Duopography: Using Back-of-Device Multi-Touch Input to Manipulate Spatial Data on Mobile Tangible Interactive Topography

Nico Li
University of Calgary
Calgary, CANADA
Nico.HaoLi@gmail.com

Ehud Sharlin
University of Calgary
Calgary, CANADA
ehud@cpsc.ucalgary.ca

Mario Costa Sousa
University of Calgary
Calgary, CANADA
smcosta@ucalgary.ca

ABSTRACT

In this short paper we present the design of Duopography[1], a dual-surface mobile tangible interface for spatial representation and manipulation of topography. The 3D physical topographic front of Duopography acts as a tangible interface, enabling sketching directly on the 3D terrain, as well as visual augmentation of the topography. At the same time, Duopography's flat back-of-device supports gestures that are hard to perform on the irregular front, allowing common interaction techniques such as panning and pinching. We contribute a prototype and the results of a preliminary evaluation of a dual-surface topography interface combining 3D printed front and a flat back-of-device.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; **Haptic devices**; **Geographic visualization**;

KEYWORDS

Back-of-device input, dual-surface interaction, topography, mobile interaction, augmented reality, tangible user interfaces

ACM Reference Format:

Nico Li, Ehud Sharlin, and Mario Costa Sousa. 2017. Duopography: Using Back-of-Device Multi-Touch Input to Manipulate Spatial Data on Mobile Tangible Interactive Topography. In *Proceedings of SA '17 Symposium on Mobile Graphics & Interactive Applications.* ACM, New York, NY, USA, Article 4, 6 pages. https://doi.org/10.1145/3132787.3139197

1 INTRODUCTION AND MOTIVATION

We present the design of Duopography (Figure 1), a dual-surface mobile tangible interface for spatial representation and manipulation of topographic information.

Classic topographic maps demonstrate the consequences of representing 3D spatial information in lower-dimensional media [Harvey 1980]. A terrain topography is a 3D spatial structure, featuring geometric and topologic properties such as elevation. When being represented on a flat media like a traditional 2D topographic map, original 3D spatial information of the terrain needs to be abstracted, distorted, and compromised. Considerable effort in physical and tangible interaction was dedicated to finding ways to preserve and visualize the topography in its original 3D form as much as possible, lowing users'cognitive load and enhancing their spatial awareness when interacting with the topography and interpreting the embedded spatiality (e.g. [Ishii et al. 2004; Leithinger and Ishii 2010; Piper et al. 2002; Willett et al. 2015]).

Past work on improving topography abstraction focused on the provision of either physical embodiments or stereoscopic vision [Mair 2011; Rase 2011]. In addition to representing the terrain with a scaled 3D model, physical topographic maps are often superimposed with rich visual augmentations and supported with touch interactions, which allows users to sense the corresponding fluctuation of the terrain [Delaney 2015; Tateosian et al. 2010]. Combining both tangibility and visualization in these new topographic representations increases the readability of the map contents compared to flat topographic maps. Ideally, these new representations provide better spatial awareness of the original topography, leading to a presumed less steep learning curve and a reduced cognitive load when reflecting on the represented space.

However, 3D physical topographic representations create new interactive challenges when it comes to direct interactions with the irregular terrain surface [Roudaut et al. 2011]. Specifically, sketching on the irregular surface of the terrain model can be difficult, since the movement of the operating pointing device (finger or stylus) can be interrupted by the constantly varying friction and geometric shape of the local area, creating a suboptimal user experience. Following, high-level interactions with the topography that world have been easy to perform on a flat interface could become difficult on the 3D physical one. For example, when planning a field excursion route on the topographic model, the user may experience difficulties when physically tracing and scrolling along the spatial twisted and entangled route path with a fingertip on the bumpy surface of the physical terrain model.

Duopography addresses this challenge by providing on its 3D front an interactive irregular surface that physically and visually representing the terrain topography, while its flat back simultaneously supports back-of-device gestures that are hard to perform on the irregular front. In the following sections we present the design, current prototype, and early evaluation of Duopography.

