In this paper, we address the theme of future products design, proposed a design for an ambient communication bracelet, which combines digital technology and with jewellery making tradition. The work presents an example of future visions where unobtrusive interactive wearables are used for emotional communication. The paper presents the concept design process and prototype for an interactive jewellery, Ambi-Bracelet. The interactive bracelet is targeted as an aesthetic and simple communication device between couples over distance. The jewellery design with Ambi-Bracelet was done by using traditional craft techniques combined with 3D modelling and rapid prototyping techniques. The functional physical prototype was manufactured by 3D printing the bracelet frame, and integrated with electrochromic displays showing user-designed graphics. The electrochromic display technique allows the printing of interactive graphics at low cost and small samples, which makes it potential for personalizing smart artefacts. The interactive prototype was implemented with Arduino-based electronics. We report on the process of creating the digital jewellery concept and prototype and discuss the lessons learnt.

**Keywords:** smart jewellery; long-distance relationships; ambient communication; electrochromic displays

1 Introduction

Digital technologies have taken a central role in many product categories, and digital communications technologies are today constantly used for keeping in touch with distant loved ones. The conventional communication technologies, developed for information exchange rather than affective communication, have been criticized for not being optimal for mediating emotions or the feeling of connectedness (see e.g. Hassenzahl et al., 2012), and they adopt obtrusive rather than ambient interactions. Especially, during the Covid-19 pandemic, the risk of loneliness has increased (Groarke, 2020), and has highlighted the importance of caring for each other especially when we must be physically apart and inspires rethinking the concept of technology-mediated communication. In this
paper, we introduce our design and research on a new type of communication device concept which seeks to support people to stay connected over a distance, the Ambi-Bracelet.

The Ambi-Bracelet represents a concept of unconventional user interfaces for communication, which go beyond the traditional communication methods, such as phone calls and text messages (Li, Häkkilä et Väänänen, 2018). The Ambi-Bracelet consists of electrochromic display elements, which are made of interactive graphics manufactured with a printed electronics technique utilizing electrochromic ink (Jensen et al., 2019). The display elements can be turned on one at a time, showing dynamic blue-and-transparent graphic patterns. The displays’ graphics can be personalized and printed by the user, which allows personalization according to the individual person’s wishes. A remote couple is connected via Ambi-Bracelets so that the display graphics on the partner’s bracelet can be activated remotely. This provides a private, ambient communication channel for a couple in the form of smart jewellery. In the following, we present the prior art related to our research and the design process of the Ambi-Bracelet.

2 Related research

2.1 Smart jewellery

Smart jewellery is jewellery that has been enhanced with technology and is framed as a sub-section of wearable devices. Some examples of smart jewellery are fitness trackers embedded in bracelets, and rings or pendants that can be used to make payments or control other devices. Smart jewellery often connects to a smartphone or other device through wireless technology, allowing the wearer to access and control the features of the device through a companion application. Smart jewellery is designed to be aesthetically pleasing and the designs often take into account the prevailing fashion preferences. Wallace et al. (2007) have pointed out that without personal meaning, so-called smart jewellery is merely a gadget. Olivier and Wallace (2009) further elaborated on the importance of emotions being connected with technical smart jewellery designs.

Fortmann et al. (2015) elaborated a set of guidelines for smart digital jewellery along the six dimensions: form factor, functionality, body location, customisability, context awareness, as well as interaction and display design. Silina and Haddadi (2015) created an overview of smart jewellery and its defining properties by analysing 187 jewellery-like devices. Different form factors for smart jewellery have gained attention in a number of case studies, where a specific smart jewellery concept has been designed and prototyped. Especially, bracelets and rings have inspired researchers to develop various concepts, which embed interactive functionalities. For instance, Fortmann et al. (2016) investigated the bracelet form factor for smart jewellery conveying various types of information utilizing an ambient display. Also, a bracelet to send text messages (Pakanen et al., 2014), and a bracelet to keep a record of the user’s water intake (Fortmann et al., 2014) have been demonstrated. The form factors of interactive bracelets have also been addressed by research, and in addition to conventional bracelet styles, Lyons et al. (2012) have presented a form factor using multiple segments.

