FoldAR: Using the Bended Screen of Foldable Smartphones for Depth Discrimination in Augmented Reality

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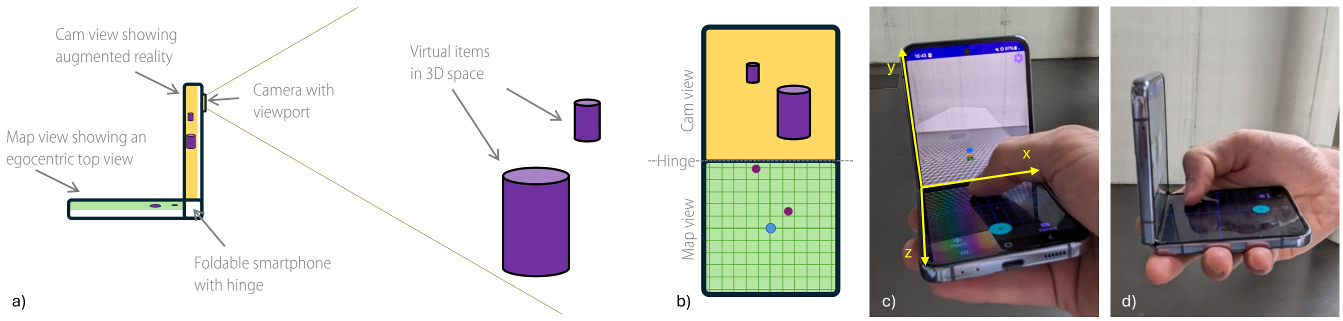

Figure 1: a) Concept of *FoldAR* with the two different screen parts and their corresponding view ports; b) cam-view and map-view on the screen; c) user's view (with annotated coordinate system in yellow) and d) side view of our prototype implementation.

Abstract

Mobile augmented reality is used in research and many commercial applications. Handheld-based AR has been widely investigated. Interacting in 3D space, however, has shortcomings when interacting along the depth axis on a flat 2D display. This paper presents the concept of FoldAR, which uses the two screen parts of foldable smartphones to display a camera view and a map view. With foldable smartphones users can spatially align the display's two parts with the dimensions of interaction. This allows to manipulate objects on two differently oriented screen parts within all three dimensions at once. We contribute a prototype and discuss possibilities and applications.

CCS Concepts

• **Human-centered computing → Smartphones**; *Interaction devices*; Interaction design theory, concepts and paradigms.

ACM Reference Format:
Max Teetz, David Petersen, Vimal Darius Seetohul, and Matthias Böhmer. 2024. FoldAR: Using the Bended Screen of Foldable Smartphones for Depth Discrimination in Augmented Reality. In *ACM Symposium on Spatial User Interaction (SUI '24), October 7–8, 2024, Trier, Germany*. ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3677386.3688903

SUI '24, October 7–8, 2024, Trier, Germany

ACM ISBN 979-8-4007-1088-9/24/10
https://doi.org/10.1145/3677386.3688903

1 Introduction and Related Work

Mobile augmented reality (AR) is commonly addressed in HCI research and widely used commercial applications, like games, education, navigation, or shopping. Interacting in 3D space on smartphone touch screens, however, has limitations since most interactions need to be projected onto a flat 2D surface. For touch-based interaction dual finger gestures can be used for depth discrimination and manipulation [7, 9, 13]. Further, mid-air gestures or device-based interaction techniques can be used [3].

There is an increasing number of users owning foldable smartphones [12], which have been studied previously: Early work by Hinckley et al. [4] and Khalilbeigi et al. [5] present device concepts featuring double-sided displays which can be folded at a hinge and propose interaction techniques and applications. Also Büschel et al. [1] conceptualize the exploration with 3D content with a foldable device. Likewise Liu et al. [6] use foldable mobile devices for modeling simple objects and navigating 3D space. Savino et al. [10] started to explore map usage on foldable phones. While related work uses foldable devices for interacting in 3D virtual space and spatially, the use of foldable smartphones for AR is unexplored.

This work presents a new approach leveraging the foldable screen of smartphones with a hinge for improving the interaction in augmented reality, which we call *FoldAR*. We propose to use the screen's upper part for the original AR view and screen's lower part for an additional map view. This paper contributes the concept and a prototype implementation. We discuss opportunities and limitations based on first user trials.

2 Concept of FoldAR

Bending a foldable smartphone separates the previously flat screen into two parts of same size connected at a hinge. This introduces a spatial alignment of the two screen parts with the lower part being horizontal and the upper one being vertical. *FoldAR* uses these two screen parts at an angle of 90 degree. The screen's upper part is used as *cam-view* and the lower part as a *map-view* as shown in Figure 1b). This creates a space where all three axis of the coordinate system have a natural mapping to the real world, see Figure 1c).