[1]Duopograpy = duo + topography

SA '17 Symposium on Mobile Graphics & Interactive Applications, November 27-30, 2017, Bangkok, Thailand

ACM ISBN 978-1-4503-5410-3/17/11…$15.00
https://doi.org/10.1145/3132787.3139197

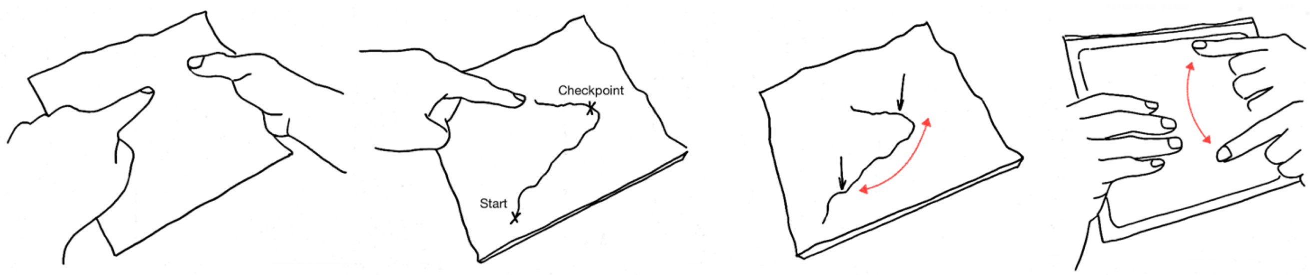

Figure 1: Duopography is a dual-surface mobile tangible interface for spatial representation and manipulation of topography (first); route planning by sketching on the front-facing 3D terrain model (second); user scrolls along the spatial route by panning the back-of-device multi-touch surface (third); a cursor moves along the front-facing route visualization, according to user's back-of-device gestures, in order to select specific checkpoints (fourth).

2 RELATED WORK

There has been a long history of making physical topographic maps in cartography, serving purposes from leisure modeling to stereoscopic data visualization, though most of them are stationary models [Mair 2011; Rase 2011]. Also, there are many recent contributions that transformed the classic topographic maps using novel interaction techniques, some provide enriched interaction with dynamic animation (for example, Relief Shearing [Willett et al. 2015], Flying Frustum [Li et al. 2015], and the HERE location intelligence installment [Delaney 2015]), while others are capable of shape-shifting, active or passive, allowing user to sculpt the physical topography with various input methods (like Illuminating Clay [Ishii et al. 2004; Piper et al. 2002], Relief [Willett et al. 2015], TanGeoMS [Tateosian et al. 2010], etc.).

Duopography is also strongly influenced by previous work on back-of-device input. A back-of-device touch surface may facilitate authentication [De Luca et al. 2013], extends the operating area [Baudisch and Chu 2009], or be integrated with the front screen in order to create a see-through effect for data and virtual object manipulation (such as Lucid Touch [Wigdor et al. 2007] and [Shen et al. 2009]) and grasping (PinchPad [Wolf et al. 2012]). Studies on gesture input with back-of-device surfaces demonstrated that users were, in general, sufficiently dexterous in using selected fingers on both sides of the device for various tasks [Löchtefeld et al. 2013; Wobbrock et al. 2008].

There exists strong research effort in either direction of (1) physically and visually enhanced topography, and (2) back-of-device interaction; however, it is very little explored that how to use both techniques together. Our motivation came from the willingness to improve the notoriously challenging touch interaction on the tangible topographic surface, during which the user is constantly interrupted by physical and visual occlusion caused by the irregular geometry. We therefore contribute the concept of introducing the back-of-device interface as an expanded operation area, resulting in more intuitive and fluent interaction and better physical and visual exposure of the physical topography itself.

3 DESIGNING DUOPOGRAPY

The design goal of Duopography is to provide a mobile device that incorporate both a tangible interactive topographic map representation and a back-of-device interface. It targets at users who need to maintain spatial and situational awareness of the topography while performing out-door activities in real terrain. We hope its physicality and the regular touch-interaction experience provide obvious affordance for understanding the topography, resulting in cognitive eases.