Researchers have been exploring jewellery-like devices to connect couples at a distance. For instance, United-Pulse by Werner et al. (2008) and Ring U by Pradana et al. (2014) are both ring-shaped wearable devices that were designed to mediate emotional communication. The former concept
promotes remote intimacy between couples by sharing each other’s pulse through touch, while the latter one using vibrotactile and colour lighting expressions. WearLove by Joi et al. (2015) is a wrist-worn device that aims to enhance enhancing affective communication by motivating the wearer to express love to the paired wearer by touching the device to send a heart symbol. Silina and Haddadi (2015) remark that these practices however often lack customisability and unobtrusiveness which are believed to be one of the essential aspects that needs to be considered when designing computer-mediated emotional communication systems for LDRs.

3 Technology-mediated emotional communication

Being connected and supporting emotional connection over distance is a central aspect when we consider caring for others, and digital transformation has enabled new solutions to support that. Hassenzahl et al. (2012) have distinguished between six strategies used for creating a relatedness experience and emotional communication between remote parties, i.e. awareness, expressivity, physicalness, gift giving, joint action, and memories. Conventional communication technologies have been criticized for not being optimal in supporting emotional communication, and different alternative design solutions have been demonstrated. In an analysis covering 52 prototypes utilizing unconventional user interfaces for emotional communication, Li, Häkkilä and Väänänen (2018) found creating awareness to be the most common category for experiencing relatedness. Different concepts for supporting emotional communication between couples include solutions such as whisper pillows (Chien et al., 2013), connected chairs (Papanikolaou et al., 2015), and expressive slippers (Chen, Forlizzi & Jennings, 2006). Couples in long-distance relationships (LDRs) appreciate meaningfulness and personal value in communications (Hassenzahl et al., 2012). Also, the ability to use the communication channel for exchanging secret messages or to encode private meanings in them is appreciated (Fortmann et al., 2016).

3.1 Positioning of our work

We present a jewellery-like device which provides the wearer an opportunity to create awareness and convey secret messages to a distant loved one. Differing from the prior work, we present a design solution that allows an easy creation of the displays with a thin and bendable material, made possible by using electrochromic display technology. This allows easier craftsmanship for display customizability and form factor design. In the following sections, we first explain the technology and then the design of the Ambi-Bracelet.

4 Electrochromic displays as interactive technology for Ambi-Bracelet

To create an interactive bracelet, we needed to consider the technology that we wished to integrate into the product design. In terms of display technology, we decided on electrochromic displays for their low-energy consumption, non-luminance, simplicity and flexibility. From the design perspective, this display type gives more freedom for designers to consider different display shapes, locations and how displays can be bent within different structures.

Off-the-shelf electronics were chosen for the concept design and were measured to get precise minimum requirements for the bracelet size. The ambient displays were defined to use electrochromic display technology suitable for calm interactive graphics and fitted with curved surfaces (Jensen et al., 2019). They are also a well-suited option for use cases which utilize interactive graphics rather than
need pixel displays. Electrochromic (EC) displays are based on inks that change their optical properties when an electric current is applied (Granqvist, 2015). Printed on PET-ITO substrate, these displays are non-light-emitting, low power, flexible, transparent and free-form (Van de Moere, 2008). They have recently been demonstrated for a number of application cases (Colley et al., 2019), including garment-type wearable computing (Genç et al., 2022) and picture frames (Li et al., 2020b). Because of the (typically) lesser need for driving electronics and due to printed electronics manufacturing techniques, electrochromic displays are estimated to be cost-efficient in comparison to LED displays. The EC displays can be manufactured individually by using screen printing or even ink-jet printers common at offices and home, and an easy DIY manufacturing process has been documented by Jensen et al. (2019). This provides new opportunities for creating personalized interactive products, which include interactive graphics elements that can switch between two stages.

