Transporters: Vision & Touch Transitive Widgets for Capacitive Screens

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Abstract
Tangible widgets are one possible answer to the lack of haptic feedback on touch screens and tabletops. In this publication, we focus on tangibles that provide input and output channels by spatially relocating a part of the touch input and visual output area from the touch screen onto their own arbitrarily shaped surface. Optical fibers that transmit light between the widget's base and its surface can be used for this purpose, but input on such tangibles only works on vision based, not on capacitive touch screens, and it forces input and output to be co-located on the surface of the tangible, excluding designs with spatially separated input and output channels, for example, back-of-device interaction.

We propose *Transporter* tangibles that exploit the technological separation of input and output channels in current capacitive touch screens. By integrating thin conductive wires into optical fiber based widgets, we can apply independent spatial transformations to both channels. This technique allows us to create tangible widgets in which the arrangement, scale, and shape of the input and output surfaces on the tangible can be designed independently and flexibly. A series of use cases illustrates the possibilities of this technology. We also explore the space of construction parameters for widgets that reliably transmit touch.

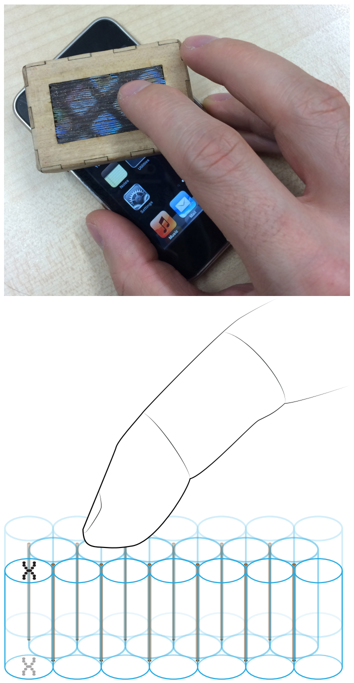

Figure 1: A *Transporter* widget transmits the image from the screen to the top of the widget while integrated thin wires transmit touch information. Note that in this example, input wires and output fibers are collocated, although they don't have to be.

Author Keywords
Tangible user interfaces; transparent widgets; passive widgets; tabletop interaction; capacitive multi-touch;

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation (e.g. HCI)]: User Interfaces: Input Devices and Strategies

Introduction
Touch screens and tabletops have gained widespread use, but they lack the benefit of haptic feedback when operating any on-screen controls. To remedy this problem, a variety of tangible widgets for tabletop and touch screen interfaces have been designed [4, 5, 6, 7]. Most of these systems differ in the way they relay the input and output capabilities of the underlying interactive surface to the user: For the input channel, the design space encompasses everything from simple positional representation (SmartSkin [4]) or basic mechanical manipulation (SLAP [7]) to providing touch sensitive areas on the surface of the tangible itself (PAPILLON [2]). For the output channel, the possibilities range from no output (ZebraWidgets [3]), to allowing the original visual output of the touch screen to be visible through the use of transparent construction materials (SLAP [7]), to transmitting parts of the screen content that is occluded by the footprint of the tangible to its own surface (Lumino [1], Printed Optics [8]).

Recent developments in the area of fiber optics [8] have made it possible to create widgets that relocate visual output and touch input to their surfaces [2, 9], even regardless of their shape. These widgets use the same optical channel for input and output, so any spatial relocation of the output is inherently applied to the input as well. The same is true for any spatial transformation, e.g., when widening the fiber spacing from the base of the widget towards its surface to create a magnifying glass effect. While this may not seem like a limitation at first glance — or even a benefit, since the direct spatial mapping between input and output is preserved — this restriction narrows down the design space for such tangible widgets and makes the implementation of some alternative interaction methods impossible. Additionally, as both the input and output channels are using optical transmission, input on these tangibles cannot be recognized by capacitive touch screens, which make up the majority of commercially available interactive surfaces today. The latter point is especially interesting, because employing two different technologies for sensing input and producing visual output, as is the case with capacitive touch screens, opens up the possibility to spatially de-couple both channels.

