Combining Tangible and Above the Surface Interaction

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Abstract: Interaction in the 3D volume above an interactive tabletop opens up new possibilities for enhancing and improving tangible user interfaces on the tabletop’s surface. We conceived and implemented a set of novel interaction techniques that rely on the combination of tangible user interfaces with a 3D volumetric user interface. We used a gaming scenario as a test bed, employing our tabletop setup enhanced with 3D tracking above the surface, and conducted a set of user tests. Based on these results, we discuss the benefit of putting tangible objects in an interactive 3D volume.

Keywords: Post-WIMP User Interfaces, Tangible User Interfaces, In-the-Air Interaction, Interactive Tabletop

1 Introduction

[UI99] introduced tangible interaction on tabletop surfaces in their system Urp. Such tangible user interfaces (TUIs) allow users to put real physical objects onto tabletop systems and interact with the table’s surface by moving and rotating the objects. Today, numerous tabletop systems allow input not only using tangible object interaction but also employing 2D multi-touch interaction on the same surface. However, commonly touch interaction and TUIs are limited to the two-dimensional surface of the particular system, disregarding the space around it.

3D cameras support interaction spaces by allowing for gestural interaction in a 3D volume. Researchers started considering 3D interaction in the space above a tabletop system, e.g. [HIW09]. Moreover, [MJGJ11] propose not to separate the interaction spaces above the surface and on the surface but rather consider them as one unified continuous interaction space with a seamless transition between gestures performed on, above and around the surface. Therefore, studies investigated how to combine touch and above the surface interaction. Although combining tangible objects on the surface with interaction above the surface has the potential to enlarge the interaction design space, only few efforts have been
spent into investigating such user interfaces.

In this paper, we contribute four techniques that employ combined tangible and above the surface interaction. We present and discuss the design and use of these techniques and give recommendations on how to implement them for future interactive systems. We evaluated our techniques in a user test. With the test results, we gain deeper insights about people’s use of such combined input possibilities.

This paper is organized as follows. In Section 2, we review related work with focus on continuous interaction. Section 3 explains our methodology, gives an overview of the setup and introduces the gaming scenario. We continue by illustrating the set of interaction techniques we conceived in Section 4. In Section 5, we present the evaluation and discuss its results in Section 6. Finally, Section 7 gives a conclusion.

2 Related Work

Several approaches use the space around the surface for interaction. Some of them use virtual layers above a digital surface like [EHK08], [MJGJ11] and [MS11]. [LAM07] propose using virtual layers through which the user’s hand moves. [EHK08] realize hover interaction techniques that substitute mouse pointing by tracking hand shadows. [HIW+09] introduce a pick up gesture that allows the manipulation of a virtual object in all six degrees of freedom. [WB10] present LightSpace, a smart room instrumented with projectors and depth cameras. This system allows various forms of interaction in a seamless interactive space, for instance transferring virtual objects from one interactive surface to another by touching first the source and afterwards the destination. [HLH+12] investigate the design space of combined multi-touch and in-the-air interaction. However, all those papers do not consider the integration of real physical objects with interactive surfaces.

[MJGJ11] propose to treat the space on and above the surface as a continuous interaction space, where users can interact by using touch, tangibles or hand gestures anywhere inside this space. They present and categorize various interaction techniques that leverage this interaction space. Although they propose the combination of tangible objects and continu-
vious interaction, they use an obtrusive 3D tracking system demanding users to wear gloves equipped with reflective markers. Tangible objects also need to be fitted with such markers. Furthermore, they do not evaluate their approach.

[BBR10] suggest using stackable objects on an interactive tabletop system in their work Lumino. They use tangibles filled with fiber glass. Their optical tracking system detects patterns of stacked tangibles. The choice of material limits the form and the possible height of stacked tangibles as the tracking software needs to see through the glass fibers in order to work correctly.

3 Methodology

Our methodology is firstly to provide a concrete setup that enables combined interaction. Secondly, we choose an application scenario providing a test bed. Thirdly, we identify interaction techniques and integrate those into our scenario supported by our setup.

Section 3.1 presents the hardware and tracking setup. Section 3.2 explains the application scenario into which we integrated our interaction techniques. The hardware setup in combination with the game allows us to implement our techniques introduced in Section 4 and to evaluate them in the user test presented in Section 5.