![Figure 1. Experimenting with electrochromic displays, which switch between two stages when the electric current is applied.](image)

For its bendability, low cost, and easy personalization features, electrochromic displays were regarded as a good option for an emotional communication bracelet between two people. As the design process started, the technical implementation needed to be considered already in the design brief. For the design brief and the detailed design, it was noted that electrochromic displays require a minimum of 3mm extra framing around the actual display. Early experimentations with the displays and the bracelet form factor are illustrated in Figure 1. In the next section, we explain the design process.

5 Designing the Ambi-Bracelet

The concept design phase started with a review of the design brief and a preliminary schedule planning for a functional prototype and user testing. 3D modelling and 3D printing were selected as the prototype creation method. The work was conducted by an interdisciplinary team. The background of key researchers participating in the design, prototyping and testing of Ambi-Bracelet consisted of two computer scientists with Human-Computer Interaction (HCI) background, one user researcher and service designer, and one User Experience (UX) and jewellery designer.

5.1 Design brief and ideation

As illustrated by prior research (Hassenzahl et al., 2012; Li et al., 2018), there is a call for new types of communication channels and device form factors that would better support emotional connectivity over a distance. The prior art has explored different form factors for devices, which would allow ambient and light-weight communication between people in long-distance relationships.
(Jarusriboonchai et al., 2020). When designing artefacts, a designer should consider body locations that are less socially exposed. We selected the bracelet form factor for our research, as bracelets have moderate social exposure and were relatively visible to the participants themselves. Bracelets can be fully visible or partly or fully hidden under the sleeve, and they can easily be brought into the line of sight when wearers are engaged in different activities. Also, a bracelet form factor allows the integration of control electronics as well as several electrochromic displays within one body. The number of electrochromic displays was in the beginning phase left open to allow the design to evolve before a final decision. The design ideas were then to be 3D-modelled for the printing of the prototypes.

When creating jewellery for a larger audience instead of designing personalized, made-to-order pieces, it is recommended to review the latest fashion trends. Ideation was started with a brief recap of publicly available 2020 accessories trends. Trend forecasting agencies provided summaries where key findings of yearly consumer buying habits, materials and form factor trends can be studied. From the WGSN accessories summary for 2020, the theme Designing Emotion provided some ideas for design ideation. Within the theme, they recommended embracing the beauty of texture and imperfection, meaning that even with the latest technology the craftsmanship can be visible in artefacts. Instead of celebrating "Instagram" like perfection, a human touch can be present and visible. They recommended designing products that can simulate emotion fostering users to attach more to objects. Technology should be used to enrich life. According to the summary, power dressing continues to evolve so they recommended using tactile materials and sculptural forms to create statement pieces. The WGSN recommendations resonated with the team’s previous study findings of personal and meaningful communications through a wearable device between long-distance partners. Wearable form factors were found to create the feeling of being always connected. New ideas for message visualisations were created with this theme in mind. The trend of power dressing and expressive statement accessories freed the ideation to allow considering bigger designs. That was seen as beneficial taken the size of off-the-shelf electronics. Even though the design had to fulfil minimum size requirements, these were not in conflict with the latest fashion trends. This evolved into the “You are my rock” design theme used in the sketching phase. Also, unisex design was preferred for our research and user testing purposes.

5.2 Sketching and low-fi prototyping
At the sketching and low-fi prototyping phase, new ideas can be visualized fast and mechanical decisions evaluated without time wasted building anything too complex, time-consuming or expensive to produce. Pencils, paper and cardboard were used to experiment with bracelet form factor and user interface shapes and locations. The base measure for our ideation sketches and low-fi prototypes was a commonly used medium measure for bracelet size (ellipse 19.5cm circumference). This size was used together with the electronic components’ sizes to find a common ground for the bracelet base form. In this phase, fusing ideas with an understanding of shape and structure to consider how design visions can be translated into jewellery is important.

