Mirror Mirror: an On-Body T-shirt Design System

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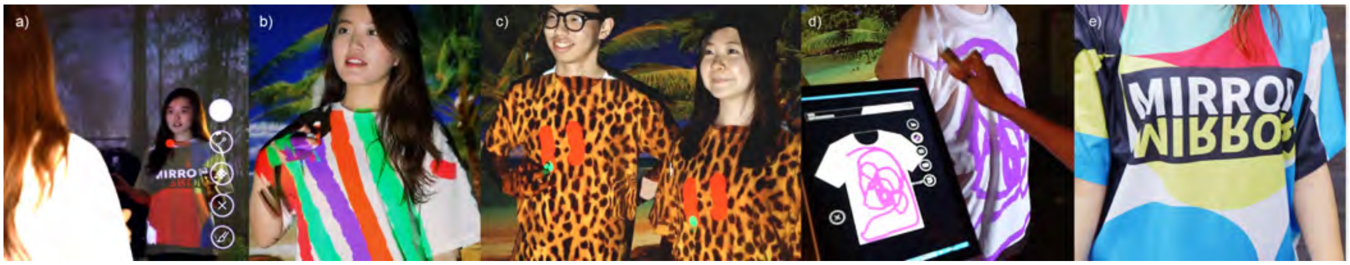

Figure 1. ***Mirror Mirror* is a design system that combines Spatial Augmented Reality with a mirror display. Virtual garments are visible in the mirror reflection (a) as well as on the body (b). Multi user interaction is supported (c, d) and designs are readily printed (e).**

ABSTRACT
Virtual fitting rooms equipped with magic mirrors let people evaluate fashion items without actually putting them on. The mirrors superimpose virtual clothes on the user's reflection. We contribute the *Mirror Mirror* system, which not only supports mixing and matching of existing fashion items, but also lets users design new items in front of the mirror and export designs to fabric printers. While much of the related work deals with interactive cloth simulation on live user data, we focus on collaborative design activities and explore various ways of designing on the body with a mirror.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation (e.g. HCI): Graphical user interfaces.

Author Keywords
Augmented Reality; Design Interface; Magic Mirror; Fashion.

INTRODUCTION
Online shopping is popular across many product categories, but the assessment of certain products such as furniture, apparel, and eyeglasses is difficult to conduct online. These products require a situated experience, on the body or in the living environment. Retail stores offering such products apply various technologies to support the selection process [6]. Virtual fitting rooms equipped with magic mirrors superimpose virtual clothing on users' mirror images. Consumers can artificially test the "fit" without actually putting on items and can "try on" various items effortlessly.

In this note, we explore one possible future of magic mirrors. Mirrors to personalize and design custom clothes in the store or at home, to be fabricated on the spot and ready to wear. Although digital fabrication allows the creation of personalized items, the design of objects in which the "fit" of the object is established in the user's context is still an underdeveloped topic in the field of design by users [16, 31].

We present *Mirror Mirror*, a personal T-shirt design system. We combine Spatial Augmented Reality [3] with a mirror to achieve high fidelity 3D feedback. In this way, augmented graphics are visible on the body, in the reflection, and on the background, and so it is possible to employ both the foreground and background of users' attention [13]. Multiple users interact not only through the mirror but also in direct line of sight as is deemed important in shared activities [4, 11].

Our contribution is twofold: 1) A novel optical setup that combines Spatial Augmented Reality with a mirror to support multi-user interaction with a direct line of sight and third-person perspective through the reflection in the mirror. 2) We explore and evaluate several interaction scenarios for designing items with a mirror.

