Tangible Tiles: Design and Evaluation of a Tangible User Interface in a Collaborative Tabletop Setup

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ABSTRACT

In this paper we describe a tangible user interface "Tangible Tiles", which uses optically tracked transparent plexiglass tiles for interaction and display of projected imagery on a table or whiteboard. We designed and implemented a number of interaction techniques based on two sets of different tiles, which either directly represent digital objects or function as tools for data manipulation. To discover the strengths and weaknesses of our current prototype, we conducted a user study that compared simple interaction with digital imagery in three conditions: 1) our Tangible Tiles system, 2) a commercial touch screen, and 3) a control condition using real paper prints. Although we discovered some conceptual problems, the results show potential benefits of Tangible Tiles for supporting collaboration and natural interaction.

Author Keywords

Tangible User Interface, Interaction Design, Human Computer Interaction, Collaboration

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces—input devices and strategies, interaction styles; H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces—collaborative computing, synchronous interaction;

INTRODUCTION

In recent years, several tabletop setups have been developed to improve face-to-face collaboration. While many projects deal with the problem of how to move data between private and public work spaces (Rekimoto et al., 1999, Haller et al., 2005) and how to design the collaborative spaces (e.g. the interactive table and/or digital whiteboards) (Dietz et al., 2001, Streitz et al., 1999, Johanson et al., 2002, Shen et al., 2002), we are mainly interested in the question of how to handle data on a digital table and how to transfer the data between several components in such a working environment.

Our approach of using physical objects (so called Tangible Tiles) as an alternative to standard input devices (mouse, keyboard, stylus, or touch screen) provides a new way of interacting with digital content. Our physical objects offer a strong affordance for direct manipulation and provide different (complex) interaction tools for manipulating the virtual data.

In this paper we first review related work in tabletop interaction followed by a description of our Tangible Tiles interface. We then present the results of a user study we conducted to investigate the ability of our Tangible Tiles interface to overcome some of the limitations of standard tabletop input devices and to test its general usability. Finally, we translate what we learned from the user study into design recommendations and improvements that we plan to realize in the future.

RELATED WORK

Our work draws on previous research in tabletop interfaces, collaborative environments, augmented reality (AR) interaction techniques, and tangible user interfaces (TUI). Although tabletop interfaces are becoming increasingly popular, it is still challenging to find suitable interaction techniques that do not inhibit people's interaction with shared objects during face-to-face collaboration. Different interaction mechanisms have been developed for tabletop systems in the past. Some research projects utilize a pen or stylus for each person to interact with digital data (Inkpen et al., 2001). Other projects provide a touch-sensitive surface for manipulation using fingers without any additional input device (Shen et al., 2002). Elaborate interaction metaphors based on gestures, sometimes in combination with speech commands, can help to invoke complex operations (Tse et al., 2006, Morris et al., 2006). There are also examples for multi-user mouse interaction on tabletop surfaces (Rekimoto et al., 1999, Haller et al. 2005). These projects use an extended mouse cursor of an attached computer to manipulate objects projected on a tabletop. However, all of these interaction metaphors do not have significant tangible user interface components.

Motivated by Scott et al.'s tabletop design guidelines (Scott et al., 2003), we wanted to develop a TUI for improving collaborative data manipulation. TUIs provide physical handles to represent and interact with digital data and therefore allow users to continue familiar collaborative work practices around real objects.

There are different approaches to the utilization of TUIs. On the one hand physical objects can represent or be bound to digital data and can thus be used to physically move digital data or to combine data fragments (Suzuki et al., 1995, Gorbet et al., 1998, Ullmer et al., 1998, Streitz et al., 1999). On the other hand physical objects can represent tools to manipulate digital data (Fitzmaurice et

al., 1995). Projects like the MetaDesk (Ullmer et al., 1997) try to combine these two approaches and use physical manipulators and data representations in the same application. Summarizing, our approach is influenced by the idea of DataTiles presented by Rekimoto et al. (2001). In their system, transparent tiles with attached RFID tags can be placed within a fixed 4x3 grid where they are recognized and their position is registered by an array of underlying RFID readers. Based on the identity and the position of every tile, associated digital content is displayed under the tile on a liquid crystal display that is mounted underneath. Also integrated into the system is an electromagnetic pen-tablet behind the display which also allows users to not only display but also to modify and create digital content for every individual tile themselves. In contrast, our plexiglass tiles are tracked by fiducial markers – thus, they can be arranged freely on the table's surface.

