Off-Surface Tangibles: Exploring the Design Space of Midair Tangible Interaction

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ABSTRACT

Tangibles on interactive tabletops are tracked by the surface they are placed on, and have been shown to benefit the interaction. However, they are tied to the surface. When picked up, they are no longer recognized, and lose any connection to virtual objects shown by the table. We introduce the interaction concept of Off-Surface Tangibles that are tracked by the surface but continue to support meaningful interactions when lifted off the surface. We present a design space for Off-Surface Tangibles, and design considerations when employing them. We populate the design space with prior work and introduce possible interaction designs for further research.

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KEYWORDS

Tangibles, Tangibles on Tabletops, Input Devices, Midair Tangibles, Design Space

INTRODUCTION

Tangibles on tabletops are physical objects that are tracked by the interactive display surface they are placed on. They combine the haptic advantages of manipulating real 3D objects with the dynamic 2D display capabilities of a large interactive tabletop [4], and have been shown to improve users' interaction speed and accuracy [9, 10].Their physicality also encourages playful and exploratory behavior, increasing user engagement [5].Finally, tangibles stand out visually on a flat surface, which makes them easier to notice, even when used by someone else [3].

So far, however, these tangibles have mostly been tied to the surface they are on. When a user lifts them off the surface, they are no longer recognized. When such a tangible serves as a physical handle for a persistent virtual object on the tabletop display, lifting the tangible also breaks that connection, and the user can no longer interact with the virtual object through its physical proxy.

To address these shortcomings, we introduce the interaction concept of *Off-Surface Tangibles*. These tangibles can be tracked by the interactive surface they are resting on, but, through embedded sensors, continue to support meaningful interactions when lifted off the table. This allows Off-Surface Tangibles to be used in midair, or even when resting on a surface next to the interactive display, to recognize object manipulation or other gestures.

We present a structured exploration of the interaction techniques that this new class of tangibles enables, and discuss specific design considerations when employing them. For example, the moment when a tangible serving as a proxy for a virtual object leaves or returns to the interactive surface is of particular importance, since the tangible and the virtual object it represents do not necessarily underlie the same spatial and orientation constraints. This issue has been identified in traditional tangibles on surfaces before; Off-Surface Tangibles both significantly widen the problem space because of their support for midair manipulation, but also offer new approaches to alleviate the problem thanks to their continued orientation tracking while off-surface.

To help designers and researchers explore this interaction technique further, we extend Card et al.'s design space of input devices [1] to describe Off-Surface Tangibles. We populate our design space with previous work, and describe several possible applications for Off-Surface Tangibles that may benefit users interacting with them.

RELATED WORK

Off-Surface Tangibles are derived from tangibles on interactive tabletops, but add capabilities for interaction in midair above the surface.

Most existing tangibles on tabletops are not tracked when above the screen. Even stackable tangibles like Chan et al.'s Capstones [2] need to be stacked on top of a display. Spindler et al.'s PaperLenses track sheets of paper above a tabletop display and use these to top-project 3D information onto the paper [8]. Their formative user study provides helpful insights for future designs. Lee et al. introduce tangibles that can levitate above a top-projected surface; the interaction technique creates "many opportunities and leaves many design challenges" [6]. GaussBits [7] take a first step into combining on- and off-screen tangible interaction, but are tracked only within 5 cm above the surface. Microsoft's Surface Dial[1] is an early commercial tangible input devices for interactive tabletops. It works on any surface, not just an interactive display, but does not provide meaningful input when in midair.

[1] www.microsoft.com/en-us/p/surface-dial

A DESIGN SPACE OF OFF-SURFACE TANGIBLES

Tangibles on tabletops are physical, graspable objects to interact with otherwise flat multitouch screens. In midair, a tangible's sideways movement is not limited to the edges of the display, and it can be rotated to any orientation since it does not need to rest on a flat surface. It can thus be manipulated freely along all six degrees of freedom. Tangibles that are tracked both on and above an interactive surface allow for a number of interesting new interactions.