3.1 Setup

The hardware that we used in our gaming scenario is a custom built rear-projected tabletop system that employs DI (direct illumination) for detecting touches and fiducial markers on the table’s surface. The system comprises a 47 screen with a resolution of 1920 × 1080 pixels. A Microsoft Kinect\(^1\) installed above the tabletop faces the surface and allows identifying interaction above it. To detect the user input, our system uses two different software frameworks. First, we use Actracktive\(^2\) for the input detection of touches by fingertips as well as of tangible objects equipped with a fiducial marker of the reacTIVision framework [Kal09] on the bottom. Second, our above the surface tracking software SPIRITED (System for Presence and Interaction Recognition In Tabletop Environments using Depth) detects and tracks hands and tangibles employing the depth data retrieved from the Kinect [HSD+13]. We transfer detected arms and tangibles over the network to applications using the TUIO [Kal09] protocol.

3.2 Gaming Scenario

As a test bed, we implemented a game. We have chosen such a scenario, because it does not require special skills. Almost any user can play simple casual games and therefore test our game. Into the game, we integrated the four interaction techniques described in Section 4.

\(^1\)http://www.xbox.com/Kinect
\(^2\)https://code.google.com/p/actracktive/
We implemented a simplified Tower Defense game for our setup controllable via tangible, above the surface and touch interaction. The goal of the game is preventing opposing computer-controlled units from crossing the game field. For that purpose, the player strategically places towers on the play field that automatically fire at opposing units. Tower Defense is played round-wise. In each round, the enemy launches new units from its side of the play field. In our implementation, a round lasts 90 seconds after which the enemy sends new units. Before the first round, players have 60 seconds to build and place their towers. The aim is playing as long as possible in order to collect points and virtual money.

Tangible objects with a cylindrical shape represent the towers. The towers have to be placed on the surface (see Figure 1). Up to three of such objects can be stacked onto each other, leading to more powerful towers. The game distinguishes three types of towers with different strengths and weaknesses. We represent each type of tower with a differently colored circle at the tangible objects base. If they have collected a sufficient amount of virtual money, players can also build factories that earn more money. An initial amount of money is available for the player. Placing towers and buildings is restricted to certain areas on the play field. To test all interaction techniques illustrated in Section 4, participants accomplish several tasks that require performing the techniques. For instance, one task requires participants to build a tower that shoots at opposing units by placing a tangible on the surface and improve its range by placing other tangibles on top of it executing the technique explained in Section 4.4. The game displays the current task to participants in its status bar.

4 Interaction Techniques

In this section, we outline the combined above the surface and tangible interaction techniques that we realized employing the setup introduced in Section 3.1. A vignette illustrates each of the necessary steps to execute the techniques. We explain how we realized it and where we use it in our gaming scenario (see Section 3.2).

4.1 Second Hand as Tangible Mode Indicator

Employing this two-handed interaction metaphor, a user manipulates a tangible object on the surface with one hand and uses the second hand above the surface as a mode indicator to set the first tangible’s mode (see Figure 2). Similar to [SAL06], we separate the space above the table into three layers. Each layer represents a specific tangible mode.

We realized this interaction as follows: In the first step a user places a tangible object on the surface with the first hand. Actracktive detects the tangible’s fiducial marker and SPIRITED recognizes the hand touching that tangible. In the second step, SPIRITED searches for the closest other hand that is at least 20 cm away from the tangible which is then assumed to be the second hand. The user moves the second hand up and down and keeps it still for a certain amount of time (we have chosen a countdown of 1.5 s) in one of
Figure 2: Users employ their second hand to specify a mode. Moving the second hand through the layers changes the mode of the tangible (held by the first hand). The graphics next to the tangible on the surface visualize the mode.

the layers in order to actually select the intended type. A visual timer illustrates the ongoing countdown to the player.

4.2 Continuous Movement of Tangible Objects

Commonly, tabletop systems only recognize tangible objects directly on the surface. If a tangible is lifted off the surface, it will become inactive. To prevent this, we extend a tangible’s functionality to leverage the continuous interaction space above the surface (see Figure 3).

Figure 3: Continuous movement of a tangible object. A tangible can be moved naturally across obstacles (in this example over another user’s hand) without losing contact with the surface.