There have been few papers which present formal user studies comparing tangible interfaces to more traditional tabletop interfaces (Hornecker et al., 2006). Maher et al. investigated if TUIs have impact on spatial cognition in collaborative design (Maher et al., 2005). They discovered that designers in TUI sessions perform multiple cognitive actions in a shorter time than in conventional graphical user interface (GUI) sessions. Hence, TUIs showed the potential to support creative processes.
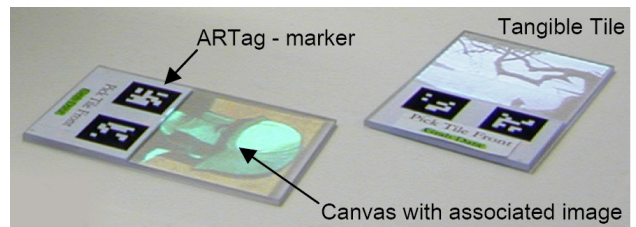
TANGIBLE TILES

In this section we describe the Tangible Tiles application. As mentioned before, we adopted the basic concept of DataTiles (Rekimoto et al., 2001) but significantly modified and extended the means of interacting with them. In contrast to the predefined fixed arrangement of the DataTiles setup, our Tangible Tiles can be moved and oriented freely on one or more given tabletop surfaces. This establishes new opportunities for data presentation, data manipulation, and collaborative activity.

Basic Principle

In the Tangible Tiles interface, digital imagery is projected onto a tabletop surface. By simply placing a transparent tile on top of these projections, the underlying image becomes associated with the tile. Moving, rotating, and flipping of a real tile is sensed by the system and directly invokes appropriate manipulations of the associated projected data. In that way, the illusion can be created that the projected data on the table becomes "graspable" through the tangible tile.

Our tiles consist of a acrylic transparent plate (10x15cm) with attached ARTag-based paper markers (Fiala, 2005) on the front and the back side. An overhead camera recognizes and tracks these markers, allowing the system to know which tiles are on the table with which side up, and where they are located. The transparent section is used as a canvas for displaying data (see Figure 1).


Figure 1. Tiles with associated data

In our interface, there are two types of tiles: *Container tiles*, that virtually "contain" digital data, and *function tiles*, that represent tools to manipulate non-tangible data. In the remainder of this section we describe these different types of tiles in more detail.
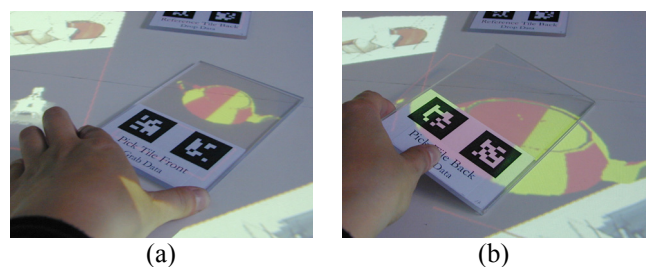
Container Tiles

We use certain tiles to pick up, transport, and drop digital data projected on the table. These are called *container tiles* since they can be used as if the picked up data is actually contained in the physical item.
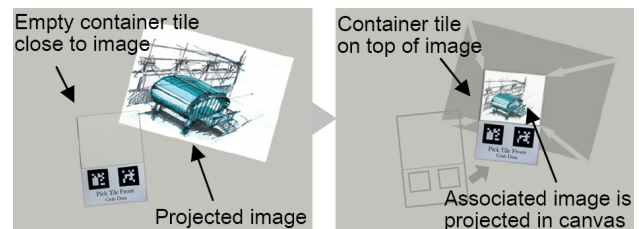
Figure 2. Container tile is associated with projected image by placing it in top of it