The design of Duopography is centered around its physical topographic terrain model. The surface of the model, which represents a region of the terrain in a scaled form, supports multi-touch capability and is visually augmented. Following, the irregular topographic surface of the model not only allows the tangible feedback reflecting the geometric structure and geographic features of the terrain, but also serves as a canvas for direct sketching with fingertips. Dynamic visualization of topographic and geoscience data is superimposed on the physical surface of the model, providing a similar experience to a regular touch screen, though Duopography replaces the screen with the irregular 3D physical topography on its front.

We also choose the physical terrain model with a comparable size and weight to the form factor of a tablet-size mobile device, allowing it to be picked up, held, and played with. Such a setup mimics the experience of manipulating nearby objects by hand, resulting in stereoscopic visual cues, direct and indirect rotation,

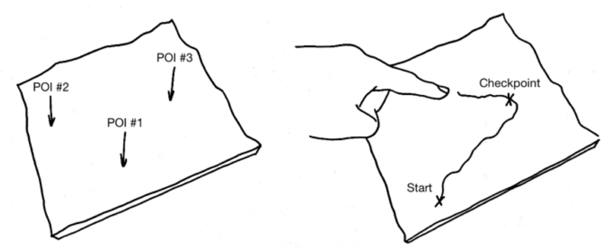

Figure 2: 3D physical topographic terrain model with visual argumentation (left); user input spatial data wish sketching (right).

etc., along with touch screen interactions that most of people are familiar with.

The front surface of Duopography allows the user to input new or to modify existing spatial data by sketching in the scaled 3D space (Figure 2). However, unlike drawing on a flat and smooth 2D plane, sketching on an irregular surface can be difficult, requiring extra effort and uncomfortable gestures to achieve [Roudaut et al. 2011].

Duopography uses a back-of-device input area as a solution to this problem, with the goal of integrating the familiarity of interaction with ubiquitous flat screens into the irregular 3D topographic front surface. A flat multi-touch surface is mounted on the back of the physical terrain model, facing backwards, supporting pinching, tapping, panning, and other multi-touch gestures (Figure 1, and also see Figure 6 for its implementation). The back-of-device interface, which remains invisible during interactions, does not replace the functions of the front terrain surface. Instead, it offers an operation area for additional manipulation, adjustments, and fine tuning on the front-facing spatial data that would have been difficult to direct interact using gestures sketching on the irregular front surface.

Previous work shows that absolute inputs are significantly difficult to perform on a back-of-device surface, especially when the hand behind is not visible [Yang et al. 2009]. Hence, our design is based on using the back-of-device surface to support only relative positioning rather than absolute positioning, which is left exclusively to the interactions with the front of Duopography.

4 IMPLEMENTATION

Our current Duopography prototype is still preliminary but was capable of demonstrating the possibility and feasibility of our mobile tangible topography vision.

The physical terrain model is a 3D printout made from hard plastic, due to the lightweight and durability of the material (Figure 3). The model has a dimension of roughly 20 cm by 20 cm by 5 cm, which is similar to the size of a regular tablet. These physical properties are designed to encourage users to treat it as a typical handheld mobile device without much physical or cognitive effort.

Visualization is superimposed with using augmented reality (AR) (Figure 3). The edges of the terrain model are extended with

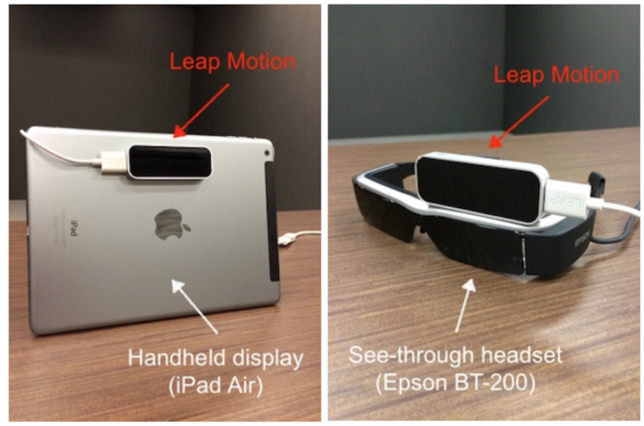

Figure 4: A Leap Motion is attached to the AR device to capture sketching over the topographic terrain surface; on a handheld display (left); on a see-through headset (right).