We realized this interaction as follows: In the first step, Actracktive recognizes the removal of a fiducial marker from the table. In the second step, SPIRITED determines the position of the hand performing the removal. Using this information, we pass over the handling from the tangible object to the interacting hand until the tangible’s fiducial marker is recognized again on the surface. A visual representation on the table follows underneath the hand in the air holding the tangible illustrating the current position of the tangible. This technique enables users moving tangible objects without losing the visual focus and to move around other physical obstacles like other hands or tangibles on the surface allowing for a more natural interaction.

We use this technique, for instance, to move and reposition tower segments in our scenario. Our playing field is subdivided into a grid consisting of cells. These cells have constraints. For instance, only black cells (see Figure 1) allow building towers. The playing
field provides a perceived affordance for this constraint by showing circles in cells underneath lifted tower tangibles only where the tower can be put. Therefore, this technique also visualizes constraints to the user.

4.3 Assigning a Mode to a Hand Using a Tangible

![Image](image1.png)

Figure 4: As soon as a user’s hand places a mode tangible on the surface, the system assigns an interaction mode to the hand.

Traditionally, each touch on the surface of a tabletop system is handled equally. We describe a method that assigns an action to the hand that placed the tangible on the surface, depending on the tangible’s type (see Figure 4).

We use this interaction technique to assign a mode for creating buildings to the hand that placed the build mode tangible on the surface. The realization of this technique is rather simple: After a tangible with a fiducial marker has been detected that assigns a build mode to a hand, SPIRITED looks for the closest hand in the vicinity of the tangible and assigns a build action to every touch performed with that hand. Removing the tangible cancels the build mode.

4.4 Stacking of Tangible Objects to Modify Behavior

Stackable tangibles allow modifying a tangible’s behavior by extending its height (Fig. 5).

![Image](image2.png)

Figure 5: Stacking one tangible object above another increases a tangible’s range.

In our scenario, we use the stacking metaphor to improve the strength of a tower, so every segment of the tower object represents an upgrade level. We realized this technique by continuously checking the height of tangible objects using SPIRITED. If a new tangible segment has been put on top of a tangible on the table, its behavior is adapted accordingly.
5 Evaluation

To evaluate our techniques, we performed a user test in which the participants played the game described in Section 3.2 on our setup presented in Section 3.1. The goal of the evaluation was to collect data about the user experience and the usability of the presented set of 3D interactions in the application scenario. Therefore, we paid special attention to issues and problems that had a negative impact on the evaluation result of a particular gesture.

We conducted the test as following. We recruited fourteen participants from the students of our faculty, twelve were male and two female. Their ages ranged from 20 to 30. In a five-minute introduction of a Tower Defense game’s basics, the experimenter gave a demonstration of the interface, the interaction possibilities and tasks that the participant needed to accomplish. When participants said that they understood all tasks and the usage of the different techniques, they completed a five-minute training trial on an empty game field. Subsequently, the actual user test started and users played the game for six rounds lasting eight minutes. Therefore, in addition the whole session lasted approximately 20 minutes for every participant.

During the test, we observed the participants’ behavior. After the test, the participants were asked to fill out a questionnaire. To be able to evaluate the user experience, the questionnaire comprised diverse statements regarding pragmatic and hedonic aspects. Participants could state their agreement on a 5-point Likert scale (1 = agree strongly, 5 = disagree strongly). We evaluated the statements using the robust non-parametric statistical method of Wilcoxon signed rank tests. We asked for the eight pragmatic and hedonic user experience properties shown in Table 1. Subsequently to this we collected feedback in interviews.

<table>
<thead>
<tr>
<th>UX Property</th>
<th>True (p value)</th>
<th>False (p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhausting</td>
<td>0.6047</td>
<td>0.9991</td>
</tr>
<tr>
<td>Enjoyable</td>
<td>0.9935</td>
<td>0.9991</td>
</tr>
<tr>
<td>Simple</td>
<td>0.9999</td>
<td>0.6047</td>
</tr>
<tr>
<td>Fast</td>
<td>0.9991</td>
<td>0.212</td>
</tr>
<tr>
<td>Precise</td>
<td>0.9999</td>
<td>0.00647*</td>
</tr>
<tr>
<td>Predictable</td>
<td>0.9935</td>
<td>0.212</td>
</tr>
<tr>
<td>Easy to learn</td>
<td>0.9713</td>
<td>0.9713</td>
</tr>
<tr>
<td>Easier with practice</td>
<td>0.00647*</td>
<td>0.9999</td>
</tr>
</tbody>
</table>

Table 1: Results of questionnaire items for different user experience properties. Statistically significant items (p <0.05) are marked with an asterisk.