We propose *Transporter* widgets that exploit exactly this technical separability of the input and output channels of capacitive touch screens for tangible widgets. By integrating thin wires into optical fiber based widgets (cf. Figure 1), these widgets become capacitance transitive, i.e., they transmit touches from their surface to the touch sensor on screen. Using this principle we can then separate the spatial distributions of the optical fibers and the wires independently and thus apply different spatial transformations to both channels.

In the remainder of this paper, we will illustrate the concept in a series of use cases and describe our prototype construction process. Results from our exploration of the construction parameter space provide a guideline for the creation of *Transporter* widgets that reliably transmit touches.

Related Work

Although interacting with a multi-touch screen allows various forms of input such as touch and gestures, there are situations where the lack of haptic feedback is a drawback. Physical keyboards and jog dials, for example, provide haptic guidance that enables eyes-free operation. SLAP widgets [7] are tangible interfaces that address the issue of missing haptic feedback. Since they are transparent, they can be relabeled dynamically to reflect the value they control. However, this labeling appears on the screen below the widget, which may lead to refraction problems, and since the widget itself has no interactive surface of its own, it only provides mechanical guidance.

PUCS widgets [6] are transparent passive widgets that can be tracked on capacitive touch screens even without the user touching the tangible. As such, they are again only a representation of a virtual entity and do not have an interactive surface.

Lumino [1] explores the possibilities of fiber based tangibles on tabletop computers. Small blocks of fiber bundles are equipped with a unique footprint on their underside that allows widget tracking and identification. Since optical tracking is used and the fibers relocate the image from one end to the other, even the stacking of widgets can be detected. By rearranging and forming the fiber bundles, spatial transformations such as rotation, shifting, and magnification become possible. However, touch on the surface of the tangibles is not sensed.

With Printed Optics [8] we can create optical fiber bundles with a much higher density and thus a higher resolution. This process allows to shape the output surface in nearly arbitrary ways and to apply spatial transformations such as scaling to the relocated image by printing tapered fibers.

Looking at the input channel, ZebraWidgets [3], made from small stripe of ZEBRA rubber[1] provide simple haptic feedback. They are touch transitive, i.e., they relocate touches from the top to the bottom face of the widget. However, the ZEBRA material is opaque, requiring visual output to appear outside the area covered by the widget.

By attaching an image sensor to a bundle of optical fibers, FlyEye can make objects grasp sensitive [9]. Infrared light is injected into the fiber and the possible reflection by a hand is detected by the sensor. While fiber bundles can be shaped into nearly arbitrary surfaces, the resolution of the touch sensing highly depends on the spacing of the optical fibers. Theoretically, this technology allows to have separated fibers for input and output, but it requires additional technology and does not work on any existing touch screen.

For using the Printed Optics approach [8], the construction of a dense grid of optical fibers is much simpler. The eyes of the Papillon characters [2] consist of such an array that relocates the output of the screen to a curved surface. Similar to FlyEye, this means that while the image of the screen can be relocated, optical touch and proximity sensing still work on the relocated surface. However, since both input and output use the same transmission channel (both are through optical fibers), any spatial transformation, e.g., magnification, applied to the visual output, is also applied to the visual input. While this keeps the interaction with on-screen content consistent, e.g., the hit target of a magnified button is scaled too, it also constrains the possibilities to create touch sensitive widgets.

[1] http://www.fujipoly.com/usa/products/zebra-elastomeric-connectors

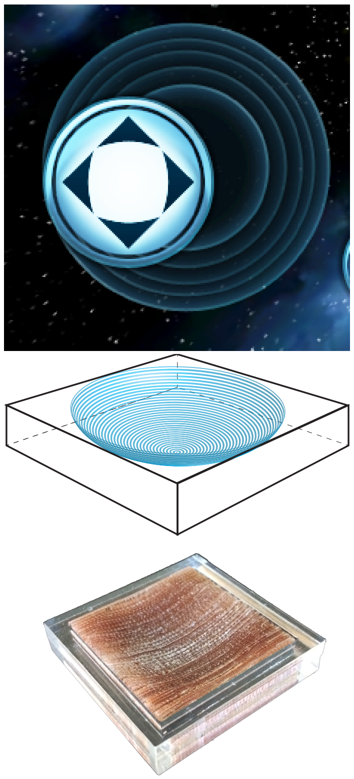

Figure 2: An example of a straight widget. The circular dent in the surface restrains the movement to the area the virtual control covers on screen. This helps to keep the finger on the joystick without looking.