cardboard to place AR markers around. An AR device, either a see-through headset (Epson BT-200) or handheld display (iPad Air), detects the location and orientation of the AR markers with its built-in camera (Figure 4 & 5). Spatial coordinates of the markers are then captured in real-time, and the visual image is rendered accordingly and overlaid on the live camera footage. As a result, both the visual image and the live footage are shown on the screen of the AR device synchronously. The Vuforia AR SDK was used to handle marker tracking and rendering in our current implementation.

Touch input on the front of Duopography is supported by a Leap Motion attached on the AR device, tracking the movement of users'fingertips (Figure 4 & 5). The dynamic AR image, combined with finger tracking, creates the illusion that the irregular surface of the physical model is capable of capturing user sketching and display situated visualization directly on the physical 3D front-facing surface of Duopography.

The back-of-device touch surface was realized using a back-facing iPad Air mounted behind the 3D physical terrain model

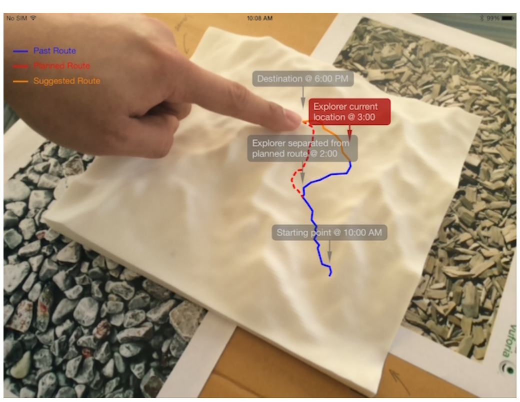

Figure 3: Duopography's 3D printout topographic model superimposed with AR visualization.

Figure 5: A user wearing the see-through headset in field.

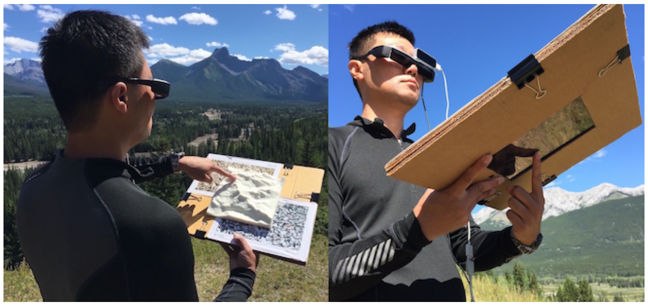

Figure 6: Using the front irregular topography surface to create spatial data by sketching (left); there is a back-of-device flat surface for interacting with the exiting spatial data (right).

(Figure 6), providing a flat and smooth interactive surface, unlike the irregular and fluctuate front one.

Though both faces of the terrain model are touch surfaces that are capable of receive gesture inputs, they serve distinguishable purposes due to their difference in geometric shapes. As mentioned previously, users may use sketch on the topographic surface for creating or modifying spatial information, while the back-of-device surface is used for performing multi-touch gestures that are not suitable for the irregular front face. Since the back-of-device surface along with the operating hand are not visible, we eliminated absolute positioning tasks that requires high precision from Duopography's back surface. We also decided against using transparent or pseudo-transparent screens, exposing the rear hand and its movement [Shen et al. 2009; Wigdor et al. 2007], as we were concerned that the transparency of the terrain model may introduce additional visual distortions on the top of the already somewhat overwhelming topography.

While we tested both a see-through headset (Epson BT-200) and a handheld device (a second iPad Air that is different from the back-of-device one) for realizing the AR, it is clear that, as the AR display, handheld device will render Duopography impractical to use with only two hands. We include the handheld AR approach as the screenshots (in Figure 3, 6, & 7) we use were generated from the iPad and benefited from the much larger field-of-view of the device.

