Foldable3D: Interacting with 3D Content Using Dual-Display Devices

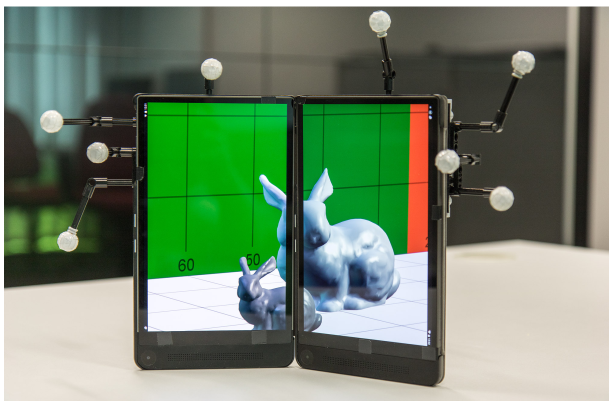

Figure 1: The current prototype running on two Android tablets and using an optical tracking system. The scene in this photo is shown as it would be perceived by a user.

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Abstract
By now, mobile 3D interaction is often limited to simple multi-touch input on standard devices and less expressive or hard to use. We present the concept of mobile dual-display devices which can be folded for the exploration of 3D content. We examine different display modes and introduce new presentation and 3D interaction techniques that make use of the special form factor and the added input modality of folding two displays. In particular, we also consider the advantages of our proposed device for head-coupled perspective rendering – virtually extending the view and providing independent perspectives for two users.

Author Keywords
3D Interaction; Head-Coupled Perspective; Dual-Display Device; Virtual Reality; Augmented Reality

ACM Classification Keywords
H.5.2 [User Interfaces]: Input devices and strategies (e. g., mouse, touchscreen)

Introduction
Using mobile devices for 3D interaction and visualization is increasingly popular and has a lot of potential in fields such as presentation of 3D content, games or Augmented

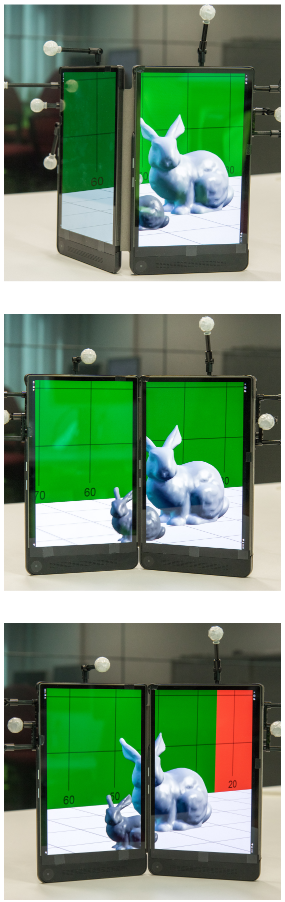

Figure 2: Pictures of our prototype showing the effect of HCP for different folding angles and viewer positions.

Reality applications. However, so far, interaction is mostly limited to multi-touch input and ordinary form factors and is not taking into account, e. g., spatial input or head-coupled perspective. On the other hand, while dual-screen mobile devices have been proposed and studied in the past (i. e., [5, 6]), their potential for 3D interaction and visualization has not been realized yet. Existing commercial devices, e. g., the *Nintendo DS* portable game console and its successors, also generally limit the use of the second screen to straight-forward input and output techniques.

For head-coupled perspective (HCP), also called fishtank VR or user-centered perspective, instead of a fixed perspective that is bound to the display device, the user's position in relation to the screen is used to determine a dynamic off-axis perspective that creates the immersion of the screen being a window through which the 3D scene is observed. However, most solutions that are available today are limited by the field of view of the camera that tracks the user and the viewing angle of the display.

We envision to combine two displays into a foldable dual-display mobile device for 3D interaction and visualization. Our research goals are to examine if such devices can benefit the exploration and manipulation of 3D content by providing new ways for spatial interaction and to investigate if HCP for mobile devices is improved by having two linked but spatially flexible displays. To this end, we analyzed the design space of the proposed form factor for 3D interaction. Specifically, we conducted iterative brainstorming sessions and discussed possible concepts in-depth, also making use of a functional device mockup and first software prototypes.

