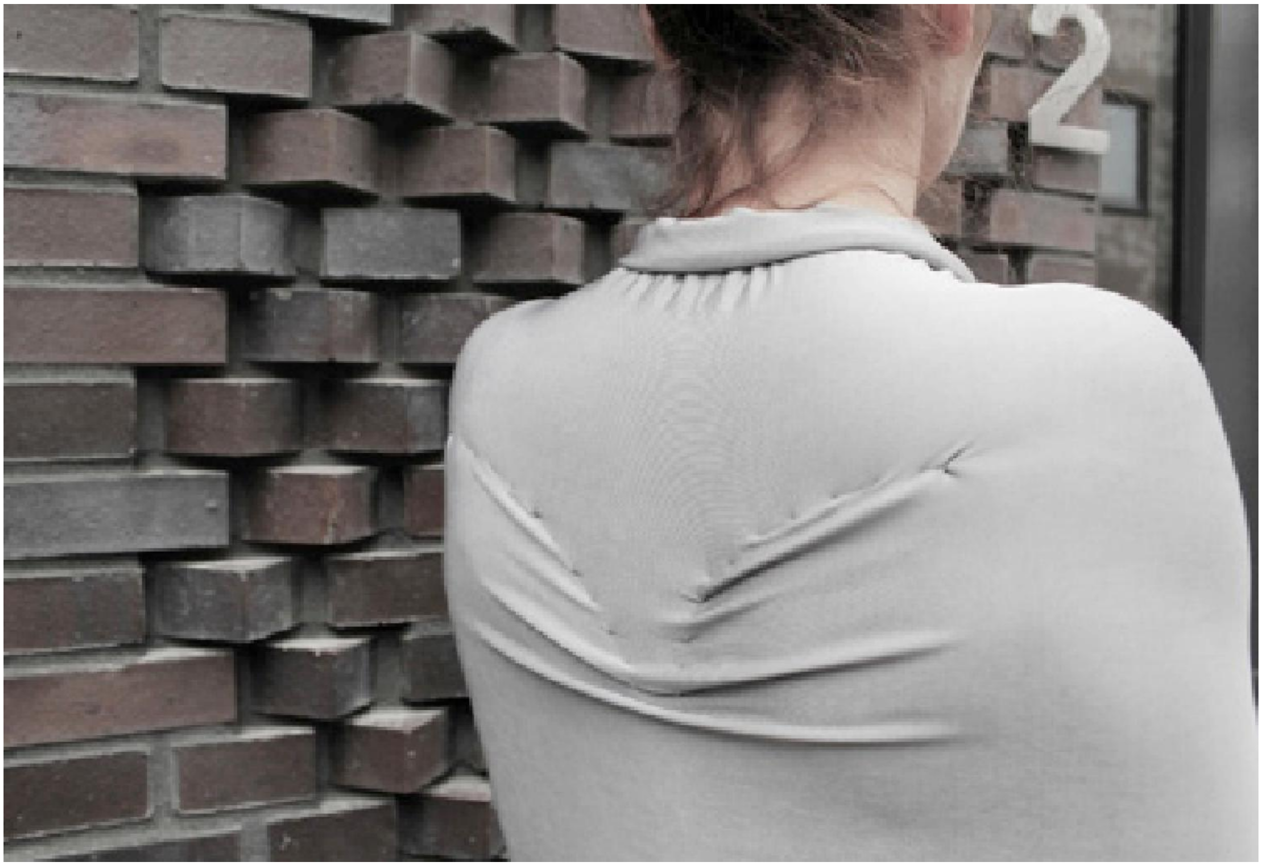

Fig.3: *Shivrr* by Theodora Kyrgia and Paul Klotz.

Implications of technology in Case 3: In *Shivrr*, the motors pull a thread with goes through the fabric. While pulling the elastic and frictional counterforces increase until the movement comes to a halt after a few seconds. Because of this, the sound of the motor and its gearbox changes: it becomes louder while going down in pitch until it stops in a grinding way. This sound fits well with the intended semantics of the visual and haptic effect (shivering, a bit scary). The visual, the haptic and the auditory modality reinforce each other. Normally we would consider the noise of the motor and its gearbox to be an undesired side-effect. Here it is a good feature, however.