Table 1 compares input modalities for the six dimensions of position and rotation in space. A normal tangible on a tabletop needs be recognized by the surface, so it cannot move sideways outside that surface. When lifted off the screen, it cannot be tracked anymore, so the input along the z-axis is only a binary *On-Surface* or *Off-Surface.* For rotation, the tangible needs to support being flipped and still be tracked, e.g., by a different marker pattern on each side, if a designer wants multiple x- and y-rotations to be detected. Most tangible UIs do not support more than one rotation in roll and pitch.

	x	y	z	roll	pitch	yaw
On-Surface	screen height	screen hight	0/1	-	-	360°
Off-Surface	±∞	±∞	±∞	360°	360°	360°

Figure 1: Available input modalities when interacting with on-surface vs. off-surface tangibles. On-surface tangibles limit the user to manipulation on the display surface; therefore, roll and pitch are not available, and the z-axis is limited to a binary distinction between On-Surface and Off-Surface.

To express the new interactive potential of Off-Surface Tangibles, we extended Card et al.'s design space of input devices [1]. That seminal paper presents a notation to characterize the mechanical capabilities of input devices. It provides insights into how different input technologies are related, and suggests empty areas that could suggest new device classes [1]. We extend the original space to distinguish between on- and off-surface manipulation.

Figure 2 shows our design space. The bottom half contains tangible technologies that are used on, the top half those that are used above or next to the interactive surface. Aside from this addition, the design space follows Card's original notation: **P** rows contain technologies that detect the absolute position of the tangible, **dP** rows those that only detect changes relative to their last position (like the mouse). Each circle represents a linear *manipulation operator* in x, y or z (z pointing away from the user), or rotation around the respective axis (rx, ry, rz). Circles connected with dotted lines represent manipulation operators that are *collocated* in the same device, but can be manipulated individually. Circles connected with straight lines represent *merged* manipulation operators that are essentially impossible to manipulate independently, like x and y on a touchscreen. For tangibles, we adapted the

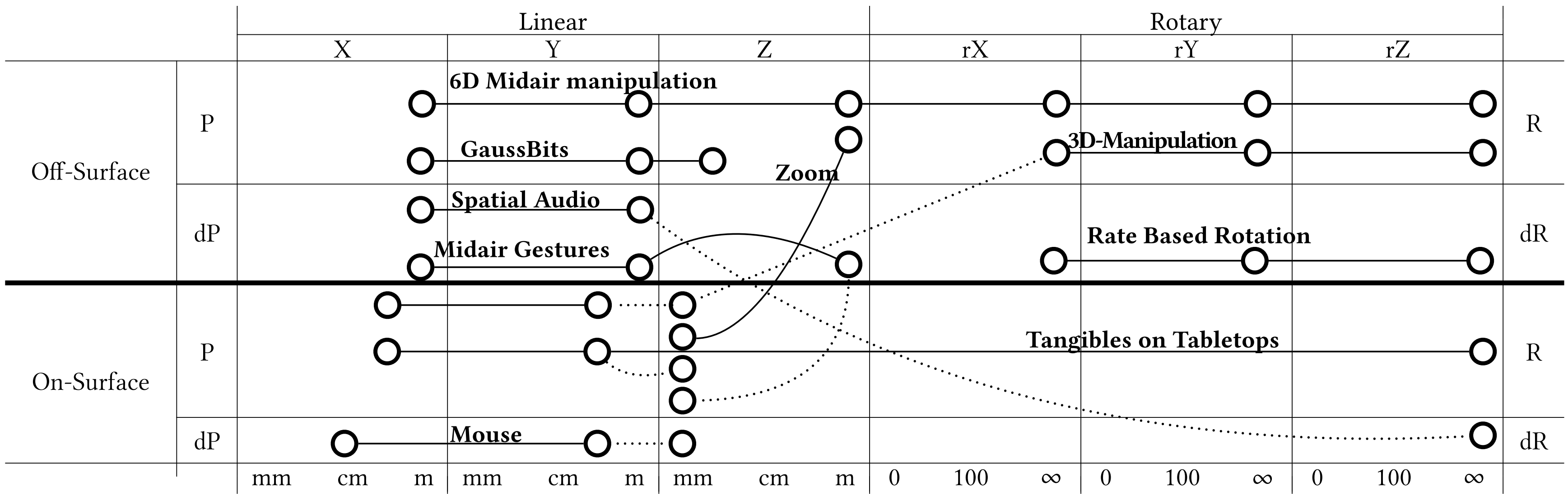

Figure 2: A design space of On- and Off-Surface Tangibles. The top half represents interactions with tangibles when they are lifted off the table.

original horizontal placement of a circle to the more informative physical *trackable range* of movement (a distance measurement) in the left columns that contain linear movement manipulation operators.

