Towards Multimodal 3D Tabletop Interaction Using Sensor Equipped Mobile Devices

Florian Klompmaker[1], Karsten Nebe[2], and Julien Eschenlohr[1]

[1] University of Paderborn, C-LAB,
Fürstenallee 11, 33647 Paderborn, Germany
florian.klompmaker@c-lab.de, eschenlohr@googlemail.com
[2] Rhine-Waal University of Applied Sciences,
Südstraße 8, 47475 Kamp-Lintfort, Germany
Karsten.Nebe@hochschule-rhein-waal.de

Abstract. Interactive tabletops have been proven to be very suitable setups for collaborative work especially in combination with mobile devices. Further on, many application scenarios require the visualization of 3D data. Therefore we present multimodal 3D interaction techniques for tabletops that allow simultaneous control of six degrees of freedom using sensor equipped mobile devices. In two early user studies we compared multitouch, tangible interaction and sensor equipped smartphones in order to start a User Centered Design process. We got important results regarding effectiveness, intuitiveness and user experience. Most notably we figured out that mobile devices equipped with acceleration sensors are very suitable for 3D rotation tasks.

Keywords: Tabletop, Multitouch, 3D User Interface, Mobile 3D Interaction, Smartphone, User Centered Design.

1 Introduction

Since the first Microsoft Surface appeared on the market in 2008, tabletop devices got quite famous and a lot of effort has been spent in technical improvements and the development of new interaction paradigms. It has been shown that these devices are suitable for special use cases like rapid prototyping [1], architecture and city / landscape planning [2,3], disaster management [4], collaborative document management [5] as well as training and learning [6,7]. In general terms it has been shown that tabletop devices in combination with Natural User Interfaces can dramatically enhance collaborative scenarios. One reason for this is the size of the display. It allows every participant in a collaborative setting to see WHO is currently doing WHAT. This so-called awareness of others [8,9] can't be found in classical Computer Supported Cooperative Work scenarios if multiple private devices are used instead of a large shared display. When developing collaborative applications for tabletop devices designers and programmers have to consider several aspects like the orientation of graphical objects [10], private and public spaces [11], security issues and group dynamics [12]. We have shown that User Centered Design (UCD) is a

D. Uhler, K. Mehta, and J.L. Wong (Eds.): MobiCase 2012, LNICST 110, pp. 100–114, 2013.

powerful tool to analyze requirements, workflows and needs of potential end users from the very beginning resulting in a high degree of usability and user satisfaction [4]. UCD experts already developed suitable methods like questionnaires, interviews and studies that are also suitable for the analysis of tabletop applications. Since technology already enables the tracking of multiple fingers as well as objects on a tabletop surface, various kind of interaction technologies have been developed. However, a single finger only allows the control of two degrees of freedom (DOF) of a graphical object on a flat surface (the x and y position) so that its interaction capabilities are limited. Multitouch gestures can help to overcome this limitation. However, using more than two fingers (controlling more than four degrees of freedom) results in lesser efficiency and a higher error rate [13]. Tangible objects equipped with optical markers that are lying on top of a tabletop device offer three degrees of freedom (x and y position as well as z-rotation). The drawback here is that objects have to be placed on the tabletop all the time for continuous tracking, resulting in a high degree of occlusion.

Our idea is to use sensor equipped mobile devices to control graphical objects on a tabletop device. Since such kind of active tangible object should be easily accessible by everyone we decided to use smartphones. Smartphones are wide spread personal devices and they consist of a variety of embedded sensors like gps, accelerometers, gyroscopes, proximity sensors and touchscreens. These sensors can easily be used for the analysis of different kind of 2D or 3D gestures. Further on, smartphones offer network access and therefore the possibility for data exchange with peripheral devices like other smartphones or tabletop computers. Another big advantage is that smartphones are personal storages and the display can perfectly be used as a personal area in collaborative scenarios, which also fulfills data security requirements. The goal of the ongoing research presented in this paper is therefore to create concepts for 3D interaction techniques with mobile devices within a collaborative tabletop scenario. We decided to perform an iterative UCD process using questionnaires, user performance tests and behavior observations.

The paper is structured as follows: First we present relevant related work in the area of 3D interactions and visualizations on tabletops as well as the combination of smartphones and tabletop devices. Next, we present our ideas of how to interact with 3D data on a tabletop using smartphones. In section four we compare these techniques with multitouch and tangible interaction techniques in two early user studies. Finally we sum up and describe ideas for future work.

2 Related Work

This section introduces relevant related work from the areas of 3D tabletop interaction and the combination of tabletops and mobile devices like smartphones.