Case 4) Aini by Josef Al Abdeli and Gustavo Ostos Rios vimeo.com/87930958 is a representation of a transformative ritual as a display of beauty, inspired by nature. Transformations in nature, such as what a peacock does, were used as inspiration. As Al Abdeli and Ostos Rios put it: “The scarf allows women to adapt their appearance responding to external interaction with the piece.”

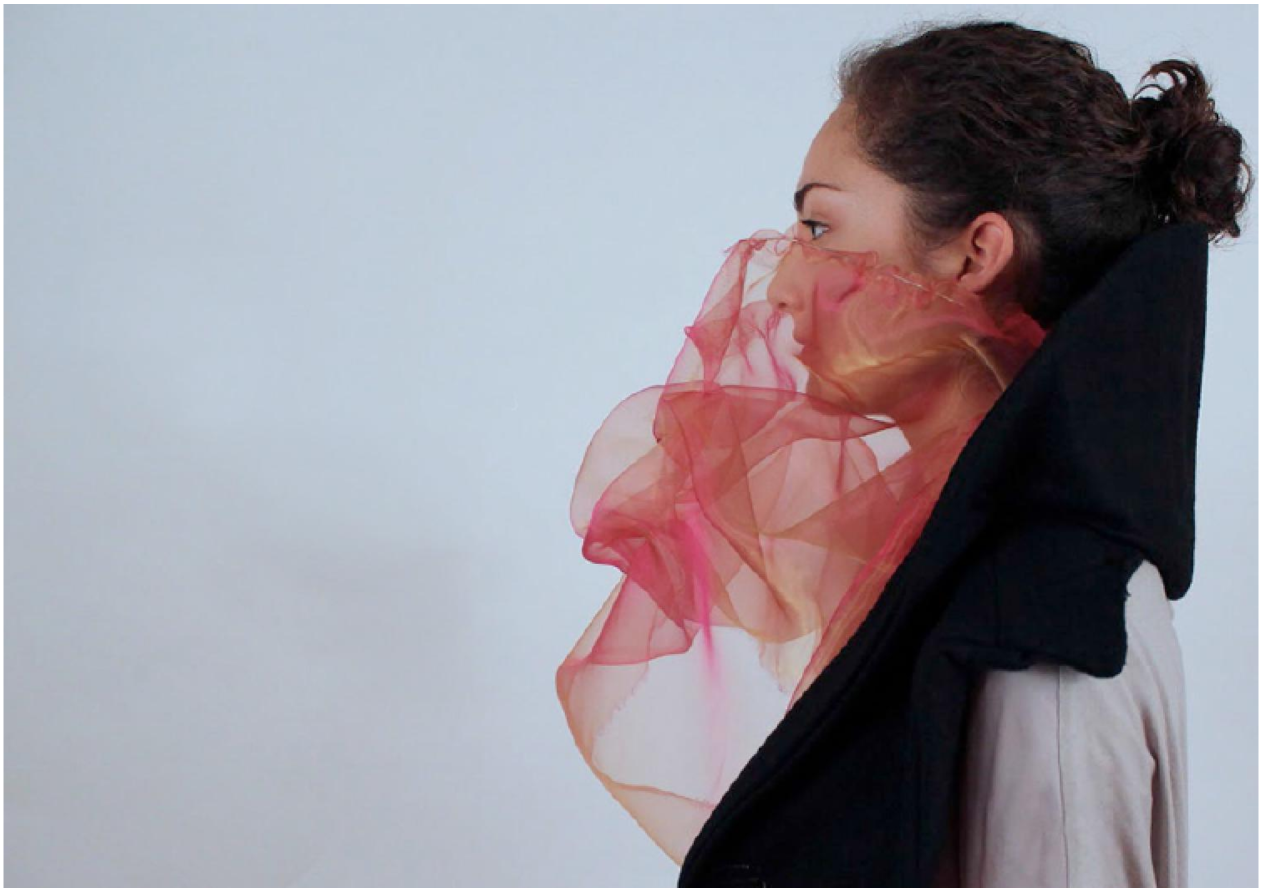

Fig. 4: *Aini* by Josef Al Abdeli and Gustavo Ostos Rios.