An image which is projected on the table can be associated with a container tile by placing the tile on top of the image (Figure 2). Once associated, the image shrinks in size and gets displayed in the canvas of the container tile. That way, a user can "grab" data by placing the tile on the projected data on the table (Figure 3a), can then move and rotate the data by moving the tile, and can finally release the data from the tile back on to the table by flipping the tile over (Figure 3b).

| (a) | (b) |

**Figure 3 A container tile is used (a) to grab a teapot and (b) to drop it back on to the table when it is flipped over.**

In our application we used three different categories of container tiles:

Pick tiles "pick" the data from the table. Pick tiles can be used to move digital data on the table, to exchange data between participants, and potentially to transport virtual data between several workstations.

Reference tiles create a new reference of associated data on the table and provide a view of the referenced data set in their canvases. That means that if the original data set is modified, the data in the tile changes as well. Reference tiles can, for example, be used to distribute a number of shared views of a sketch that is permanently updated through a collaborative session.
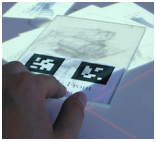
Copy tiles create a copy of associated data on the table and display the copied data set in their canvases. Similar to reference tiles, copy tiles can, for example, provide distributed views of a sketch. However, as the tile contains a new instance of the virtual data, changes of the original data set will not be shown in the tile.

Function Tiles

Function tiles are used exclusively to manipulate displayed data. They differ in their appearance, as the canvas shows an icon of the function they provide.
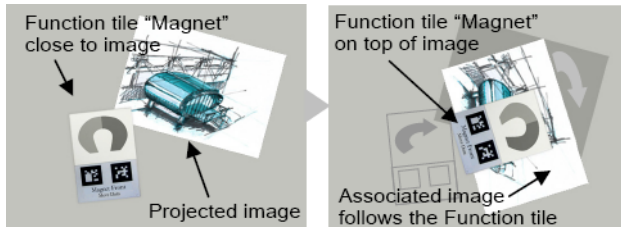

Figure 4. An image is associated and manipulated with the "magnet" function tile.

Like container tiles, function tiles can be associated with projected data sets by placing them on top of them. Once associated, the data set is modified depending on the individual function provided by the tile. In the example shown in Figure 4, the image "snaps" to the tile and can therefore be rotated and moved by rotating and moving the function tile. To release the data from the tile, the tile has to be flipped over.

We have implemented three different kinds of function tiles:
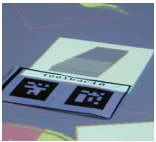
The *eraser* is used to delete data from the table. By placing the tile on the projected data, it is removed from the table.
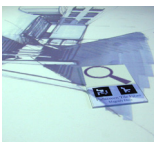
The *magnifier* tile displays an image in a big full-table view when placed on top of it. To rescale the image, the tile may be flipped.

The *magnet* connects to the projected data on the table and can move and rotate the projected image. This tool is different from a pick tile as it preserves the original size of the object whereas pick tiles scale the data to fit in the canvas.

IMPLEMENTATION DETAILS

Hardware Setup

Our hardware setup is based on an off-the-shelf PC with a projector on the ceiling mounted above the table (in a front projection setup). As projection area we use a flat, diffuse, white surface. A webcam (resolution 800x600 pixels) captures the table surface from above. In order to guarantee a good fit between the projected data and the physical tiles, we implemented a projective mapping approach to calibrate the camera with respect to its viewing angle. Figure 5 shows the hardware setup.
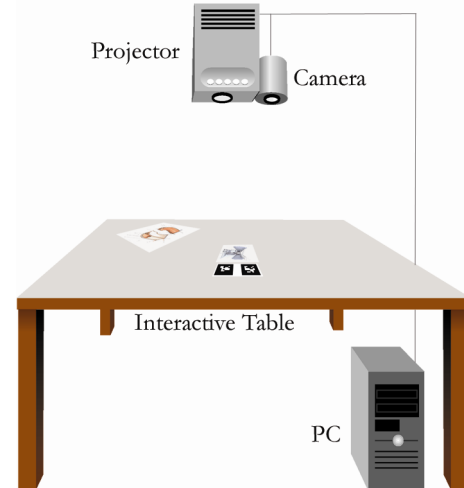

Figure 5. Hardware setup for Tangible Tiles.