RELATED WORK
Several art installations [2, 20, 24] and fashion shows [27] use projectors to color persons and objects with digital video. However, this process requires a carefully calibrated setup and limits the freedom of motion. Systems that support projection mapping on free-moving 3D objects, require a sophisticated motion capture stage. For instance, dynamic shader lamps [3] and digital airbrushing with Spatial Augmented Reality [18] let users draw with virtual paint on physical surfaces using tracked

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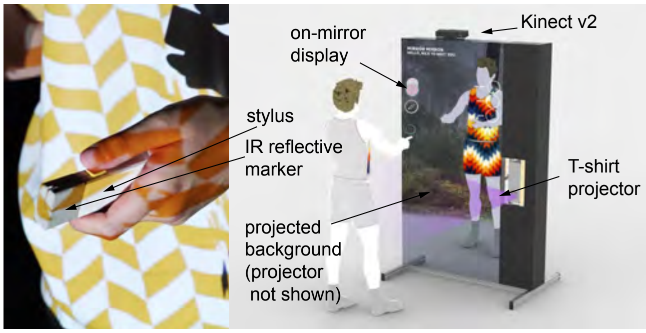

Figure 2. The *Mirror Mirror* system consists of a Kinect v2 depth sensor to capture the pose of multiple users. A projector projects virtual T-shirts on them. Gestures with tracked styli, shown on the left, support interaction directly on the body or with the on-mirror display. A second projector (not shown) projects virtual background behind the users.

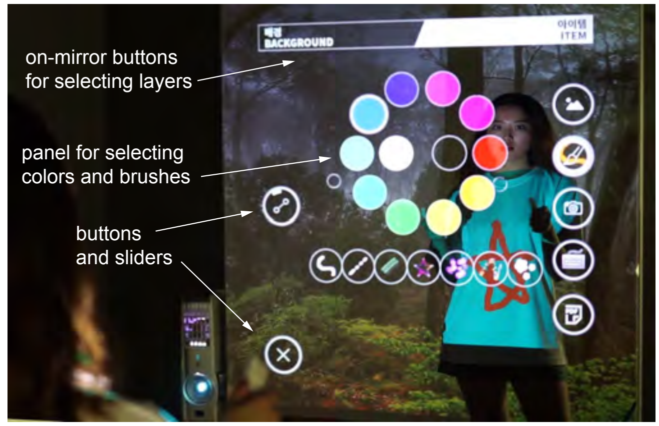

Figure 3. The display behind the Half-Silvered mirror reveals an on-mirror User Interface when a user is pointing at the mirror. Virtual buttons on the edges provide access to system functionality such as switch layer, undo, clear, take snapshot, or activate panels with additional functionality such for choosing colors and selecting brushes.

brushes. Omnitouch [9] mounts a depth camera on a user's shoulder to track hands and arms for interactive projections such as virtual watches. We build upon this work but track multiple persons in front of a mirror with a single depth sensor mounted on the mirror.

Most magic mirrors [12, 26, 28] use video based Augmented Reality that combines a camera and a display. Other systems [1, 17] optically combine real reflections with digital content using a display and a Half-Silvered Mirror (HSM). The Holoflector system [23] places the display at a distance behind the HSM equidistant to the user in front of the mirror to co-locate the digital content. By combining a regular mirror with projection mapping, *Mirror Mirror* achieves a similar 3D experience with a thin form-factor.

Related work in apparel design includes several magic mirrors [12] that have focused on real-time cloth simulation and the fit to the body [32, 33] or on accessories such as shoes [7] and handbags [30]. Whereas these systems focus on speed and accuracy *Mirror Mirror* instead target multi-user interaction and design of new items. Dressup [31] is a prototype for designing garments directly on a real tracked mannequin with tracked cutting and surfacing tools. Tactum [8] is a design system for designing wearables directly on the skin of the forearm with finger gestures. Both systems are relevant to our system, but both separate the input and visualization and thus require context switching. Nonetheless, both suggested projection mapping to situate visualization and interaction as future work.

DESIGN

With *Mirror Mirror* we explore design interfaces with a mirror and with interaction directly on the body. We aim to situate the design process; in the case of apparel, the fit on the person is an important criterion. Next, we aim to explore multi-user collaboration, because shopping is typically a social activity.