Implications of technology in Case 4: The initial explorations of *Aini* were based on stiff materials and a big collar. This turned out difficult: the stiff material would not move easily and at the same time there was hardly an opportunity for hiding the motors. But after several more explorations the larger and more informal shape created with an organza-like fabric was found to be easy movable (hardly any force needed). At the same time the motors would easily disappear in the big folds and wrinkles of the fabric. The hood also offered a nice and natural affordance for the control switches, realised as a conductive yarn switch formed by the handles of the hood. If the hood is closed, and hence the (electric) switch is closed, the scarf is up and face hidden. When the user opens the hood, and hence opens the switch, the scarf lowers.

Case 5) Actuating bag by Bart de Klein and João Paulo Lammoglia targets the issue of organizing and finding objects in a handbag by letting light come in. youtube.com/watch?v=8cf2NZU5s_w

The bag consists out of two layers; a stiff transparent one and a thin stretchable black textile layer. By opening the bag the outer layer is lifted by a servomotor. This allows light to pass through from below. Lifting the outer layer also unveils the content of the bag and maybe the identity of the wearer?

Fig. 5: *Actuating bag* by Bart de Klein and João Paulo Lammoglia.

Implications of technology in Case 5: The *Actuating bag* concept works because of the fortunate situation that a bag is large enough and has a bit of surplus capability of carrying weight to easily embed a motor, a battery and so on. Still, the heaviness and size has its implications for the looks and usability of the bag.

Case 6) Toer de force youtu.be/a7LPEf6WvTg by Sophie Roumans, Yasmina Ajbilou, Emma Mulder, Marleen van Egmond, Maaike Staal, Wim Ewals, Marina Toeters, and Loe Feijs is a showpiece dress with architectural qualities and having lots of lace. It had to be interactive, we wanted it to show a kind of breathing, and there had to be moving layers were lower layers would be hidden and revealed in a dynamic fashion. It was designed specifically for the exhibition “Traditie ontmoet de toekomst: Van streekdracht naar intelligente textiel” in museum De Kantfabriek in Horst, The Netherlands. Kantfabriek is an old “lace factory”.It served as a symbolic bridge between the two parts of the exhibition: the part on a collection of very tradition ladies’ hats called “toer” from the Horst region in Limburg, the other part being about technological innovations and smart textiles. Another design element in Toer de Force has the same meaning: a layer of laser-cut transparent Perspex where cut-out pattern is inspired by lace.