Software Architecture

The Tangible Tiles solution is divided into three main elements: the lower level tracking applications, a tracking framework, and the high level Tangible Tiles application.

The framework is responsible for marker tracking and image frame-grabbing. It is implemented as a distributed, extensible application. The tracking of the tiles can either be accomplished on a local computer or remote, using a client-server-mode. The framework allows using different low level tracking technologies, although for the current version we use ARTag marker tracking (Fiala, 2005). Figure 6 shows the remote version of the framework. If used in the local setup, the tracking information for the application is retrieved directly by the LocalTileTracker.
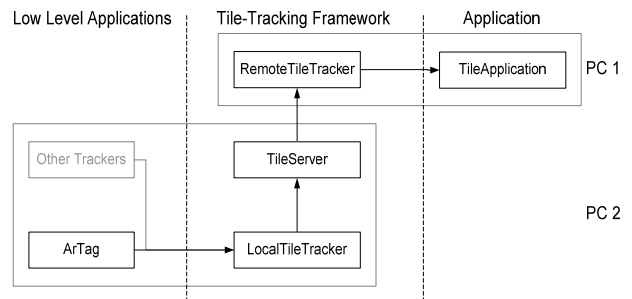

Figure 6. Software architecture

The high level Tangible Tiles application analyses the incoming tracking information from the framework, checks intersections between tiles and displayed data, and generates the resulting projector image. This application is only available on a local computer in the current

version. Thus, tiles can only be used at one location (e.g. an interactive table).

The whole solution is written in C++ using the freeware library JazzUp[1] for frame-grabbing based on DirectShow. For tracking the marker arrays we chose ARTag, while OpenGL is used for rendering the content.

The Tiles Environment
We envision the interaction techniques provided by our Tangible Tiles to be integrated in a future office environment (Haller et al., 2005), where users can move digital data from a private PC to a shared table or shared whiteboard using different interaction metaphors.

USER STUDY
We conducted a user study to explore how the approach we took with our Tangible Tiles would be received by first time users. By contrasting our tiles with a paper control condition as well as with an off-the-shelf touch screen, we hoped that potential benefits as well as potential problems of our current setup would emerge. The results of the user study will be able to guide us in the iterative improvement of our system in the future. Our experimental measures comprise subjective questionnaire ratings as well as notes made during observations and interviews. In the rest of this section we outline the details of the experiment design.

Participants
Twenty participants (6 females and 14 males), aged 21 to 38 years, were recruited from amongst mostly post-graduate students at a local University. In order to avoid mixed gender effects, we formed ten same sex groups consisting of two members who already knew each other before the study. Some of the participants had briefly seen the system before, but none of them had extensively worked with it. The first two groups were initial trial pilots and were not considered in the final results.

Task
We designed a collaborative task involving five images that needed to be rotated, translated, and exchanged extensively in order to reveal hidden objects that had to be found by the participants. For example, subjects were asked to find and write down all occurrences of animals they could spot hidden in the five images. To make the task challenging, non-trivial images were chosen. These images showed, for example, different animals depending on the orientation of the picture (see Figure 7).

Figure 7. Example picture: a frog and hidden horse.

The allowed time for the task was fixed at seven minutes in each condition. Participants were encouraged to make

the most of the time and also to show and discuss all individually found objects with the other team member.

Conditions
We used a within-subjects design. Each group of participants worked on a different set of images in each of three conditions:

(a) Touch Screen (b) Tangible Tiles

(c) Paper

Figure 8. The three experimental conditions.