2.1 3D Interaction and Visualization on Tabletops

Having a look at multitouch related literature the direct coupling is often mentioned as one of the biggest advantages. Using 2D graphical user interfaces, one or two fingers can be used to drag, rotate and scale a virtual object while every finger remains on the same position on it. However, using 3D user interfaces, a touchpoint may drift over the object due to the perspective projection and 2D input combined with 3D output [14]. Hancock et al. introduced Sticky Tools [15]. A 3D gesture set that allows the usage of one up to three fingers to control graphical 3D objects while the virtual objects do not drift but remain stuck on the user's fingers. The classical pinch and spread gestures are in this case used to perform depth translations. However, as already mentioned, two fingers are not sufficient to perform six DOF interactions for full 3D translation and rotation. Therefore three finger interactions have also been realized within Sticky Tools. However, these gestures are only suitable for large screens and hardly useable on smartphones.

Similar approaches have been developed by Martinet et al. [16], but here only translations are considered. Reisman et al. [17] present a solution where also three fingers are used to control six DOF. However, according to Han et al. [5] we already showed that it is often easier and more efficient to use widgets or buttons for 3D control [18] even though the naturalness and the direct coupling of touch are lost. Visualizing 3D data on multiple screens and windows allows multiple perspectives to be rendered. Martinet et al. showed that the sequent control of just a few DOF on multiple different viewing perspectives could result in a simple and direct control of six DOF [16,19]. For the visualization of depth transparency and shadows have been proven to be suitable solutions [20]. It has to be mentioned that without using stereoscopic display technology it is only possible to simulate objects that are inside of a tabletop device.

With tangible objects on interactive tabletops users can control three degrees of freedom at once (x, y position and z rotation, see figure 1 center and right). Hence, using two objects or a state switch, all six DOF are controllable. With *dSensingNI* we already presented an approach of tracking objects in 3D space above a tabletop device [21]. This approach has the advantage that arbitrary physical objects can be used. However, as already mentioned, in collaborative settings it is reasonable to offer private screens and storage to the user. Smartphones could be tracked using depth-sensing cameras and *dSensingNI* but due to body occlusions when interacting with the device near to the human body, integrated sensor technology is much more reliable and precise.

2.2 Smartphone Interactions with Tabletops

Until now smartphones in combination with tabletop computers have mainly been used to transmit data from the private storage to the public available tabletop interface. Cuypers et al. present an approach where the embedded camera of a smartphone that is placed on the tabletop surface is used to detect its position and therefore it can be used as a classical tangible object [22]. The UbiTable [11] introduced the combination of mobile devices and tabletops using public working areas on the table, private areas on the mobile device and private areas on the table likewise. This setting allows for multiple kinds of collaborative workflows while considering data security and multiuser interaction conflicts.

The Bluetable [23] can establish a Bluetooth connection between a smartphone and a tabletop. Therefore the table detects the shape of the phone via computer vision algorithms before user authentication takes place. The authors further on present a simple photo-sharing application that makes use of this technology.

A similar scenario was realized in the PhoneTouch project [24]. Here trigger gestures are realized. If a user places a corner of the smartphone on the tabletop surface this is recognized via touchpoint detection and also by the phone itself by analyzing the accelerometer data. Therefore detection and identification can be performed automatically.

2.3 Summary

Until now much effort has been spend in developing interaction technologies for tabletop devices that allow the control of six DOF in order to interact in 3D space. Multitouch as well as tangible interaction using arbitrary physical objects have been studied. Smartphones have been used to create private workspaces, to transmit private data to a collaborative setting and to identify devices and users. However, to the knowledge of the authors there is no project existing that uses smartphones as private storage, private workspace and interaction device in combination with 3D user interfaces on a tabletop. We think that there is a huge potential for such scenarios. Therefore we developed multimodal interaction techniques that are introduced in the next section and performed two early user studies to evaluate our ideas within an architecture use case scenario.

3 Multimodal and Mobile 3D Tabletop Interaction

As already stated, there are important use cases that require a visualization of 3D content within a collaborative tabletop scenario. Yu et al. report the high degree of immersion and the possibility to use natural skills for interaction [14]. In order to find the best possibilities to control 3D data and to support group dynamic and workflows we created three different kinds of interaction techniques. We first developed techniques for multitouch as well as for tangible objects that are placed on the tabletop (this technique is called *tangible interaction* in the following sections) in order to control 3D objects. After that we built a prototype that uses smartphones. Since a smartphone additionally offers a private screen to its user, we think that this type of interaction has a very huge potential. However, it has to be investigated whether the control of six DOF is realizable with a smartphone device and if interaction metaphors can be found that are intuitively useable.