The *Mirror Mirror* system, shown in Figure 2, consists of a vertically mounted 55" display covered with HSM foil and is from top to bottom two-meter height. This mirror display provides an on-screen User Interface (UI), shown in Figure 3. Adjacent to the mirror, a short throw projector (BenQ W1080ST) projects on users in front of the mirror, and is calibrated with a Kinect v2 depth sensor using the OpenCV toolkit. We employ standard skeleton tracking to capture user pose and to dynamically generate 3D meshes for their upper body using 3D point cloud data. We render virtual T-shirts as UV textures on these meshes. Because we made graphics scale proportionally with the body size and shape, users can start right away, without calibration. This technique allows dynamic posing with interactive framerates (30fps) for up to four persons.

Users interact with the system using two wireless styli. Each stylus has a button and an absolute orientation sensor (BNO055) to determine whether users are pointing at their bodies or at the mirror and interacting with the on-screen UI. An IR reflective area on the tip of the stylus, shown in Figure 2 left, is used to estimate the position, by ray casting and blob tracking in the Kinect infrared camera feed. Kinect hand tracking, specifically near the body, has proved problematic and clicking buttons was felt to be more intuitive than hand gesture recognition. In multi-user scenarios the stylus might make the on-body interaction on the other person less uncomfortable [10] than using fingers.

Mid-air gestures with the styli are mapped to on-screen cursors to access system functionality such as activating virtual panels for selecting colors, graphics and brushes (Figure 3). Virtual buttons are located on edges of the mirror for easy access without obstructing mirror reflection and projection. Graphics and brushes can be transformed using mid-air gestures, or stamped and drawn directly on the body. Further on-body gestures place/scale/rotate graphics or strokes, similar to multi-touch applications. Dragging graphics outside the body deletes them. This seamless switching from on-screen to on-body interaction is enabled through the custom stylus and on-body, in-place, visualization.

Finally, a second projector (Benq MX842UST) projects a background in the room behind the user [14]. Immersing the users in the intended use-context helps design and evaluation.

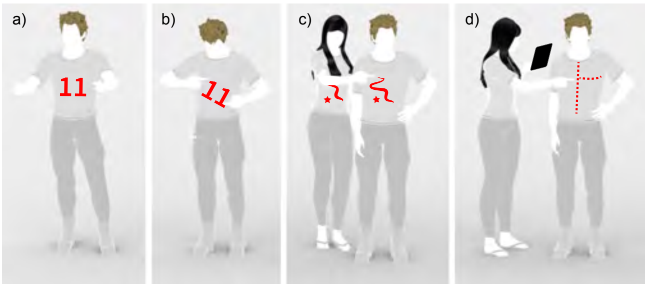

Figure 4. With *Mirror Mirror* we explored several scenarios for designing in front of a mirror. By using mid-air gestures for global transforms (a), or on-body gestures (b). Multiple users sharing a single design (c), or have a unique design. In tailor scenarios (d) a tablet replaces the on-mirror UI and lets the tailor face the client.

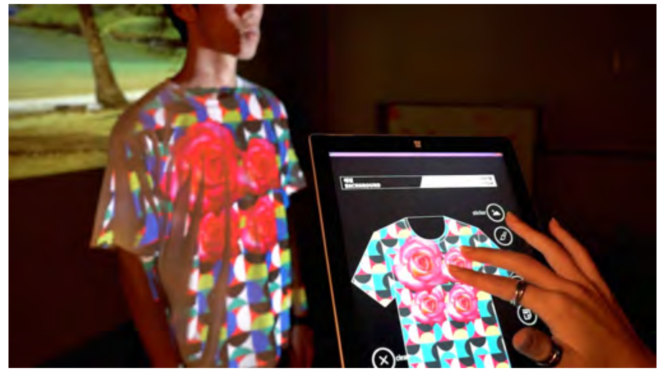

Figure 5. In a tailor scenario one user is drawing on another user. Because 'tailor' is facing the client, we provided a tablet UI in addition to the on-mirror UI. The tablet is realtime synchronized with the mirror.