For further insight, we ran a participatory design session with design students. The purpose of this was two-fold: firstly, to gain more insight from the user perspective, and secondly, to introduce students to a design task where they could familiarize themselves with the idea of using emerging future technologies for connecting over distance. The students (N=13, BA level industrial design students)
were divided into four groups, consisting of 3, 3, 4, and 3 participants, respectively. In the ideation and low-fi prototyping session, they were asked to consider the following aspects: 1) Identifying types of long-distance relationships (LDR) for emotional communication bracelets, 2) paper prototyping of concept ideas, and 3) identifying smart jewellery form factors and body placements for LDR. Examples of created paper prototypes are presented in Figure 2. The concepting exercise resulted in various different use cases for remote communication between two people, where the emerging themes were using the bracelet for creating awareness of one’s activity, for checking that everything was well with the remote person, and for signalling that one was thinking of him/her.

![Figure 2. Design students’ paper prototypes of concept ideas.](image)

### 6 Refining the bracelet design

The participatory design session focused on early concept ideas which gave inspiration and insight for the Ambi-Bracelet design team. When the detailed design for Ambi-Bracelet was created, the multidisciplinary design team was in charge of the design direction and the decisions. The prototype had to take into account the technical and mechanical requirements, and at the same time, the designers must think of the balance between making jewellery that is beautiful but also comfortable and wearable. Also, the user’s interaction and the usability of the jewellery had to be considered and tested, as one had to think about how the wearer could interact with the jewellery. We tried initial ideas with a segmented wrap-around display, individual links or elements mounted on a centre rail. Between different ideas the bracelet size, possible weight distribution and wearability were considered, Figure 3. We finally decided to go with a two-piece hinged bracelet with integrated individual displays. Each body part was further split into two segments to allow easy integration of mechanics and displays.

![Figure 3. Sketching the design ideas (left), the 3D printed model of the design, and the bracelet rendered in silver illustrating the final form of the design (right).](image)
Several design sketches and cardboard mock-up iterations were made to refine the form and a draft for 3d-modelling was selected. Several 3d-model versions were designed to experiment with display sizes and their placements on the bracelet, Figure 4. Three display elements were designed, and electrochromic display elements were integrated into the 3D-printed bracelet with electronics, Figure 5. The displays illustrated a heart, tears, and an abstract figure of circles, where the graphics elements could be switched between blue and transparent.

We implemented the interactive functions via an Android mobile phone app, which was connected to the bracelet via bluetooth. In the interactive prototype, each display element was controlled by selecting it from the phone application. By selecting the display element on the phone, one of the three bracelet display elements, e.g. the heart, was actived, and changed its colour. This proof-of-concept implementation demonstrated the functionality and maturity level of the prototype.

To conduct an initial evaluation of the wearability, we tested the Ambi-Bracelet with two people (one male, one female, both with industrial design background). They were wearing the bracelet for one
day to the test overall wearability of the bracelet design as well as the visibility of the displays, see Figure 6. Further, we chose to go with white as a colour for the final bracelet, bearing in mind that ultimately the bracelet was meant to be cast from precious metal, such as sterling silver, Figure 3 (right). The feedback gained from the participants was positive and it paves the way for further development of the prototype.

![Figure 6. Trying out the prototype in field study conditions.](image)

### 8 Discussion

Nowadays the jewellery industry utilises 3D modelling and 3D printing increasingly much in creating new designs. The 3D-modelled jewellery design can be 3D-printed with castable wax-based resin. Wax-based resins are designed for jewellery and dental prints, where the print itself is not the final product but the casted object. Printed wax pieces can be set inside a steel flask and covered with liquid plaster investment. Investment is set to dry after which the flask is heated in the high-temperature oven. In the oven, the wax-based resin burns and leaves an empty funnel inside the flask. The flask is then placed in a casting machine and the void left behind in the plaster is filled with molten metal. The metal artefact is cleaned from solid plaster and individual parts are then sanded and polished for assembly.