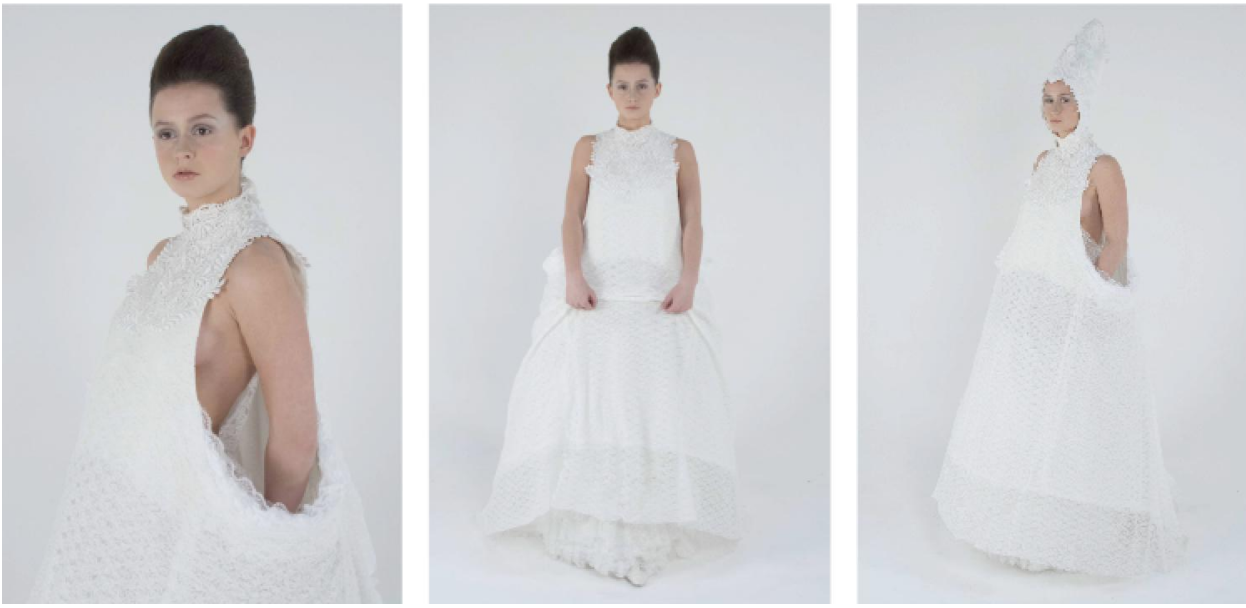

Fig. 6: *Toer de force* by Wendy Cornelis, Sophie Roumans, Yasmina Ajbilou, Emma Mulder, Marleen van Egmond, Daisy van Loenhout, Wim Ewals, Marina Toeters, and Loe Feijs. Photos and movie: Elise Borsboom, Hair, Roel Evers, Make-up: Danay Reyes Enamorado, Model: Emma Mulder.

Implications of technology in Case 6: In the design of *Toer de force*, the breathing mechanism works with motors and gearboxes (hacked servos) which make a characteristic sound. Initially we prepared for acoustic shielding and we explored special sound-absorbing materials we got from an expert. Yet it was impossible to get them really silent and the enclosing shielding boxes made everything bulkier. Then we applied pulse-width speed control, programmed in Arduino, modulating the speed in a breathing rhythm (moving forward for a few seconds, moving reversed for a few seconds). The motors were driven by a software-generated sine-wave loop. This was easily interpreted as breathing and we found that if we explained the movement (as seen from the outside) as “breathing”, guides and visitors of the exhibition would pick it up and started using similar wording. This is, in our view, a nice example were the characteristic of an actuator (unavoidable sound) is well aligned with the essence of the design concept (breathing).

Lessons learned on the exploration and realisation processes

The main lesson is that contemporary actuators are usable, even though they are larger, heavier and noisier than we would want them to be ideally. But we learned that it is best to explore the experimental garments and the embedding of actuators simultaneously, in an iterative manner. This helps to discover new opportunities quickly and avoid practical problems. Feasible concepts have the characteristic that either the size, the weight, or the sound works as a functional or aesthetic contribution to the concept. Conversely, designing the concept and realising the garment in isolation while hoping for a tiny, lightweight, silent, yet powerful actuator, probably leads to late-phase disappointments.

The design process of *Moving Skirt*, *Shivrr*, *Aini*, and *Actuating bag* was perfect for the task at hand: small teams, one location, simple timing constraint (one week, Monday-Friday including video-shoot and final presentation). The coaches (Feijs and Toeters) insisted on the iterative process and the students had already experience with such processes. The design students have less fashion skills than the HKU fashion students of course, but some students who happened to have relevant skills would help the others; the guidance of Marina ~~Toeters~~ and the expertise (and materials) provided by museum De Kantfabriek was helpful too.

Another finding is that our students enjoyed this way of learning about electronics, programming and video making immensely while also learning about fashion and aesthetics.

Toer de force was designed in a larger team with quite distinct backgrounds during a larger time frame, allowing for a bigger effort and with a larger ambition since the garment was intended to be on display in an exposition during many months, which was already widely announced and was going to be seen by thousands of visitors. Whereas the HKU team worked on the textile construction work, the lace, the overall architecture, the laser-cutting of the embedded lace-like plastic layer and so on, Feijs would prepare small technical demonstrators showing what specific motor/servo/transmission combinations could do at TU/e and occasionally discuss them at HKU. There were many trips back and forth between the two sites for brainstorming and technical integration. But the high ambition level worked a bit against the original plan of doing lots of explorations. The mechanism for breathing of the inner layer turned out to work fine from the very beginning. Perhaps the choice for a crankshaft mechanism was a stroke of luck, but it could not get blocked, did not need a stop-sensor and it was easy to embed (also because there was a lot of space underneath the inner skirt layers). The garment itself was developed with a drive for perfection and was finally completed in a race against the clock before the exposition opening day. The second technology integration step was about a vertical movement of an outer layer, somewhat like Sédress. This step was not so smooth: the mechanism was not tested in the lace-based environment and at the integration day, fabric weight and friction forces were higher than expected whereas the intended location for the mechanism was hard to reach. At the same time we had to be very careful not to damage the by-now precious large lacework. In short, the technology failed. Later we developed a completely different mechanism using a long threaded end and a stepper motor, which made less noise, and whose position could be estimated with only a single stop sensor. Still, the embedding/hiding of the latter mechanism was tricky (one can “see” through several layers of lace and even when the lace and the mechanism are all white, the interplay of light, layering and slightly different shades of white is a subtle matter). The interactivity itself was based on an LDR sensor of environment light (detecting approaching visitors), which was a reliable solution tested before in Drapely-o-lightment (Feijs, Toeters, 2014) and documented in (Feijs 2013).