When designing outdoor apparel one could select a forest and when designing suits for salarymen an office environment.

Content Creation

Mirror Mirror includes a sophisticated graphics design system with brushes for painting, and composing and patterning artwork from existing source materials, as is frequently seen in fashion design. For instance, a sports jersey can be quickly made with 1) a background color, 2) a stripe pattern scaled and rotated, 3) a club logo stamped in a new layer and 4) a hand drawn back number. Graphics are rendered as a texture for interactive projection or exported to PDF for printing. We have experience with several printing technologies including direct to garment professional T-shirt printers, shown in Figure 1e, and DIY transfer printing using irons.

Drawing on the body also supports a set of brushes with various colors, sizes and styles. Some brushes provide generative patterns, such as growing cherry blossoms or randomly sprinkled stars. Completed brush strokes are treated as objects that can be transformed and tiled. Using these features we have observed users make complicated graphics with tiling sketch strokes and masking, in similar to Vignette [15].

By using a mirror, graphics are lateral inverted. Hence, a text projected on the body appears to be mirrored in the reflection. Because the mirror provides the main feedback, we project graphics as reversed so that they look "correct" when observed in the mirror. Looking through the mirror while interacting on the body does not cause confusion in manipulation as in other mirror applications [19] because we perform on-body manipulation mostly parallel to the surface of the mirror. However, drawing text or numbers proved problematic in early user feedback. Therefore, a text input functionality was included.

Multi User Scenarios

A key feature of *Mirror Mirror* is multi-user interaction. Multiple users (Figure 4c and 1c) can design together while interacting with each other, providing feedback and recommendations. Shared design is useful for dance groups or sports teams and in couple design, for couples who want to express their affection by wearing matching outfits. Users draw on a shared T-shirt (the same design is projected on all users, but scaled to their body size), or on their own shirt. In current implementation, only one user can interact with the system and users raise hand to take control.

We explored tailor and client scenarios (Figure 4d and 5), in which one user makes a design fit another user. The tailor uses a tablet-based UI that is real time synchronized. With the tablet as a palette, brushes selected on the tablet are drawn on the body of the client, or graphics are directly manipulated on the tablet or a combination of both thanks to projection mapping. The client observes the process in the mirror.

USER STUDY

From early on we evaluated the system with pairs of design students. Several indicated that the on-body drawing was good to setup a quick sketch for a T-shirt, but it lacked the precision required for drawing a production-ready design: *"When I design with 2D programs such as Photoshop and Illustrator, I have purposes and goals for what I want to make. But this system gives me new inspiration and the chance to design something that I couldn't imagine or think of before, all using existing patterns."* Designers also wanted to continue detailing the design in Photoshop or Illustrator before having it made: *"I like this system to check the scale, position, and things like that. But I think I couldn't control things in detail with this"* and *"I think this is good for rough prototyping. I would like to move the design file to my computer after designing with this system, and edit the details."* Drawing on the body was reported to be difficult. Hence, we decided to compare the on-body and mid-air gestures with the tablet-based multi-touch interface in a within-subject user study.

We recruited 12 participants (M=23.75 years, SD=2.22) of which seven were females. Six participants were industrial designers working in industry, while the others were students without design background recruited from a local university. After a short introduction, we first demonstrated the mid-air and on-body user interface and gave the participant some time to familiarize with the system. We then asked them to reproduce two T-shirts from reference drawings with moderate complexity; the tasks involved drawing, stamping and patterning. This was followed by a free T-shirt design task. We then introduced the tablet-based interface , and let them reproduce

Figure 6. The top row T-shirts are designed during the user study using the on-body and mid-air gestures. The shirts on the center row are the corresponding designs made using the tablet. Bottom row shirts are designed by people during exhibitions.

two T-shirts from new reference drawings, also followed by a free design task. After finishing the designs, we interviewed the participants about their experiences. We videotaped the entire session which took about 40 minutes per person.

