



Linn Dress: Enabling a Dynamically Adjustable Neckline

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ABSTRACT

We present the design and prototype of the Linn Dress, a transforming dress that allows its wearer to dynamically reveal and conceal areas of skin, as they feel comfortable and appropriate for different contexts. Electrochromic displays are employed as the elements enabling the garment's dynamic transparency. The Linn Dress is designed for office workers with a lively lifestyle, who shift directly from the work environment to social evening events. The dress presents professional working attire, and when transformed to reveal exciting open cuts and patterns, a cocktail dress.

CCS CONCEPTS

• **Human-centered computing** → **Interface design prototyping**; *Interaction design*; • **Hardware** → *Displays and imagers*.

KEYWORDS

Transforming clothing, wearable display, fashion, aesthetic wearables, electrochromic display.

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1 INTRODUCTION

People put on clothes not only to protect their body, but also for social and psychological functions [19]. Clothes can be

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Figure 1: A woman wearing Linn Dress for an evening event with her colleagues. The dress is adjusted to reveal the low neckline and the cutouts in the back.

considered as a display canvas, where a wearer can curate her/his identity and expression being seen by others. One's choice of clothes is socially influenced and, at the same time, conveys a message about the wearer, e.g., identity and status [11, 13]. Suitable clothes allow wearers to feel that they are part of a group. People also choose their clothes to curate a desired appearance that is appropriate for a certain context. Each context has its own norms and expectations, and typically this results in the need to wear different garments to fit to each situations.

Social norms set boundaries for the appropriateness of clothing items being worn in a certain context. One aspect of the boundaries is related to body exposure in public [19]. For example, in many cultures, displaying cleavage is inappropriate in workplaces, churches, or schools, whereas it may suit a party or festival. This paper presents the design and implementation of a transforming dress, the *Linn Dress*. The dress integrates wearable displays with controllable transparency, as a technique to control body exposure and alter the look and feel of the dress. The main design idea of the Linn Dress is to allow the wearer to easily reveal or cover more/less of their body as they feel comfortable in different situations. While a person can prepare two different garments for two different planned events, dynamic clothes could offer an alternative for ad hoc occasions, for example, a sudden meeting with old friends or need to travel by public transport. The transparency changing display elements integrated into the Linn Dress are based on electrochromic display technology.

2 DYNAMIC AND TRANSFORMABLE CLOTHES

Dynamic and transformable clothes are clothing items designed so that they can be easily altered by the wearers. Fashion designers have explored dynamic and transforming clothing for decades, applying techniques such as unzipping to detach/attach, buttons, and double layering to create multiple looks and multipurpose garments, e.g., [3, 4]. Some designers have used more complicated sewing techniques to create 2-in-1 transformable garments offering two notably different looks, e.g., [1, 6].

In the last decade, designers and researchers started to integrate interactive technology into clothing to create automatic dynamic and transforming features. Chalayan's *Hundred and Eleven Collection*, Spring/Summer 2007 comprised self-transforming dresses that automatically lift and release different parts of the dresses, creating different silhouettes and forms. Ying Gao [10] created *Living Pod*, a dress that curls and unfurls when exposed to light. Kao et al. [15] create a kinetic wearable by employing a small robot moving on the garment to manipulate it.

Other designers used technology to dynamically change the colour or patterning of garments. In *Programmable Plaid* [5] a dress of woven fabric incorporating fibre optic threads allowed wearers to dynamically change the colours of the dress' tartan pattern. Kleinberger and Panjwani [16] presented *Enchanted Wearable*, a digitally augmented dress where the dome skirt of a dress forms a blank canvas on which audiovisual content is projected. Personalizing clothes with green screen and removable augmented reality (AR) markers has been proposed as a way to customize clothing both in its physical appearance and through digitally overlaid AR content [12, 17]. Clothing integrated displays have also been considered as information displays, presenting an embellishment or an information visualisation channel, e.g., [7, 8].

Ellinwood [9] define space as: 1) three-dimensional empty area around the body, and 2) two-dimensional empty space on a surface. Cutouts in clothing, revealing the body underneath, are one approach used by designers to use two-dimensional space. In the Linn Dress, we explore the potential of dynamically manipulating such two-dimensional empty space in clothes. A similar approach was employed in the *Intimacy dress* [2], areas of which become transparent as its wearer's heartbeat increases during interacting with another person. In contrast, the Linn Dress gives its wearer full agency to control the space and body exposure in response to context.

3 LINN DRESS

The Linn Dress is a dress with cut out areas that the wearer can dynamically adjust the transparency of, revealing or covering the underlying body. The dynamic areas are located

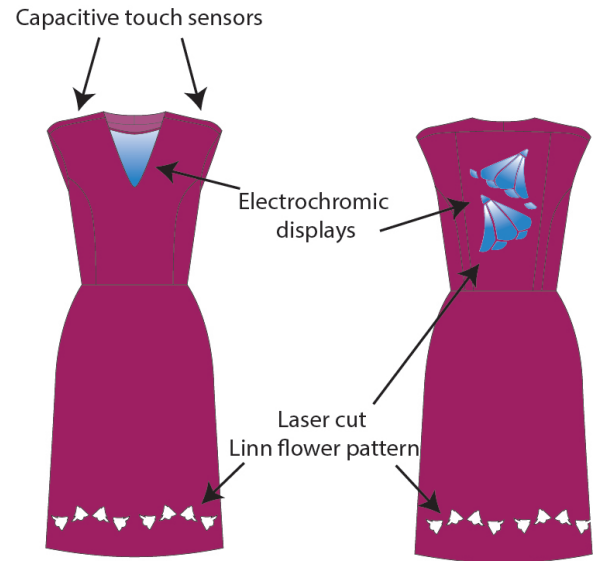


Figure 2: Linn Dress flat sketch.