The cam-view implements the usual AR screen: the camera's video is combined with an overlay of virtual objects, as shown in Figure 1b). Objects are being rendered in their appropriate 3D appearance and location. The screen of the cam-view is aligned with the xy-pane, as shown in Figure 1c).

The map-view shows an egocentric map [8]: the center of the map is the user's location in the physical world. When the user moves or rotates, also the map changes accordingly. Virtual objects have their own representation on the map as a marker. Mini-maps have been used in addition to AR views, esp. for visualizing off-screen items [2, 11]. *FoldAR* makes distinct use of the map-view on the lower part of the bent display, so that the map is in parallel to the ground floor. The map-view solves the problem of manipulation items along the dimension of depth, e.g., moving items further away from the user. The screen part of the map-view is aligned with the xz-pane, as shown in Figure 1c).

Items, which are in front of a user can be seen on the cam-view as an AR object and on the map-view as a marker. Items which are not visible in the cam-view as AR-objects would still appear on the map-view, e.g. if they are behind the user.

FoldAR supports basic interactions and manipulations of objects:

- Select items by clicking into the cam view or the map view,
- translate items by dragging and dropping them on the cam-view along the x- and y-axis and on the map-view along the x- and z-axis,
- rotate items by two-finger touching items on the cam-view for rotation around the x- and y-axis and on the cam-view for rotation around the x- and z-axis,
- scale items with preserving aspect ratios by pinching on either screen.

Especially for translation and rotation of objects *FoldAR* allows for manipulation along all axes without any additional gestures or settings. Our approach implements the paradigm of a connected workspace for foldable devices [1]: two separate screens provide interactive views of the very same scene.

3 Prototype

We have built a prototype using a Samsung Galaxy Z Flip with Android OS as shown in Figure 1c) and d). The current version supports selecting and translating items. The app is based on *ARCore* (Google's augmented reality SDK) for implementing everything related to augmented reality. The source code is available on GitHub[1].

The prototype implements an Android activity which hosts a *GLSurfaceView* to show the cam-view on the upper screen part. Herein all 3D objects are being rendered. An Android fragment is implemented to show the map-view using custom widgets on the lower part of the screen. All relevant data about the 3D scenery and objects is shared between these two components through a common model. The map view is being updated with real time tracking data from the AR component. New objects can be added or deleted via a menu.

4 Discussion and Proof of Concept

During first trials in our lab users could grasp the concept, as they related the prototype's two distinct screens to familiar paradigms, i.e., AR and digital maps. We identified unique features of FoldAR. One aspect is the support of one-handed, touch-based interaction which facilitates easy manipulation, as also shown in Figure 1. Users found it easy to interact with the map using their thumb, although interaction with the cam-view was less ergonomic due to its vertical alignment and reduced reachability for thumbs.

When holding the device upright as in Figure 1, the map-view aligns parallel to the ground surface. However, users could change this orientation to visualize objects on planes not parallel to the floor. For instance, rotating the device 90 degrees around the z-axis allows the map-view to show objects intersecting the space vertically. Additionally, device-based manipulations, such as moving the phone while holding an object on the map for replacing it, could also enhance the interaction experience.

Adjusting the map's scale enables a more precise object placement. Providing such fine-grained control over item movements is not possible within an AR, since it has to maintain its scale and 3D registration with the real world. Additionally, the map-view shows objects which are invisible in AR due to occlusion by real objects or being off camera. While zooming and panning appears to be reasonable, it can also destruct the connected workspace [1] of map-view and cam-view, esp. if the user's location moves off the map. Hence, an egocentric map perspective appears to be beneficial. Currently, the map-view centers the user's position.

Another advantage of interacting with the map-view rather than with the cam-view is that fingers are not occluding the AR scenery. Users can see the AR screen without their fingers obstructing the view. This indirect manipulation gives rise to a higher precision when placing items.

As a disadvantage, the available screen real estate is effectively halved when bending it an using two views. Furthermore, in contrast to other research [1, 4–6, 10] the usage of the folding hinge is more static rather than dynamic: the screen parts are used at a fixed configuration of 90 degrees as described above.

The concept can be applied to different domains, including gaming, storytelling, and authoring AR environments. In particular, it can support editing tasks and manipulation of objects like moving items where depth discrimination is important, e.g., in home decoration scenarios. Future work will investigate *FoldAR's* performance compared to other concepts (e.g., [7, 9, 13]) using a formal study.

5 Conclusion

In this paper, we propose a new concept for interacting in augmented reality, called *FoldAR*: users can use the two screen parts of foldable smartphones for distinct interaction panes when looking at a scenery in augmented reality. *FoldAR* uses the upper display part of the foldable device to show a camera view with AR objects, and the lower part to show an egocentric map view of the objects. On both views users can directly select, translate, rotate and scale objects according to the plane of the display.

[1]https://github.com/moxdlab/FoldAR

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