In this work we present our first steps towards these research goals. We introduce the novel concept of using HCP on a dual-display mobile device for interacting with 3D content. We also present display modes and several techniques for 3D interaction and presentation with such a device, taking into consideration both HCP and the additional input modality of folding.

Related Work

Multi-Display and Foldable Mobile Devices

Mobile devices with two or more displays have already been proposed and studied in the past: Hinckley et al. presented *Codex* [5] as a dual-screen mobile device with embedded sensors and pen input capabilities. Besides presenting the prototype, the authors also proposed a taxonomy of dual-screen postures, organizing the different classes of postures for dual-screen devices. Spindler et al. [14] used passive, projected displays for the prototype of foldable tangible GUI palettes (TUIP). Unfolding allowed users to adaptively show more GUI elements on the palette. *FoldMe* [6] by Khalilbeigi et al. is a similar foldable device. The authors investigated different types of folds and the combination of folding with touch. They also proposed continuous value adjustment by folding.

Several other works have examined folding and bending for interaction, such as [4, 8, 12, 18]. While most of these display prototypes are independent of the specific content that they show, few have specifically looked at 3D content and its particular requirements. For the *FlexPad* by Steimle et al. [15], volumetric 3D datasets where one application example, classic 3D interaction however was not investigated. Kratz & Rohs [7] examined 3D object rotation with a dual-screen device supporting simultaneous front and back multi-touch input.

Besides such research prototypes, several design concepts (e. g., Microsoft's *Courier*) and also off-the-shelf consumer

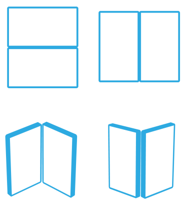

Figure 3: Top: Device orientation in landscape (left) and portrait mode (right). Bottom: Folding inward (left) and outward (right)

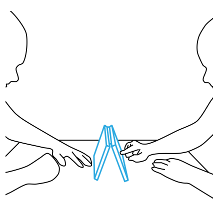

Figure 4: Two users working with the system. Each one has a dedicated screen.

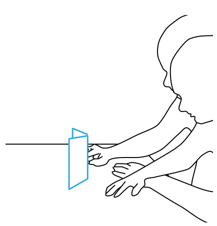

Figure 5: Collaborative usage, users either have a dedicated display or share a unified workspace.

products such as the *Nintendo DS* portable game console or Acer's *ICONIA* dual-display notebook from 2010 have been developed. One of the earliest examples is the *Knowledge Navigator*[1] by Apple, a 1987 conceptional video showcasing concepts for future computers. One of the concepts already shows a a portable device with a large, foldable display.

Head-coupled Perspective
Head-coupled perspective (HCP) has already been proposed in the early 1980s [2] and has in recent years been studied for mobile devices as well (e. g. [3, 13]). Spindler et al. [13] used HCP to support spatial interaction with 3D tracked tangible lenses in a tabletop environment. A positive effect compared to a standard device-centric perspective has been observed by Pucihar & Coulton [11]. Baričević et al. [1] and Tomioka et al. [17] combine tablets with RGB-D cameras to capture a 3D representation of the environment for correct HCP in (video see-through) AR applications. All these systems however only use planar, single-display devices, limiting the user's view into the 3D scene. The *pCubee* device [16] addresses this issue. It is a cube of displays that allows to view virtual content placed inside correctly rendered from all sides. The display configuration is however static, limiting the use of the device to this specific application case. A dynamic, shape-changing interface supporting HCP has recently been presented by Lindlbauer et al. [9].

Principal Concept
We assume a device consisting of two screens flexibly connected with a hinge on the long side, similar to a book. We envision each of the displays to be touch capable, enabling standard multi-touch input.