Result

All participants were much faster at completing the tasks on the tablet compared to doing so with the gesture-based interaction (in seconds: M=217.91, SD=96.64 vs. M=155.64, SD=84.99). Users felt very familiar when interacting with the multitouch surface whereas the gestures were new to them. Also, working on real scale requires more time due to the large gestures. However, fatigue due to the mid-air gestures was not reported. That being said, two-thirds of the participants experienced the gestures as more intuitive and enjoyed the novelty.

In the free task, we observed differences in the design process between the two conditions. The gestures engaged the users in an explorative process of playing with graphics and patterns while they gathered ideas for their design. In contrast, on the tablet, they were goal orientated and made their design without iteration. Although this difference can be well explained by the order of the conditions and users gaining familiarity with the system, however, as shown in Figure 6 participants made complete new designs.

When using the tablet, most users did not look in the mirror to evaluate the fit on their body as they were immersed in designing on the tablet: *"When I use the tablet, it is hard to check the mirror. I only concentrate on the tablet."* Some of the designers occasionally looked at their reflections in the mirror while scaling and positioning artwork with their fingers, using the tablet as a trackpad. Upon finishing the task, most participants realized that there was a discrepancy between what they had designed on the tablet and how it had turned out on their bodies; this caused them to make adjustments on the tablet while checking the result in the mirror.

We found differences between the novices and the professional participants. Novices preferred the tablet due to the ease of control, even though they answered that working with gestures was more intuitive. In contrast, the professionals rated the tablet as more intuitive and, two-thirds of them preferred gestures because of the situated design feedback.

DISCUSSION AND FUTURE WORK

The advantage of projection over screen based mirrors is the rich and vivid 3D on-body experience that makes the virtual clothes feel as if they are parts of the users. The situated design experience and the serendipity that occurred when designing directly on the body were highly valued. Interacting with *Mirror Mirror* engaged participants in a trial and error process of playing with graphics while generating new ideas; this is a good indication that the system supports creativity. The level of refinement and ambiguity matches qualities that are often attributed to sketching [5]. Working with gestures complements the precision and control that users said they appreciated when designing T-shirts with the tablet.

The lack of precision reported when using gestures was not an issue when we exposed the system to the public in multi-day demonstrations [25]. Novice users enjoyed designing T-shirts, did not require training, and many wanted to buy their personalized shirt. They frequently used features such as text input and making self-portraits for their designs. Introducing templates could further make the toolkit match with the user's skill [29]. Within the boundaries of such professional templates, on-body interaction is engaging and intuitive for non-professionals to customize fashion items. For professional fashion designers, on-body interactions could function as a sketching or rough prototyping stage. However, for applications that require detailing and precision, the refined control of a tablet is preferred with the occasional on-body in-place feedback. Possible a future version could explore on-mirror multi-touch interaction [21] with a hybrid on-mirror 2D representation of the T-shirt.

The current prototype has several limitations and does not implement a full body mannequin needed to support dresses and trousers. Future work should address this and explore interaction on difficult to reach places such as on the back and legs. Whereas viewing and evaluating is possible with (multiple) mirror(s), manipulation might require an on-mirror "virtual" transformable mannequin.

The "fit" and "cut" of items was frequently mentioned by consulted fashion designers and should be addressed in the future work to explore the potential for professionals. Perhaps by simulating shape through shading and with a sophisticated clothes simulation, or to use tangible fabrics, possibly encoded with invisible textures [22] to support layering of clothing, and capes and dresses [31] and apparels and accessories such as hats and bags.

With *Mirror Mirror* we have introduced and explored a novel area of mirror based design applications; the combination of multiple display and interaction surfaces provides a seamless design experience. Exported user-generated designs can be printed with fabric printers or on embroidery machines.

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