Touch Screen
We created a touch sensitive surface by placing a Next Window touch frame[2] on the table and projecting image data inside it (Figure 8a).

The Inkscape[3] image editing program was used to allow people to view and manipulate the images. Participants could move the pictures by grabbing them using one finger, and rotating/scaling them using handles, which were placed at the corner of the pictures. The Next Window frame only recognizes a single touch at a time so two handed interaction was not supported and only one person could input data at a time.

Tangible Tiles
The Tangible Tiles hardware was set up as described in the section "Hardware Setup". For the given task, we provided four pick tiles and two function tiles (magnifier and magnet) that allowed the image data to be moved, rotated, and scaled (Figure 8b).

Paper
In the paper condition, paper prints of the images were evenly spread on a table. No further display or any digital representation of images was used (Figure 8c).

Procedure
Before the experiment started, subjects were introduced to the nature of the experiment task and were asked to fill out a questionnaire asking for demographic data. At the beginning of each of the three rounds, the condition was explained and, if necessary, demonstrated to the subjects, followed by a warm-up phase where the subjects could become familiar with the systems themselves. After each

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[1] http://sourceforge.net/projects/jazzup

[2] http://www.nextwindow.com/
[3] http://www.inkscape.org

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round, participants were asked to fill out a questionnaire with items assessing our dimensions of interest. Finally, after the last round, participants were asked to rank the three conditions and were informally interviewed about what they especially liked or disliked about our Tangible Tiles approach, and how they would improve the overall system. Each session lasted about 45 minutes.

Expected Results

We expected the paper-based condition to offer the most efficient, familiar, and preferred mode of interaction and collaboration. Tangible Tiles support many of the beneficial tangible affordances of paper that are not available in standard touch screen interfaces. Therefore, we generally expected the results in our dimensions of interest to be in the order: Paper > Tangible Tiles > Touch Screen.

RESULTS

Questionnaire results and data from observation and interviews of 16 participants were collected and analyzed.

Questionnaire Results

Main effects were first tested with a repeated measures analysis of variance (ANOVA). If a significant effect was found, post-hoc pair wise comparisons were calculated using the Bonferroni adjustment for multiple comparisons. A significance level of 0.05 was chosen for the entire analysis. The questionnaires were made up of 15 items (seven point Likert-scale), which were grouped into the categories learnability, interaction, collaboration, system, and tangibility.

Learnability measures

Three items of the questionnaire addressed learnability and the ease of use of the systems:

L1: It was immediately clear to me how to use the system.

L2: It was easy to learn how the system is used.

L3: I always knew how to perform a desired action.

	Paper (I)	Tiles (II)	Touch (III)	Main effect (df =2)	Post-hoc comparisons
L1	6.44 (0.27)	4.63 (0.44)	6.13 (0.18)	$p < 0.001$	III > II; I > II
L2	6.38 (0.29)	5.44 (0.37)	6.13 (0.22)	$p = 0.027$	I > II
L3	6.81 (0.14)	5.06 (0.36)	5.63 (0.30)	$p < 0.001$	I >III; I > II

Note: Average scores; Standard error in parentheses

Table 1. Results for learnability measures.

All three items showed significant main effects, mainly due to significant differences between the touch and tiles conditions to the paper condition (see Table 1). Subjects felt that it was not immediately clear how to use the tiles interface compared to both the touch and paper conditions. In general, the paper condition was rated highest in learnability and ease of use, followed by the touch condition which in turn received higher scores than the tiles condition.

Interaction measures

Four questions concerned the basic forms of interaction that were provided to grab, move, and rotate an image.

One further item investigated if people used both their hands for interaction.

I1: It was easy to select / grab a picture.

I2: It was easy to move a picture.

I3: It was easy to rotate a picture.

I4: While interacting with the pictures I always used both hands.