[1]http://www.digibarn.com/collections/movies/knowledge-navigator.html

Additionally, the folding angle can be measured with a rotary encoder in the hinge and cameras in each device can track the user's face to support HCP. For our mockups and early prototype (see Figures 1 and 2), we combined two commercially available Android tablets with a screen size of 8 inches each in a self-built case. We use an external optical tracking system to determine the positions of the device and the user's head, as well as the angle of the hinge between the two displays. However most presented concepts could instead be implemented using the cameras of the envisioned hardware. The device can either be held in hands in portrait or landscape orientation (see Figure 3), or placed on a table in different ways (see Figures 4 and 5) and supports both a single user or two users simultaneously.

Among the use cases for our proposed device are 3D games, the inspection of 3D content in a mobile setting, or Augmented Reality applications, e. g., for interior design and decoration. We identify three main advantages of our concept for those use cases: (1) The combination of two angled screens provides a larger viewing angle, allowing for a more flexible use of HCP. (2) Folding serves as an additional degree of freedom for interaction, providing another input modality. (3) Two individual but connected screens support both the meaningful arrangement of content and new interaction techniques. In the following we will discuss possible screen modes and how switching between those modes can be benefitial for different use cases. We will also present specific 3D interaction techniques.

Screen Usage & Mode Changes
Having two connected but otherwise independent displays lends itself to a variety of different display modes. As briefly mentioned by Hinckley et al. [5], interaction with a

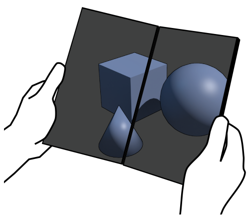

Figure 6: Unified workspace for a continuous canvas, showing one large HCP view into the 3D scene.

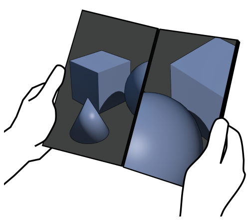

Figure 7: Connected workspace showing a dual perspective view, allowing the user to inspect a scene from two directions.

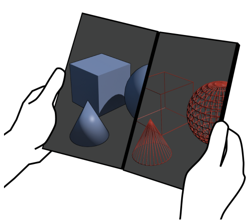

Figure 8: Connected workspace showing an alternative wireframe view for easier object inspection.

dual-display device can be classified according to the relationship between the content of the two screens. Based on this, for 3D interaction we propose to differentiate between three classes of content relations:

In *Unified Workspaces*, both screens are used for one large, unified viewport. In such a continuous canvas both displays are showing a HCP view of the same scene (see Figure 6 and our prototype in Figures 1 and 2). This mode not only provides a larger viewing angle for HCP compared to single-display devices, it also gives the user two spatially configurable input surfaces that can be used for interaction with the 3D content (see below), as well as the additional input modality of the folding itself.

One the other hand, *Connected Workspaces* are two separate viewports into the same scene (see Figures 7 and 8). Among other possibilities, this addresses one of the limitations of typical HCP systems: Normally, with the perspective adapted to one point of view, they only support one user. However, the two separate displays allow the system to be used for *co-located multiuser tasks* (see Figure 4 and Figure 5) in a way not possible with a singular display.

Finally, in *Extended Workspaces*, one screen is a viewport into the scene, while the other one is a secondary screen with completely independent, different functionality. For example, this can be used to offload user interface palettes (see Figure 9).

The analysis of the use of multi-screen devices in the related work shows that different display configurations (folding angle, screen orientation) may be used for different use cases. Thus, we propose to choose the active mode according to the context. The main mode described above, using a continuous, unified workspace for 3D content, is the default and used in *portrait orientation*. We propose to change to one of the other modes in the following situations: When the device is used in *landscape orientation* with an *inward fold* (i. e., like using a laptop computer), the mode switches to an extended workspace with the 3D content being shown on the upper screen and controls displayed on the lower screen. This type of configuration has been used for adaptable multitouch tool spaces in 3D interaction [10]. It would also be possible to use the angle to differentiate between modes in *portrait orientation*. This however comes at the cost of losing the folding angle as an input parameter. We therefore suggest to not use automatic mode changes for handheld portrait orientation.