While the above projects show the benefit of tangibles on tabletops, no technology has been presented so far that allows the independent transformation of visual output and capacitive input. With the *Transporter* principle presented in this paper, touch sensing is decoupled from visual output. This allows the creation of widgets that relocate or reshape the visual output to a surface that does not need to correspond with the touch sensing area.

Use Cases

Below, we describe three types of *Transporter* widgets, ordered by the complexity of input/output mapping.

Straight Widgets In straight widgets, the optical fibers and the conductive wires are parallel to each other. This construction relocates the visual output to the upper surface of the widget, but does not apply any other spatial transformation, neither to the visual output nor to the capacitive input. One application of this type of widgets is a haptic guide for virtual joysticks used in games (Figure 2). A problem of this type of virtual controls is that the player has no haptic feedback telling her that the finger is still in the touch sensing area of the control. Since the focus is on the interaction on-screen, readjusting the finger position is distracting. A widget with a circular dent in the upper surface restrains the movement of the finger to the area the joystick covers on the screen.

Modifying Input and Output This use case applies the same transformation to input and output. Clip-on gadgets [10] provide physical buttons that are larger than the area they need on the touch screen to communicate a press. Extending this concept, we do not only provide physical controls that relocate the touch input, but we can also dynamically relabel these controls (Figure 3). Using optical fibers, we can relocate the visual output of that screen area to the surface of the button.

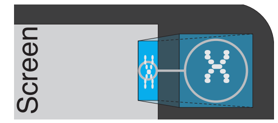

Figure 3: An off-screen button that can be dynamically relabeled. The output resolution decreases, but simple color feedback is possible. The ring transmits the button press information to the touch screen.

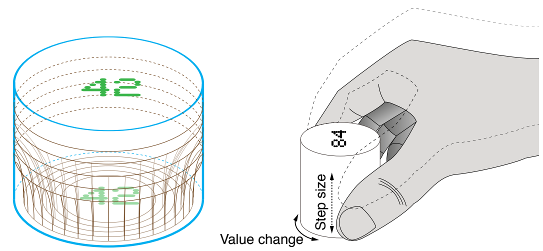

Figure 4: With separated input and output channels, we can create a jog knob for capacitive screens, which allows to control a value in different granularities depending on the height of the touch on the widget.

Since the screen area is smaller than the button, the visual output resolution is lower than on-screen, but still high enough to ,e.g., color-code different buttons.

Separating Input and Output Using two distinct channels to sense touches and provide visual output allows us to create widgets with touch sensitive surfaces that do not need to be collocated with the visual output. Using the *Transporter* principle, we can create a cylindrical jog knob (Figure 4) that transmits touches from the outer face of the widget to its base. At the same time, the visual output is relocated to the unobstructed top face of the widget, where it easiest to see during operation.

Box 1: Prototype Construction
Equipments: PMMA optical fiber, copper wire, end epoxy glue
Procedure:

1. Wind an optical fiber around a long rectangular aluminum beam, aligning the turns in parallel and keeping them straight.
2. Wind the copper wires between the ridges of the optical fibers.
3. Apply a thin layer of epoxy glue to fixate everything.
4. Cut the long layer into pieces of equal length. (Cutting the fibers with a laser cutter melts the endings of the fibers, resulting in good optical transmission.)
5. Stack these pieces to a block and squeeze it into an acrylic frame.

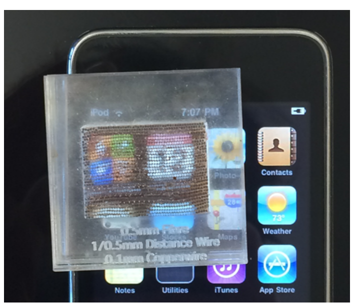

Figure 5: Our prototype of a straight *Transporter* widget.