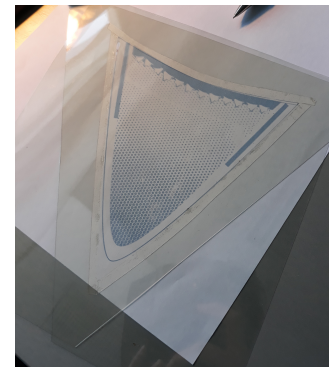


Figure 3: The electrochromic display for the neckline before sewing to the Dress.

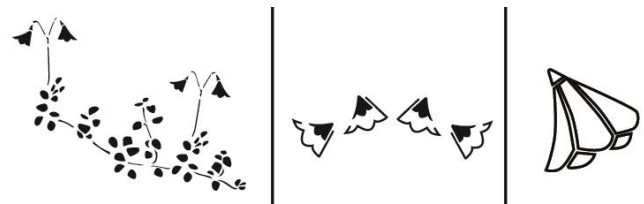


Figure 4: The development of *linnaea* flower pattern used in Linn Dress. Left: the early design. Middle: the design used for the hem. Right: the design used on the back side of the dress.

at the neckline and in the back of the dress (see Figure 1). The transparency of the areas is controlled through the use of electrochromic displays, which can switch between two



Figure 5: Linn Dress, front and back view.

states with higher and lower opacity levels. For daily work time wear, the displays could be set to high opacity, covering the underlying skin. At social evening events, the wearer may select to reveal more skin by decreasing the opacity of the electrochromic display areas. The dress' state can be controlled by capacitive touch sensors in the two shoulders of the dress (see Figure 2).

Design Inspiration and Process

The Linn Dress is designed for the fall/winter season 2019. We used the 2019 fashion forecast as a guideline for our design. The colour of the electrochromic displays used is blue in the opaque state (see Figure 3), which influenced the colour choice for the dress. To make it suitable for fall and winter, the tone of the dress is dark. The pattern on the dress was inspired by *linnaea borealis*, an arctic flower. The pattern combines the natural form of the *linnaea borealis* flower with geometric forms (triangle and circle), see Figure 4.

The design process of Linn Dress followed a typical clothing design process [20]. The fabric for the dress was selected such that it was suitable for both workplace and evening wear – a polyester in a deep plum colour.

The silhouette of the dress was a compromise between the two different target environments and atmospheres: more conservative workplace and informal evening wear. The dress has a tight-fitting bodice silhouette, which is stylish

for both environments. The two settings also have different norms and expectations for body exposure. A low neckline and cutouts in the back of the dress (see Figure 5) enabled control over exposure of the cleavage and back areas. Electrochromic displays were sewn directly onto these areas to enable the dynamic revealing and concealing feature. The wearer can set the transparency of the displays as they feel comfortable for the situation (Figure 6, Figure 7).

Technology and Implementation

The Linn Dress uses electrochromic technology to create the dynamically transparent areas of the dress. Electrochromism is the property of certain materials to change their optical parameters, such as colour or opacity, when a voltage is applied. [18]. Electrochromic displays printed on PET-ITO film, such as those used in the dress, are flexible, transparent, and free-form in shape, making them particularly suited to integration in clothing. The bi-state displays created for the dress switch between being almost transparent and an opaque blue colour, when a switching voltage of 1.5V is applied. Detailed fabrication instructions for electrochromic displays can be found in Jensen et al. [14].

Two electrochromic displays were sewn into the Linn Dress, one at the neckline and a second in a panel on the upper back of the dress (see Figure 8). Depending on the state of the display, the area of the wearer's skin under the display is either hidden or visible (see Figure 6). The displays are controlled by a LilyPad Arduino, sewn into the inner lining of the dress. Capacitive touch sensors in the dress' shoulders enable the wearer to control the transparency of the electrochromic panels.

4 DISCUSSION AND CONCLUSION

Rather than the more typical application of wearable displays as an embellishment or information visualisation channel, the Linn Dress presents a novel way to use wearable displays as a cover for the body. Electrochromic displays, which can switch between being transparent and opaque, are attached to the dress, enabling a dynamic control of body exposure. The feature allows the wearer to decide ad hoc if they want to reveal or conceal certain body parts, as feels appropriate in different contexts. Although the electrochromic displays used have a plastic look and feel, it is not uncommon in the fashion industry to integrate materials other than cloth or fabric into a garment. As a non-light emitting display, electrochromic displays blend in with the garment's fabric. This also makes the displays suitable for clothes being worn on a daily basis, as opposed to clothes with integrated lights and light-emitting displays, that are considered suitable for parties or performances [7].

We consider the development of Linn Dress as a starting point to explore different use cases of wearable pervasive



Figure 6: Left: The display in transparent state, revealing the body underneath. Right: When opaque the display masks the wearer's skin.



Figure 7: Left: The display in transparent state, revealing the low neckline. Right: Display opaque mode, covering the neckline.



Figure 8: Sewing one of the displays to the dress.

displays. In this version of Linn Dress, we focus on technology exploration, particularly to understand the potential and limitations of electrochromic displays as a body covering. The displays were sewn into the dress, which can only be done at the borders of the display, not through the centre of the displays. Thus, smaller displays would allow more seamless and cleaner integration. We found that smaller displays work better in terms of switching time and contrast between states. In future iterations of the dress, we plan to use multiple layers of displays to create better contrast and pattern variations. We will also explore other alternatives to better integrate the displays to garments, e.g., using fusible web. Additionally, we will focus on the user experience of wearing and using the dress as well as approaches to overcome issues of washing technology integrated garment as the electrochromic displays and the circuit are not totally waterproof.

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