These experiences have led us to believe that it is best to explore the experimental garments and the embedding of actuators simultaneously, in an iterative manner. A new dynamic language is waiting to be discovered.

Technical aspects; current limitations and future developments

For the actuators we worked with electromechanical devices such as servo motors, hacked servo motors and stepper motors. We combined these with conductive yarns for touch sensors, contact switches, and position sensors. Moreover the conductive yarns are used to feed the motors. In some of the designs, the motors drive a small bobbin to pull and release hidden ropes. As a classical engineering principle, sensing and actuating should go hand in hand, because this facilitates closed feedback loops. Using feedback, positioning can be more precise and all kinds of calibration problems can be solved. In fact, every servo motor has an internal feedback loop, since it measures the position of the outgoing axis. The limitation of the cheap off-the-shelf servo motors is that they rotate only 270 degrees, but they can be modified in a variety of ways (which is what we did). Stepper motors are attractive since they make less noise (no gear wheels). We are very much aware of the limitations of these actuators (too much weight and noise; bulky). But we consider them to be the forerunners of more light-weight actuators, now in the lab stage. Therefore it is worthwhile exploring the dynamic form language of garments, even with imperfect actuators. In the remainder of this section we mention a few alternative and emerging actuation technologies.

Another actuation technology is shape-memory alloy (SMA), materials that return to their original shape after being exposed to heat. NiTinol for example can go to a pre-set memorised form when heated and will become flexible again when it cools down. In his TU/e graduation project Misha Croes used it for an active snuggle to cocoon and comfort babies. Dutch designer Mariëlle Leenders used SMA in her “Moving Textiles” graduation project at the Design Academy Eindhoven in 2000. It is a shirt using SMA threads woven into the textile. The shirt shrinks when it becomes warm (see photorepeats.com/work/shapememorytextiles/). Lines of stitching SMA are added to the basic material of the shirt. One disadvantage of SMAs compared to motors is that heating and cooling are slow processes. Polymer SMAs are under development and hold great promises for the future.

For an overview of all kinds of new actuators being proposed for robotics applications by Harvard University and Trinity College Dublin, see the “soft robotics toolkit” on softroboticstoolkit.com. Stretchable ionic conductors are sandwiched sheet and gel materials working as a special capacitor and turning thinner and hence larger under voltage control (Kepplinger et al. 2013). Another class of actuator systems is driven by air pressure. The pumps are usually mechanical pumps driven by an electromotor but there are interesting innovations in the actuators themselves which can be pneumatic networks formed by channels and chambers in flexible material, such as elastomer, cast using 3D-printed molds (Mosadegh et al. 2014). Similar techniques can be used for sensing. In yet another variation, elastomer bladders are reinforced with fibers (Menguc et al 2013). Pneumatic systems are not easy to control in a closed-loop way because of the non-linear behaviour of compressed air.

Related work

One of the most inspiring designers working with actuating garments is Hussein Chalayan. The transformative dresses of his spring/summer 2007 collection, made in cooperation with Moritz Waldemeyer are ground breaking. As (Seymour 2010) writes: “Hussein Chalayan tapped into technology as a means of expression as a fashion designer. The inspiring pieces are conceptual and have a performance character”. In 2013 Chalayan proposed the “Black Line”, where daywear and evening wear are merged into a single transformable garment.