When *placed on a surface* however, we propose to switch to a multi-user mode: A configuration in *landscape orientation* using an *outward fold* supports a scenario where the device is placed between two users (or two small groups of users). The 3D content is shown on both devices using dual-perspective rendering in a connected workspaces pattern. With two independent views into the same scene, users can interact with the content independently of each other (see Figure 4). If HCP is to be used, both users can have their own perspective, limited to one screen. We propose to use this mode for two-player games and similar applications where collaboration on the same representation of the content is not crucial. In contrast, when placed in *portrait orientation* in a book-like fashion, collaborative work on the same content is easily supported. Again, both users can have their own perspectives but in this configuration, the other display is in sight and reachable (see Figure 5).

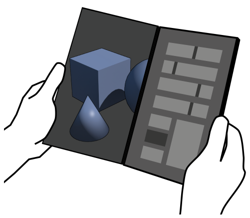

Figure 9: Extended workspace combining a 3D viewport and a user interface palette.

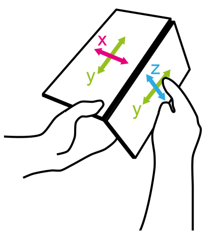

Figure 10: Object translation on all three axes with the help of angled displays.

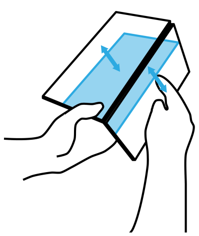

Figure 11: Manipulation of a clipping plane parallel to one of the displays.

Techniques for 3D Interaction

Besides the different display modes made possible by the device, we also propose to use folding as an additional input parameter in combination with multi-touch and thus use the potential of the dual display configuration for interaction purposes. The following techniques all make use of the non-standard input modalities of a foldable dual-screen device

Camera Control by Folding

Folding displays towards or away from the user has been used for changing the zoom level, e. g., in [12]. Bringing this technique to 3D interaction means changing the camera's field of view/focal length depending on the fold. When using HCP however, the camera's FOV is determined by the user's relative position to the displays. Thus, we propose to instead move the scene closer or farther away from the camera (dolly), a movement that is often employed for "zooming" in 3D applications anyhow.

Rotation and Translation Frame of Reference

Rotation and translation of selected objects is done via touch with one or two fingers, respectively. The two dimensions of each display are mapped to the best fitting axes of the 3D camera coordinate system. For example, for a display facing the user, translation and rotation would be on/around the X and Y axes (see Figure 10). Thus, by configuring the device for a folding angle of around $90°$, all six degrees of freedom for translation and rotation of a selected object can be supported by touch on both the front and the side facing displays. If no object is selected, the camera is rotated or translated instead, in the same manner as described above. As a drawback, by having one display not facing the user, content can only be displayed on the remaining one.

Clipping and Snapping Planes

For the exploration of complex scenes, it can be useful to filter the objects to be displayed using clipping planes. Also, snapping objects to previously defined snapping planes (e. g., a ground plane) can support the user in placing and arranging objects. We therefore support the easy manipulation of such planes. By swiping inwards from the screen bezel, an axis-aligned plane is created quasi-orthogonal to the display (e. g. on the x-z-plane for an upwards swipe on the front-facing display) and can then be moved like any other object. Consequently, with our proposed device, such planes can be manipulated on one display without obstructing the view on the other one (see Figure 11).

Conclusion and Future Work

We have presented the concept of using a dual-display, foldable mobile device for 3D interaction. By making use of two independent but connected displays, we virtually extend the field of view for head-coupled perspective and, at the same time, allow for exciting ways to display 3D content for one or multiple users. We examined concepts of different possible screen configurations and their usage, as well as new interaction techniques that make use of the special capabilities of the envisioned system. Initial, in-house feedback on our concepts has been promising. We have begun to implement our concepts in a hard- and software prototype (see Figures 1 and 2). One of the main challenges is to combine existing techniques and different new concepts into one consistent system. We are already partially addressing this issue in this work by our proposal of mode switches depending on the usage context. We plan to expand on this in the future and to evaluate our prototype in appropriate user studies.

Acknowledgements

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