Before silver casting the bracelet 3D-model, it often requires some adjustments. For example, the material thickness should be checked and refined throughout the bracelet model. Hinges designed in the prototyping phase for a plastic material can be significantly smaller and thinner when made from durable metal. Also, the wall thicknesses of the bracelet parts can be made thinner. Material thickness from 0.8-1.0 mm is recommended throughout the piece to reduce bracelet weight but still keep it strong enough to withstand daily wear. Working with displays, it was noticed that the minimum frame could be diminished to 1.5mm. This provides crucial millimetres to adjust the design if needed. The exact replica made from the model designed for plastic printing would weigh almost 300 grams if cast with silver, so some streamlining will be needed to reduce the bracelet’s weight before it is cast. When the silver bracelet is assembled with electronics, some considerations are needed to avoid short circuits. Insulation may be needed and this should be taken into consideration in the final design.

Electrochromic displays are a printed electronics technique, which rises further interest in employing them for such a use case as smart jewellery. The lesser need for electronics and the printed electronics manufacturing approach makes electrochromic displays economically appealing, although the final cost of the components depends on the production volumes. The ability to manufacture a small
number of samples cost-efficiently and to allow the end user to create the design provides easy personalization possibilities. This is an appealing feature when future product manufacturing is considered. The case of being able to do highly customized products which can even use the customer’s own drawings provides a differentiation possibility for the product when compared against mass-manufactured smart jewellery. We believe the presented case study is an interesting example of new opportunities for designers around new printed electronics techniques.

In our previous research, we have explored the use cases and emotional messages of light-weight wearables (Jarusriboonchai et al., 2020; Li et al., 2020a) and with an ambient picture frame (Li et al., 2020b) for communication between couples. The ability to be connected without being distracted has been found to be a key element in the design of a communication channel to support messages for emotion and caring (Li, Jarusriboonchai et al., 2020). The findings have revealed that with design integrating ambient displays, the ability to send secret coded emotional messages through unobtrusive communication media was appreciated. Whereas the prior work (Jarusriboonchai et al., 2020) utilized low-fi prototypes in a field study, the research reported in this paper focused on the bracelet form factor and creating a more mature design prototype, which would take into account the requirements of jewellery design and the hardware. The wearability study with the bracelet prototype, even a brief one, helped in confirming the design decisions and identifying possible pain points with the design. A short-term, one-day evaluation session provides valuable feedback for planning a more thorough user study and helps us to replicate the design into additional prototypes for use in a long-term evaluation. We acknowledge that our research is limited by the maturity level of the prototype, and the brief evaluation in-the-wild. In future work, our wish is to deploy pairs of bracelets to couples in long-distance relationships for an in-the-wild study over an extended period of time and explore more about the jewellery craft techniques integration into the smart jewellery concept design.

9 Conclusion

In this paper, we have presented the design process and a prototype for Ambi-Bracelet, a novel interactive jewellery type of communication device between two people. The pandemic era has shown how caring and emotional connectedness between people becomes especially important in times of societal crisis. Ambi-Bracelet showcases how digital transformations can offer new types of solutions, and explores how design can contribute to novel ways of connecting people over distance and mediating the care for each other. The design process with Ambi-Bracelet showed that the participatory design approach was fruitful for inspiration, but not usable for detailed design insight. As it was essential to take into account both the technical and jewellery design requirements, it had to be the design team which took care of the final design direction. Integrating electrochromic displays as an ambient communication technology creates a novel contribution in the area of smart jewellery design, and offers insight into this new product development approach.

References


About the Authors:

Virve Inget: Virve Inget is a UX designer and user research specialist with extensive industry background. She is also a professional goldsmith and jewellery artist, and a PhD student at the University of Lapland, Faculty of Art and Design.

Heiko Müller: Heiko Müller is a senior researcher in Media Informatics and Multimedia group at the University of Oldenburg. His research interests lie in Smart Jewellery, Ambient Display Technology, Making and Soft Robotics.

Hong Li: Hong Li is a senior researcher affiliated with the University of Oslo. She holds a doctorate with distinction in the field of Human-Computer Interaction from the University of Lapland. Her research interests include digital healthcare, participatory design, and user research.

Jonna Häkkilä: Jonna Häkkilä is professor for Industrial Design at the Faculty of Art and Design, University of Lapland. She leads Lapland User Experience LUX research group conducting research at the cross-section of design and technology, and is the PI of TechFashion and DecoChrom projects.

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