Preliminary Study

While working with our initial prototypes, we observed that the diameter of the copper wires is an important factor of touch transmission. However, to reduce occlusion of the screen image, it is desirable to reduce this diameter as much as possible. At the same time, creating dense wire meshes is a tedious task when done manually and they may create an intrinsic capacitance in the widget; therefore, we also compared wire spacings. The length of the wires may also influence the touch transmission performance [6]. Larger finger contact areas, touching more wires, are likely to generate more reliable touch signals than small ones. Finally, signal filters in each touchscreen could influence the resulting effectiveness of *Transporter* widgets. We observed how these parameters influence the capability to sense touches in a preliminary study.

Apparatus
We created prototypes using the procedure outlined in Box 1. As shown in Figure 5, The wires are placed in the gaps that occur when bundling round optical fibers. Although the visual feedback quality is limited, these prototypes are adequate to test the touch sensing capability.

Experimental Design and Procedure
Eight straight widgets were constructed with 2 wire diameters $\times$ 2 wire spacings $\times$ 2 wire lengths (Fig. 6). We tested these widgets on a capacitive touch-sensing 27″ Perceptive Pixel display and on an Apple iPad 4[2]. One tester touched the widget for one second through non-conductive rubber masks that had a cutout of 8, 12, or 16 mm diameter.

We measured *TransportRatio*: the ratio between on-widget and on-screen touch size[3]. A *TransportRatio* of 1.0 means that touching on a *Transporter* widget is registered as the same size as touching on the screen. Additionally, touch signals during the one second in the test must be continuous to prevent mis-recognition, such as a touch-and-hold turning in to as multiple taps.

Preliminary Results
The preliminary results in Fig. 6 show that longer wires generate touch signals that are bigger than the original. However, there are complex interactions between wire space and diameter. While one would expect that wires with larger diameter perform the same or better, this is not always the case ,as highlighted in the graph. This could result from the capacitive coupling among the wires itself or from artifacts in our construction process. We plan to investigate this interaction further.

Summary and Future Work

In this paper we presented *Transporter* widgets that exploit the fact that capacitive screens use two different channels for input and output. The widgets consist of optical fiber bundles with integrated wire meshes, which allows us to relocate the optical output independently of the touch input. While interaction with capacitive screens already benefits from very simple constructions applying this technology, more complex widgets can relocate touches to nearly arbitrary shapes.

[2] Retina display; Model MD522FD/A

[3] The size is determined by the length of major axis, as reported by the API of the touchscreen

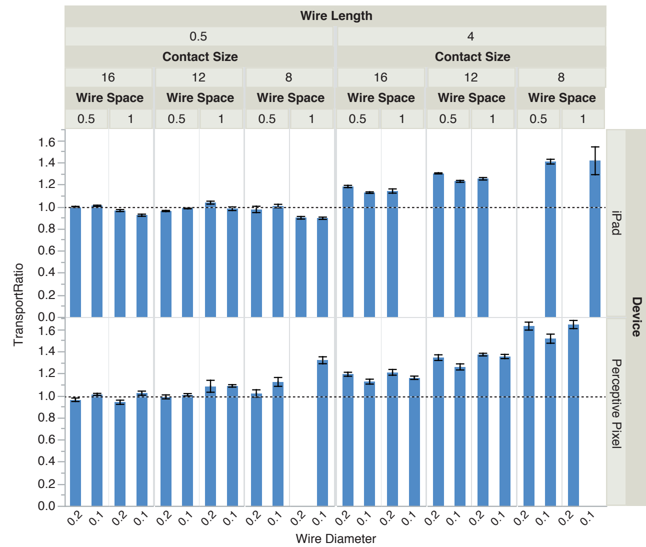

Figure 6: The preliminary study shows complex interactions among the construction parameters. Values that should lead to better performance are shown to the left (larger contact size, larger wire diameter, shorter wire, narrower wire space). The expected graph should show a consistently increasing trend. (Missing bars: sporadic touch signals. Error bar: 95% confidence interval of mean)

In a preliminary study, we explored the space of technical parameters of wire thickness, spacing, and length to determine characteristics that lead to widgets which reliably transmitting touch.

In the future, we plan to create *Transporter* widgets using the Printed Optics approach, which results in much higher output resolution and simpler construction. We will also investigate the use of other conductor materials and their effect on capacitive touch transmission.

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