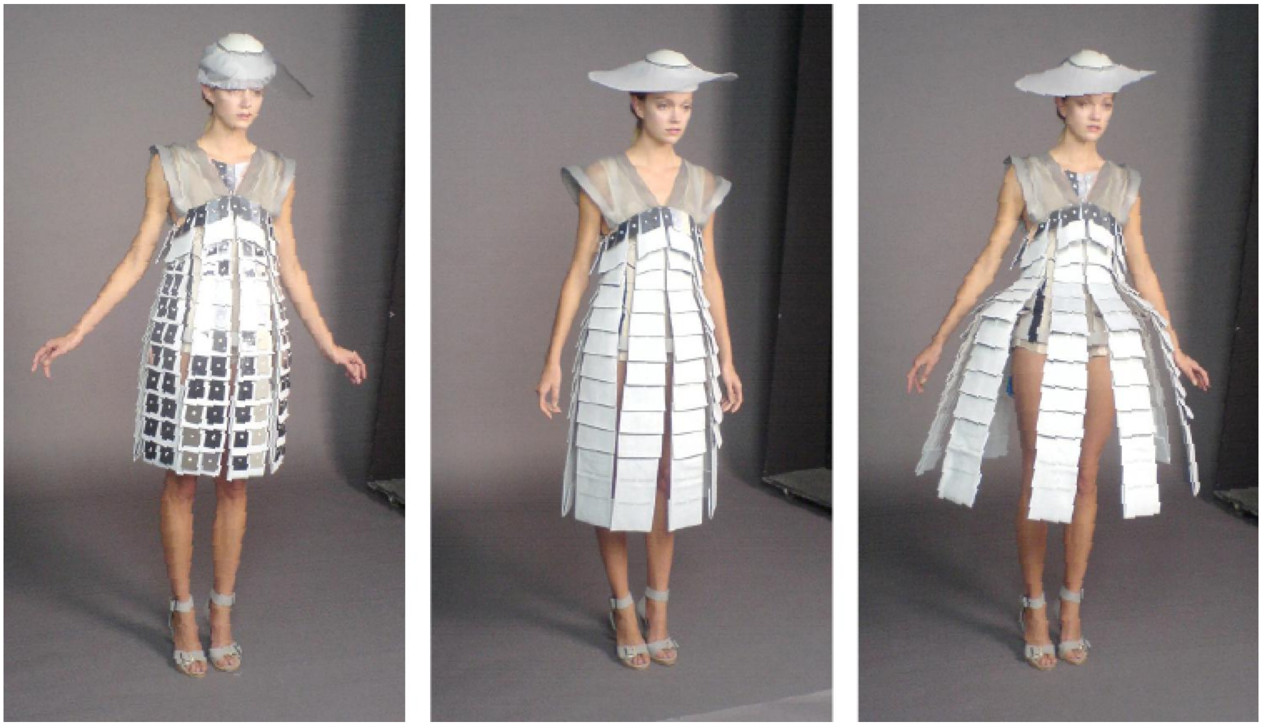

Fig 7. *Actuated dresses S/S 2007* (2006) by Hussein Chalayan youtube.com/watch?v=Ae81FcczsI8

But Chalayan is not the only designer working with dynamic garments: Venus by Eun-Mi Jung and Youngsil Lee of Hongik University moves in response to a proximity sensor. The main theme is “personal space”: when someone gets too close, the collar of the garment transforms from friendly to hostile. As components of the technology, PVC film, DC motors, servo motors, wooden sticks, Hanji paper, origami-style folding, Arduino, IR proximity sensor, and LEDs are mentioned. Fantastic and very expressive examples of actuated garments are created by Anouk Wipprecht, for example the Robotic Spider Dress, the Smoke Dress, or Intimacy 2.0 (which becomes transparent based on personal interactions).

Fig 8. *Spider dress* (2013) by Anouk Wipprecht, photo's Mojmir Bures.

youtube.com/watch?v=Aybs6rmcjk8

Others designers explore alternative actuators, based on air or gas. For example, Velikov et al. 2014) created "Nevous ether" which is a cellular pneumatic skin, exploring the expressiveness of the dynamic form language and developing the technology simultaneously. The system includes Grasshopper, Firefly and Arduino to control air supply through an electro-pneumatic regulator. The company Hövding developed a head-mounted airbag for cyclists made in an ultra-strong nylon fabric that won't rip when scraped against the ground (Olsson and Sellegren 2012). It is actuated by a cold gas inflator that uses helium. (Sung et al. 2014) discuss the disadvantages of motor-based-actuators in detail, and conclude that the high-torque demands and high-gear ratios of the motors tends to slow down the movements of the garments. Then they move on proposing actuators based on pneumatic cylinders, achieving high torque with that, and demonstrated in a dress with transforming wings for the musical "Turandot".