5 INTERACTING WITH DUOPOGRAPHY

We demonstrate a usage scenario of Duopography (Figure 6, and the conceptual scenario in accompanying Video Figure). To plan a route during a field excursion using the mobile Duopography, the user first sketches it on the topographic surface. The tangibility provided by the terrain surface plays an important role, since the geographic and topographic feature along the route will have significant impact on the performance of the excursion. Once a route is planned, the user can use the back-of-device surface to scroll along the route by panning, and select a checkpoint to review detailed information such as the tentative arrival time at that particular point. During the process neither the terrain model nor the dynamic spatial data is occluded because the operation surface now is behind the physical model. (Figure 7)

The user then pinch-to-zoom on a part of the route to observe a higher resolution view of the area nearby a specific point. During this process, denser checkpoints may appear depending on the zoom level, and while zooming the scale of the visualization may be different than that of the physical model. When the user releases the fingers from the back-of-device device, the overlaid visualization shrinks back elastically. (Figure 8)

Notice that the zoom feature allows the user to dynamic modify the scale of the superimposed visual overlay, creating an inconsistency with the terrain representation. We included it in the design due to both the lack of material flexibility of the map model (i.e. the map model cannot be zoomed physically), and users'willingness of checking out detailed information around a certain region on the terrain. Certainly, it will be replaced with more appropriate approaches such as a shape-shifting surface so the physical map representation can be zoomed along with its visual cue.

In addition, during our critique sessions with participants we observed the usages of the pinch-to-zoom feature with little confusion. We argue this is still a valid operation because the zooming action only takes place in a relatively short period. In the process the participants were still able to keep their spatial memory of the physical model, even though during the action the visual presentation is mismatched with the physical one.

6 PRELIMINARY EVALUATION

We conducted an early evaluation of Duopography while hiking in Banff National Park, AB, Canada. The reflections we collected below are very preliminary in nature and are based on our current early prototype. At this stage, we focused on qualitative results

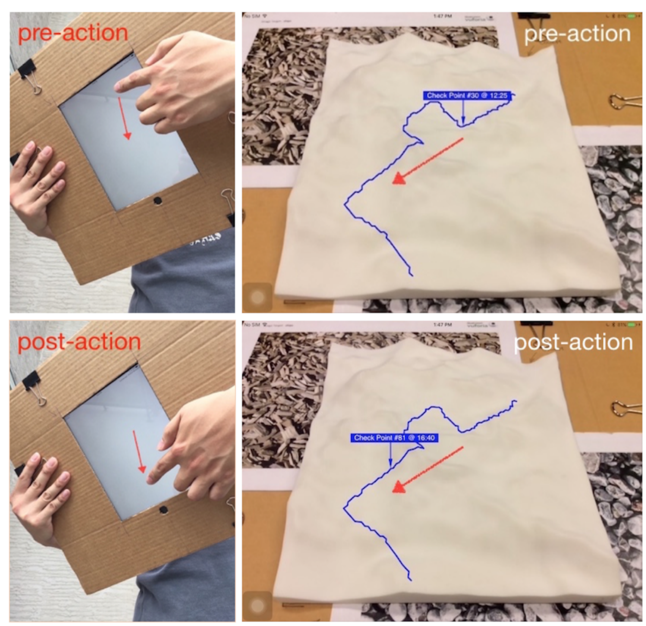

Figure 7: Panning on Duopography's back-of-device surface to scroll along the route at different checkpoints (upper: pre-action, lower: post-action); back-of-device surface (left); front topographic surface (right).

via observations and questionnaires, and the main purpose was to provide some validation to the design approach. More formal quantitative precise confirmation of our interaction technique is clearly required and is beyond the scope of this paper.

Our preliminary evaluation included 7 participants who used Duopography in limited interactive scenarios. Among our participants 3 were males and 4 females; 2 were familiar with topographic maps and 5 not. The input was collected during multiple hiking sessions.

In the early phase of the study participants were asked to attempt absolute positioning on the back-of-device. Unsurprisingly [Yang et al. 2009], we observed the difficulty of absolute positioning due to the invisibility of the rear hand. Participants constantly tilted the device in order to expose the rear hand, and in some extreme cases the topographic model was even flipped over completely. This finding matches the result of previous research efforts and led to us eliminating absolute positioning in Duopography's back-of-device interaction techniques.