	Paper (I)	Tiles (II)	Touch (III)	Main effect (df =2)	Post-hoc comparisons
I1	7.0 (0.0)	5.56 (0.26)	5.56 (0.29)	$p < 0.001$	I >III; I >II
I2	6.81 (0.14)	5.50 (0.32)	5.44 (0.37)	$p = 0.006$	I >III; I > II
I3	6.94 (0.06)	5.25 (0.31)	2.88 (0.34)	$p < 0.001$	I >III; I > II; II >III
I4	2.94 (0.50)	2.38 (0.33)	1.25 (0.11)	$p = 0.005$	I > III; II > III

Note: Average scores; Standard error in parentheses

Table 2. Results for interaction measures.

Table 2 shows the results for the four items. All questions showed a clear main effect. Post-hoc comparisons showed significantly higher scores for the paper condition for all four items. In addition, two significant differences were found between the touch and tiles conditions in questions *I3* and *I4*. Subjects felt it was easier to rotate an image in the tiles condition than in the touch condition, and subjects used both their hands more often in the tiles condition than in the touch condition. However, in general the scores for question *I4* are low indicating subjects felt that they did not use both hands very much in any condition.

Collaboration measures

Two questions addressed aspects of collaboration:

C1: It was easy to hand over a picture to my partner.

C2: My partner and I worked with different pictures simultaneously.

	Paper (I)	Tiles (II)	Touch (III)	Main effect (df =2)	Post-hoc comparisons
C1	6.88 (0.13)	5.94 (0.27)	5.56 (0.34)	$p = 0.004$	I > II; I > III
C2	5.69 (0.36)	4.8 (0.49)	1.81 (0.33)	$p < 0.001$	I > III; II > III

Note: Average scores; Standard error in parentheses

Table 3. Results for collaboration measures.

Results for both items are shown in Table 3. Both questions showed a significant main effect. Subjects felt that it was easier to hand over the picture to their partner in the paper condition than the other two conditions, while there was no difference between the tiles and touch conditions. However, subjects did feel that they worked with different pictures simultaneously more often in the tiles condition than the touch condition.

System measures

Three questions were designed to investigate the perceived stability of the system and picture quality:

S1: The system was very robust.

S2: The system never distracted me from the task.

S3: I could always see the pictures clearly with sufficient level of detail.

	Paper (I)	Tiles (II)	Touch (III)	Main effect (df =2)	Post-hoc comparisons
S1	6.69 (0.20)	5.56 (0.29)	4.75 (0.36)	$p = 0.001$	I > II; I > III
S2	6.13 (0.43)	5.0 (0.48)	4.13 (0.39)	$p = 0.013$	I > III
S3	5.0 (0.49)	3.81 (0.43)	4.81 (0.45)	$p = 0.17$ *	

Note: Average scores; Standard error in parentheses;
Asterisk = no significant differences

Table 4. Results for system measures.

Table 4 shows the results. Significant main effects were found for questions S1 and S2, but there was no significant difference for question S3. Subjects felt that the paper condition was the most robust, and there was no difference between the tiles and touch conditions. The subjects felt that they could see the pictures equally clearly in all three conditions.

Tangibility measures
In this category, three items addressed the tangible and natural aspects of the interaction.

T1: I could handle the pictures like printed photographs.

T2: I was never aware that I was working with a computer program and digital data.

T3: Generally, I could work in a very natural way.

	Paper (I)	Tiles (II)	Touch (III)	Main effect (df =2)	Post-hoc comparisons
T1	6.75 (0.25)	3.94 (0.44)	3.38 (0.39)	$p < 0.001$	I > II; I > III
T2	6.69 (0.31)	3.19 (0.38)	2.75 (0.39)	$p < 0.001$	I > II; I > III
T3	6.81 (0.14)	5.13 (0.35)	4.69 (0.30)	$p < 0.001$	I > II; I > III

Note: Average scores; Standard error in parentheses;

Table 5. Results for tangibility measures.