Of the eight tested properties in the questionnaires, only two produced significant results (see Table 1). Participants found the interaction too imprecise but were of the opinion that they could execute the techniques better if they had more practice (p <0.01).

In the interviews, we asked participants about positive aspects that they remembered
about the experiment. Six participants pointed out that the stacking of tangible objects (see Section 4.4) was a very good metaphor for upgrading towers and a very natural interaction. Six participants criticized the build mode (see Section 4.3) because they often forgot to remove the tangible object from the surface in order to deactivate it.

The observed behavior while using above the surface interaction frequently correlated with the notes of the personal interview. Numerous participants recognized visual feedback relatively late, for instance, when a virtual object did not follow their hand holding the tangible anymore (using the technique presented in Section 4.2).

6 Discussion

From our observation and given the interviews, the stackable tower technique from Section 4.4 was the most popular technique amongst participants and did work well in the user tests. Thus, we can recommend using it without any limitations. Similar to this, we also recommend using the technique from Section 4.2 as participants could effortlessly move a lifted tangible over other tangibles on the surface. Our approach to visualize such constraints by showing the tangible’s position only on cells where a tower was allowed to built was misleading for the majority of the participants. Most participants thought that tracking shortcomings caused the visualization not to follow the lifted tangible. Therefore, a visualization consisting of two modes has the potential to improve the technique’s usability. In the first mode a semi transparent circle shows the current position directly underneath the user’s hand. If the hand hovers in the vicinity of a cell that allows placing the tangible, the second mode is started. In this mode, the circle is visually snapped to the cell in an animated fashion and made opaque. Moving the hand beyond the proximity of this cell causes the snapping to be released and to re-enter the first mode.

The interaction techniques from Section 4.1 and from Section 4.3 have shown numerous usability issues in the user tests. Users frequently tried using the same hand that put down the tangible to choose the mode in the volume above it. Furthermore, even if participants used the second hand as mode indicator, lifting and holding the arm still in the air for 1.5 s (the time that was needed to trigger a mode) was reported to be tedious for the muscles. As participants stated in the interviews, it was furthermore often unclear whether they finished the interaction or not. Interaction designers could improve these three issues (memorization of the mode changing arm, exhaustion of the muscles, clarifying the currently selected mode) by considering the following steps. The memorization problem of the mode changing arm could be improved by re-designing the technique to be a one-handed technique, i.e. the same hand putting down the tangible would be used as the mode indicator. Regarding the exhaustion of the muscles, a shorter timeout than 1.5 s could be chosen. However, by choosing a shorter timeout, the risk to select an incorrect mode rises [HLH+12]. Thus, different values should be evaluated in a user test in order to figure out the optimal timeout. To clarify the mode belonging to the layer in which a hand currently hovers, it is advisable to visualize the mode directly underneath the hand. This could be achieved, e.g., by showing
a circle containing a text with the currently selected mode and by giving a visual feedback as soon as the mode has been successfully selected in the air. Moreover, this interaction metaphor did not provide good results in the user test. Users frequently forgot removing the mode tangible from the surface leading to unexpected results. Hence, when reusing this technique, it is advisable to remind the user of the hand’s current mode by showing an appropriate visualization (e.g., a circle with the words “Build mode”) underneath the hovering hand.

7 Conclusion

The continuous interaction space presented in this paper enlarges the design dimensions for tangible user interfaces. It provides an additional interaction dimension that lies in the orthogonal axis to the surface. It offers knowledge about the position of a lifted tangible in relation to the surface. This information can be used to visualize perceived affordances like visual cues and constraints. It also allows moving a tangible from one point on the surface to another by lifting the tangible and putting it down on the target destination. Thus, obstacles on the surface like hands or tangibles can be avoided easily. The height of stackable tangibles provides an additional, natural design property of the tangible. In our scenario we used it, for instance, to change the range of a tower.

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References