We also noticed that slopes and curvatures had significantly impacts on the performance and accuracy when sketching on the topographic front surface. Participants often needed to adjust their finger positions, sometimes repeatedly, in order to reach certain part of the terrain model, causing noticeable cognitive efforts. This is consistent with the finding in previous research on curved surface interaction [Roudaut et al. 2011], and further supports Duopography's back-of-device operations.

Generally, all the participants understood and managed to use Duopography's dual-surface topography interface, along with the

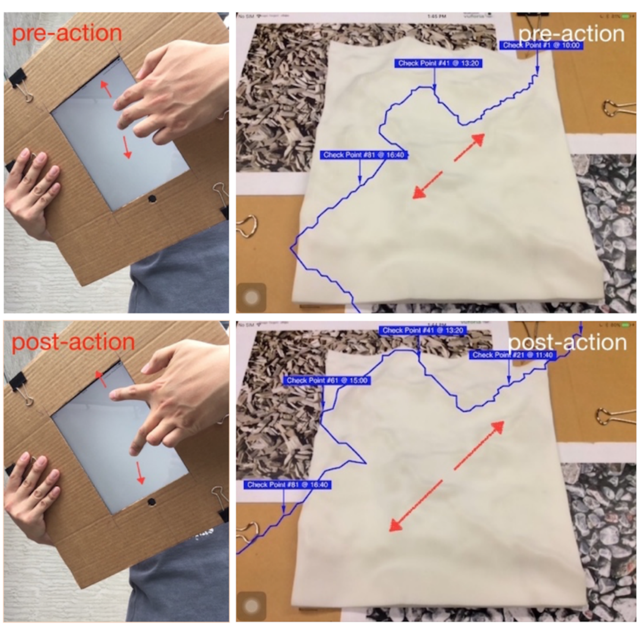

Figure 8: Pinch zooming a local region for detailed info at different zoom scales (upper: pre-action, lower: post-action); back-of-device surface (left); front topographic surface (right).

concept of the back-of-device touch surface. Most of the participants suggested that the back-of-device surface can be beneficial over the classic flat topographic map, increasing spatial awareness and cognitive ease during map reading. However, participants also highlighted some of Duopography's limitations. Most of the complains focused on the less accurate and occasionally unresponsive tracking method, along with the current prototype's oversized AR marker (roughly 60 cm by 50 cm as shown in figure 3, 6, 7, & 8) and relatively heavy weight (the glasses weigh 88g; 212g combined with the controller [Epson Japan [n. d.]]).

7 CONCLUSION AND FUTURE WORK

Our Duopography prototype is still very preliminary, and the early study we conducted is limited. Both the fidelity of the prototype and the scope of the study need to be improved prior to any conclusive and specific confirmation of Duopography's interaction techniques.

Technical improvements would include the replacement of the current Duopography prototype components with cutting edge ones, such as integrating the Microsoft Hololens in the front-facing display in order to determine how the dynamic visualization experience can be enriched. We also plan to experiment with a larger coverage of input gestures and with more complex spatial data, ideally taken from a valid application domain such as orienteering or geoscience. In addition, we also intend to engage with geoscience domain experts in order to add a more domain-specific and valid interactive layer to Duopography.

In this short paper we presented the design of Duopography, a dual-surface mobile tangible interface that has a front 3D irregular topographic interface for sketching spatial data, and a back-of-device flat multi-touch surface for inputting gestures that more suitable for flat touch areas. We contribute a prototype and the results of a preliminary evaluation of a dual-surface topography interface combining 3D printed front and a flat back-of-device. We foresee a future for Duopography-like maps which would allow rich in-the-field direct interaction with mobile 3D physical topography, with a back-of-device layer enabling interaction techniques that are hard to perform on the font-facing irregular surface.

REFERENCES

Patrick Baudisch and Gerry Chu. 2009. Back-of-device interaction allows creating very small touch devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 1923–1932.