Results are shown in Table 5. All three questions showed a significant main effect. Post-hoc comparisons confirmed the highest scores for the paper condition in all three questions. No significant differences were detected between the tiles and touch conditions. The tiles condition was on average rated higher than the touch condition but not significantly higher.

Preference and Enjoyment
After completing the three conditions, participants were asked to rank the systems in order twice according to (1) the system's ability to support the task solving process, and (2) the level of enjoyment they felt using the system. From their ranks, a normalized preference score was calculated from 0 to 1, where the rank 3 was normalized to score 0, and a ranking of 1, being the most preferred, is normalized to 1. Results of preference scores for task support and enjoyment are shown in Table 6.

Most of the participants rated the paper condition as the most efficient to solve the task, followed by the touch and then tiles conditions. The touch and tiles conditions were rated equally enjoyable and were rated as more enjoyable than the paper condition.

	Paper (I)	Tiles (II)	Touch (III)	Main effect (df =2)	Post-hoc comparisons
Task Support	0.75 (0.10)	0.28 (0.08)	0.47 (0.10)	$p = 0.023$	I > II
Enjoyment	0.19 (0.08)	0.66 (0.09)	0.66 (0.10)	$p = 0.006$	II > I; III > I

Note: Average scores; Standard error in parentheses;

Table 6. Preference scores task support and enjoyment.

User Comments and Observation
An experimenter wrote notes during the sessions, capturing observations of the subject behaviours. Although these observations lack empirical evidence, they are able to provide some insights to explain the reasons behind the questionnaire results.

Most groups used both magnet function tiles and pick tiles to move and rotate the images on the table. While applying the magnet tile, participants complained that the images that were moved with the magnet were not completely visible because of the occluding magnet-icon that was displayed in the magnet tile. We underestimated that problem and will have to fix it in future versions.

Two out of eight groups did not use any function tiles at all and accomplished the task using pick tiles only. Interestingly, these particular groups rated the system as being "easy" to use, whereas the other groups rated it as "a bit difficult".

Surprisingly, many groups looked at the same picture at all times and did not hand over pictures to their partner, which contradicts what we initially expected.

Almost half of the participants reported that it was confusing and cumbersome to use the different function tiles, especially as their form was indistinguishable from pick tiles. In order to find the correct tile, it was always necessary to read the labels of the individual function tiles. As an improvement, participants suggested to modify the shape of every individual function tile, so that the shape would suggest the function of the tile. Furthermore, they recommended marking the front and back side of all tiles more distinguishable as it is too difficult to read the current small labels quickly.

Tracking the positions of the tiles with optical markers proved to be reliable and allowed for a fluid interaction with the tiles. The marker tracking mechanism was explained to the users before the experiment. Therefore, they paid attention not to occlude the markers with their hands and could handle and correct eventual marker occlusions and resulting loss of displayed data easily.

Many groups remarked that using the touch screen was easier and more efficient simply because they were more familiar with these types of interfaces and thus knew better how to handle them.

One person admitted that he was "afraid" when he saw all the technical equipment for the Tangible Tiles setup and therefore felt uncomfortable using the system.

Some people mentioned that they did not really see the benefit of using tiles on a single table, but that they instead see a great potential for using tiles as a data exchange medium between several digital tables or other components.

DISCUSSION

The results of our experiment show that, as expected, paper is the best way to handle multiple images in a co-located collaborative task. In most cases the users felt that tiles and touch conditions were worse than the paper condition and not significantly different from each other. However, in some situations, Tangible Tiles come closer to the paper condition than a standard touch screen. This is especially true for basic manipulation such as rotating an image, for allowing two-handed manipulation, and the ability to support simultaneous work. In these cases Tangible Tiles showed some improvements over a standard single-touch surface.

All three items in the category "tangibility measures" were rated on average higher for our Tangible Tiles than for the touch screen. Although these differences did not reach a significant level, they might still indicate that our Tangible Tiles were perceived to offer a more natural and transparent interaction than the touch screen. We see this as a small confirmation of the value of tangible approaches for data manipulation that encourages us to pursue this direction further.