We populated the design space with related work in tangibles on tabletops and midair tangible interactions. The trackable range of tangibles on tabletops (Fig. 2) is limited to the size of the display in x and y, so those dots are placed more to the left in their cell. The trackable range of these tangibles in z is 0 m, since a lift-off can be detected, but any further movement away from the surface is not trackable. For rotation around the z-axis, input resolution is only limited by the tracking technology used, so the rz circle is placed towards the right of the cell.

If a tangible can track its position or rotation in midair, its manipulation operator is placed in the upper half of the design space (Off-Surface). A pure midair manipulation tool like an object tracked in position and rotation by a camera system would be described as a merged tool with infinite input resolution on all six axes (Fig. 2: 6D Midair manipulation)

New Interactions

This design space lets designers explore new combinations of manipulation operators to create novel device designs and interaction techniques. We consider device designs connecting the upper (Off-Surface) and lower (On-Surface) halves most interesting, because they represent solutions that can be used both on the tabletop and above it.

We employed this technique by looking at empty cells in the design space and identifying possible apps for *Off-Surface Tangibles* in those cells. Below, we present some of these applications that were inspired through the design space notation, and explain how they combine surface and midair input.

3D Manipulation: Even when interacting with virtual, displayed 3D objects, using tangibles as input “proxies” still has the potential to benefit these interactions. While the user cannot reach “into” the display to grab the virtual object, she can pick up a tangible as a proxy, initiating a direct mapping of her physical movements to the virtual object.

Spatial Input: With midair position and rotation tracking, a tangible camera or speaker token can be designed that changes the viewport or sound source on a 3D scene. This way, users can manipulate position, rotation, and the zoom level or volume freely, with live feedback. Off-Surface Tangible can also be designed to detect when they are shared between users. By tracking the position above the screen, designers can detect which person currently uses a tangible even if it is above the screen.

Midair Gestures: Off-Surface Tangibles open up new opportunities to augment interactive surfaces with additional midair gestures. For example, the “shake-to-undo” gesture on modern smartphones could be used with a midair tangible controller to undo manipulations of virtual objects. Another intriguing gesture to explore are quick moves in z-direction, e.g., to switch between different input modes. This way, midair gestures may also help alleviate some of the challenges that Off-Surface Tangibles present to users and application designers, discussed next.

Challenges

Adding midair input to tangible user interfaces also creates new challenges to designers. For example, it is not possible to fix a physical object in midair: if the user just lets go after interacting with it, it would simply drop to the floor. But even if she puts the object down safely, it is not immediately clear when she wanted the interaction to stop.

Another issue is resynchronization: If the user can suspend the mapping of their midair tangible input, the position and orientation of the tangible is now detached from the virtual object it was tied to before. When the user reenables this mapping later, how should the interaction continue?

CONCLUSION AND FUTURE WORK

In this paper, we introduced Off-Surface Tangibles and a design space of on- and off-surface tangible interaction. It provides a structured approach to classify different ways of combining midair input with classic tangible interaction on surfaces. We discussed sample designs that our design space inspires, and identified possible crunch points at the transition between midair and on-surface interaction.

The design space we presented suggests a wide array of potential interaction designs. We suggested several examples in section that are waiting to be implemented. We are particularly interested in learning more about the transition between on-surface and off-surface interaction, how user input can be saved across that boundary, and how such interactions may be made clear to the user. We hope that our design space encourages researchers to explore these issues in more depth, to find out how the challenges we mention affect users, and to find solutions to these issues and discover ideas for new interaction techniques.

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