Alexander De Luca, Emanuel Von Zezschwitz, Ngo Dieu Huong Nguyen, Max-Emanuel Maurer, Elisa Rubegni, Marcello Paolo Scipioni, and Marc Langheinrich. 2013. Back-of-device authentication on smartphones. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2389–2398.

Ian Delaney. 2015. This 3D-model changes how we visualize location intelligence. (2015). http://360.here.com/2015/09/30/this-3d-model-changes-how-we-visualize-location-intelligence/

Epson Japan. [n. d.]. MOVERIO BT-200 product information. ([n. d.]). http://www.epson.jp/products/moverio/bt200/feature

Paul Dean Adshead Harvey. 1980. *The history of topographical maps: symbols, pictures and surveys with 116 illustrations 10 in colour.* Thames and Hudson.

Hiroshi Ishii, Carlo Ratti, Ben Piper, Yao Wang, Assaf Biderman, and Eran Ben-Joseph. 2004. Bringing clay and sand into digital design—continuous tangible user interfaces. *BT technology journal* 22, 4 (2004), 287–299.

Daniel Leithinger and Hiroshi Ishii. 2010. Relief: a scalable actuated shape display. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction*. ACM, 221–222.

Nico Li, Stephen Cartwright, Aditya Shekhar Nittala, Ehud Sharlin, and Mario Costa Sousa. 2015. Flying frustum: A spatial interface for enhancing human-uav awareness. In *Proceedings of the 3rd International Conference on Human-Agent Interaction*. ACM, 27–31.

Markus Löchtefeld, Christoph Hirtz, and Sven Gehring. 2013. Evaluation of hybrid front-and back-of-device interaction on mobile devices. In *Proceedings of the 12th International Conference on Mobile and Ubiquitous Multimedia*. ACM, 17.

Toni Mair. 2011. The Landscape Relief Model-An anachronism or still a useful object for contemplating the landscape. In *True-3D in Cartography*. Springer, 415–434.

Ben Piper, Carlo Ratti, and Hiroshi Ishii. 2002. Illuminating clay: a 3-D tangible interface for landscape analysis. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 355–362.

Wolf-Dieter Rase. 2011. Creating physical 3D maps using rapid prototyping techniques. In *True-3D in Cartography*. Springer, 119–134.

Anne Roudaut, Henning Pohl, and Patrick Baudisch. 2011. Touch input on curved surfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 1011–1020.

Erh-li Early Shen, Sung-sheng Daniel Tsai, Hao-hua Chu, Yung-jen Jane Hsu, and Chi-wen Euro Chen. 2009. Double-side multi-touch input for mobile devices. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems*. ACM, 4339–4344.

Laura Tateosian, Helena Mitasova, Brendan Harmon, Brent Fogleman, Katherine Weaver, and Russel Harmon. 2010. TanGeoMS: Tangible geospatial modeling system. *IEEE transactions on visualization and computer graphics* 16, 6 (2010), 1605–1612.

Daniel Wigdor, Clifton Forlines, Patrick Baudisch, John Barnwell, and Chia Shen. 2007. Lucid touch: a see-through mobile device. In *Proceedings of the 20th annual ACM symposium on User interface software and technology*. ACM, 269–278.

Wesley Willett, Bernhard Jenny, Tobias Isenberg, and Pierre Dragicevic. 2015. Lightweight relief shearing for enhanced terrain perception on interactive maps. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 3563–3572.

Jacob O Wobbrock, Brad A Myers, and Htet Htet Aung. 2008. The performance of hand postures in front-and back-of-device interaction for mobile computing. *International Journal of Human-Computer Studies* 66, 12 (2008), 857–875.

Katrin Wolf, Christian Müller-Tomfelde, Kelvin Cheng, and Ina Wechsung. 2012. Pinch-Pad: performance of touch-based gestures while grasping devices. In *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction*. ACM, 103–110.

Xing-Dong Yang, Edward Mak, Pourang Irani, and Walter F Bischof. 2009. Dual-Surface input: augmenting one-handed interaction with coordinated front and behind-the-screen input. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services*. ACM, 5.