The design of products with shape-changing qualities is also getting more attention in the field of interaction design. An important question in that research is the meaning or interpretation of distinct shape-changing behaviors. vimeo.com/105327051 (Kwak et al 2014) study the mental constructs and terms that people would use to describe a wide variety of shape-changing behaviors. They find categories such as "interaction with others" (friendly/distant), "approach" (cautious, ambitious) and "stubbornness" (rebellious/cooperative), amongst others. They confirm our observation that there is a whole dynamic language to be discovered.

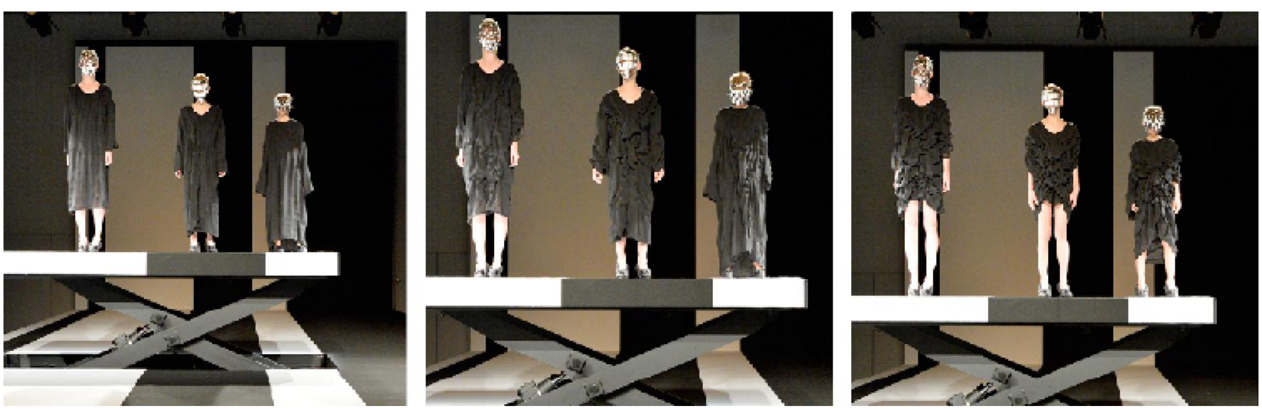

Fig 9. *Collection Size S/S 2014* (2013) by Kunihiko Morinaga (JP) anrealage.com
youtube.com/watch?v=uQ-k-IFoCxs&feature=youtu.be

Relevance of activated fashion

Outlook and implications: The problems in the industry around fashion on a global lever are not ignorable anymore. The fashion system has to reinvent itself and clean the problems that are made. Working in the field of interactive systems and fashion technology we see a bright future for the fashion industry if we start innovating together into the direction of taking care and supporting their customers during everyday life. We propose connecting the needs of users with the current technological possibilities, connecting technologists and designers, connecting sensing and activation. When this happens the fashion world can take his responsibility again towards a relevant and bright industry. Comparing the fashion industry to, for example, the consumer electronics industry, the pace of technological innovation in the latter industry is much higher. Although great cultural value can be created by inventing (and recycling) forms and styles, even more added value can be created by adding technological innovation too. We share the optimistic view expressed by Sabine Seymour (Seymour 2010): "*Today, technologies have matured and range from mechatronics to nanotechnology. These innovations will shape the future of clothing. Much of the essential technology is already available to create meaningful and commercially viable products*." This paper only shows one of the opportunities current technology is offering, and still only on a research level. But we think that via educating students in this explorative approach, building interactive and integrated activated fashion by our self and communicating these possibilities to the world as we do right now will lead us to relevant concepts and profitable strategies for the future of fashion. Sabine Seymour stresses the development of a common vocabulary: *"a common vocabulary is evolving to allow efficient and fruitful collaboration between disciplines, such as physical computing, fashion design, industrial design, wireless networking, software engineering, and graphic design."* (Seymour 2010). We hope that the experiments described in this paper are a contribution to the development of this vocabulary.

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