On the other hand, problems with the intuitiveness of our approach surfaced in the category "learnability measures", in which the touch screen was rated superior in every question. Although it can be acknowledged that this is a challenge for every novel interface when being compared to an existing standard interface that subjects are more familiar with, we can see some of the problems that were observed with regards to the use of the function tiles reflected in these results. This suggests that the interface needs to be redesigned to increase the ease of learning.

The user study also identified some of the hardware limitations of our setup. The overhead projector could have been brighter, especially for supporting interaction in a normally lighted room. The tracking camera could have had a higher resolution to improve the tracking and to provide a larger interaction area. With the use of an infrared camera the tracking could have been further improved. Generally, we discovered that a front projection setup has some disadvantages concerning occlusion of displayed images and tracking markers and visibility of technical equipment.

We acknowledge that the low preference score for task support mirrors these issues that we did not anticipate.

It appears that a tangible interface like ours could be intuitive and easy to understand, as long as the affordances of the physical handles for manipulation lead to consistent actions on the underlying digital data. While this was the case for pick tiles, it was not for the function tiles, where the design of the Tangible Tiles did not match the functionality of the tile. The function tiles and pick tiles were similar in shape and thus could be easily confused.

Design Recommendations

Based on these findings, we can suggest the following design recommendations for tabletop collaborative interfaces that use tangible elements:

1. The form of the tangible interface element should suggest how it should be used.

2. Tangible interface elements with different functions should look different to avoid confusion.

3. The interface should support parallel input, enabling users to work independently as well as collaboratively.

4. Tangible interfaces that represent digital imagery should aim at realizing affordances similar to those of paper to allow for natural basic interaction.

5. For manipulation of digital imagery that goes beyond the possibilities of paper, metaphorical physical handles are required that clearly communicate their tool character.

In the future we would like to realize the following improvements in our next system:

Use of a Rear Projection Table. The use of a rear projection setup would allow us to hide the technology that distracted some users from the task while at the same time further improving the robustness of the marker tracking and quality of the projected images.

Redesigning the Pick Tiles. Although generally well adopted, the pick tiles could still have been more usable. Some groups claimed that the pictures were scaled too small in the pick tiles. Therefore, we plan to provide different sizes of pick tiles in the future. In addition, we plan to use new tiles with a hollowed out container shape (see Figure 9) to emphasize the container metaphor, and at the same time to provide a haptic distinction for the front and back side.

Figure 9. Improvement of pick tiles: the shape of a container should help to distinguish front and back side.

Alternatively, we will also start to experiment with replacing the acrylic tiles with thin transparent plastic foil to stronger communicate paper-like affordances.

Redesigning the Function Tiles. Function tiles should not be "tiles" but should adopt the concept of phandles (Ullmer et al., 1997) and have a distinct shape to make their functionality clear on first sight. For example, our scaling tool could look like a magnifying glass, our magnet tool like a horseshoe, and so on. Furthermore, to avoid occlusion of imagery on the table, a new association mechanism should be provided, which "snaps" an image sideways to the magnet-phandle when the phandle and image are brought close.

CONCLUSIONS AND FUTURE WORK

In this paper we have presented a tangible user interface for tabletop interaction. Our work builds on previous research and also introduces several novel interaction techniques. In addition, unlike most other tabletop research papers, we conducted a user study that compares this new interface to an off-the-shelf touch screen as well as paper condition with printed images. The results showed that our interface assists with the basic interaction methods.

We also see a potential for this type of interface to support collaborative work in an office environment. Two-handed and simultaneous interaction is supported and thus makes it easier to solve several tasks together. However, we discovered some conceptual issues pointing to a limited learnability and intuitiveness of the current system. Therefore, in the future we will focus on the redesign of both container tiles as well as function tiles to create a better fit between the tangible affordances of the physical tile and the corresponding actions that can be performed with them.

In the future we will also evaluate improved versions of our interface in more rigorous user studies including video analysis, and a multi input touch screen.

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