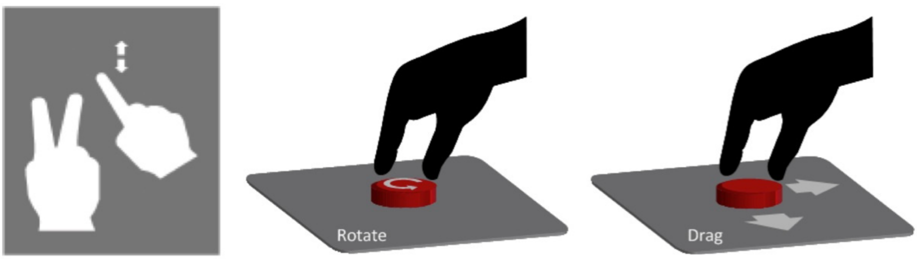

Fig. 1. Multitouch and Tangible Interaction Controlling Multiple Degrees of Freedom

3.1 Multitouch and Tangible Interaction

Our 3D multitouch concept is based on the Opposable Thumb approach presented by Hancock et al. [15]. Using one single finger a user can translate an object in the x/y plane[1]. Since we plan to implement scaling possibilities of 3D objects in the future we decided not to use the two-finger spread and pinch gestures for z-translation. Instead we implemented a three-finger approach. While the user touches a virtual object on the tabletop screen with two fingers she can move a third finger up and down for z-translation (see figure 1, left). This only works if the third finger is not touching the object. Using three fingers ON the object causes 3D rotations as described in the Opposable Thumb approach [15]. Z-rotation is performed using two fingers as known from many 2D multitouch applications. Hence, this approach allows the control of six DOF using one up to three fingers.

Our tangible interaction concept uses two physical objects to control a virtual 3D object. The physical objects are black cylinders with a height of 2 cm and a radius of 3.5 cm. Each cylinder is able to control three DOF: Two via x/y translation (drag) and one via z rotation (see figure 1, center and right). We decided to use one cylinder for translation and one for rotation only. The translation object controls the x/y position of the virtual 3D object via dragging and the z-position via rotation. The second cylinder controls the pitch angle via horizontal dragging, the roll angle via vertical dragging and the yaw angle via rotation.

Since tangible interaction results in a high degree of occlusion of the display we decoupled the virtual and real objects. Therefore a cylinder can be placed at an arbitrary position on the tabletop surface. Hence, every cylinder is bound to a specific virtual 3D object and to a specific functionality (either translation or rotation).

For the tracking of fingers and objects we use FTIR and DI infrared illumination on our tabletop device *useTable*[2]. The image analysis is done by reacTIVision[3] and CCV[4].

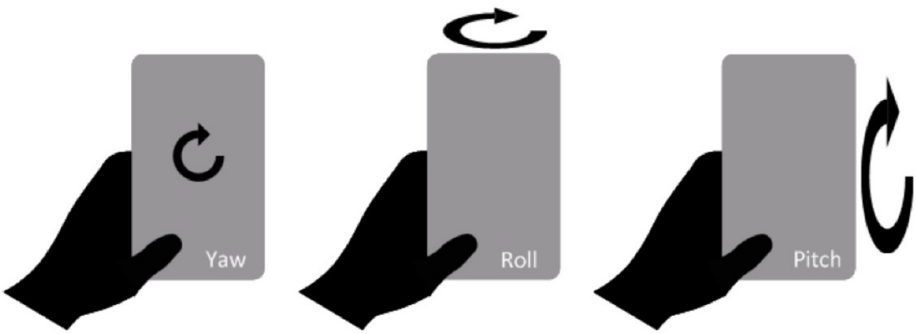

Fig. 2. 3D Orientation Angles of the Smartphone Measured by Accelerometers

[1] In the context of this paper the x/y plane is defined by the tabletop surface while the z-axis extends into the table.

[2] `http://www.usetable.de`

[3] `http://reactivision.sourceforge.net/`

[4] `http://ccv.nuigroup.com/`

3.2 Using Smartphones as 3D Input Devices

The embedded sensors of a smartphone offer different possibilities to control the six DOF of a virtual 3D object. Within the ongoing research project presented in this paper we plan to evaluate different approaches within a UCD process. Our initial idea is to mainly use accelerometers that offer three values for 3D orientation (see figure 2). Since the touchscreen of the smartphone is going to be used as personal display it is obvious that is can also be used for data input. For example a button could be realized that switches between translation and rotation control. Hence, the three accelerometers and the button could be used for six DOF control. The applied interaction concept will be explained in the upcoming evaluation section.

For the prototype realization we used Windows Phone smartphones[5] and created an extendable software framework that handles the communication between the mobile device and the tabletop. It is called SmartPhoneControl-Framework. For the transmission of sensor data that is used to control 3D objects we used the TUIO [25] protocol. We created a new profile /tuio/STobj that offers data fields for acceleration as well as 3D rotation using quaternions. Further on predefined states and gestures that are interpreted on the device side can be transmitted using two newly created fields.

In order to enable a bidirectional communication of rich data we also implemented the XMPP protocol. It may be used to send feedback to the mobile device, personal documents or 3D objects to the table. Figure 3 shows a scheme of the frameworks hard- and software components.

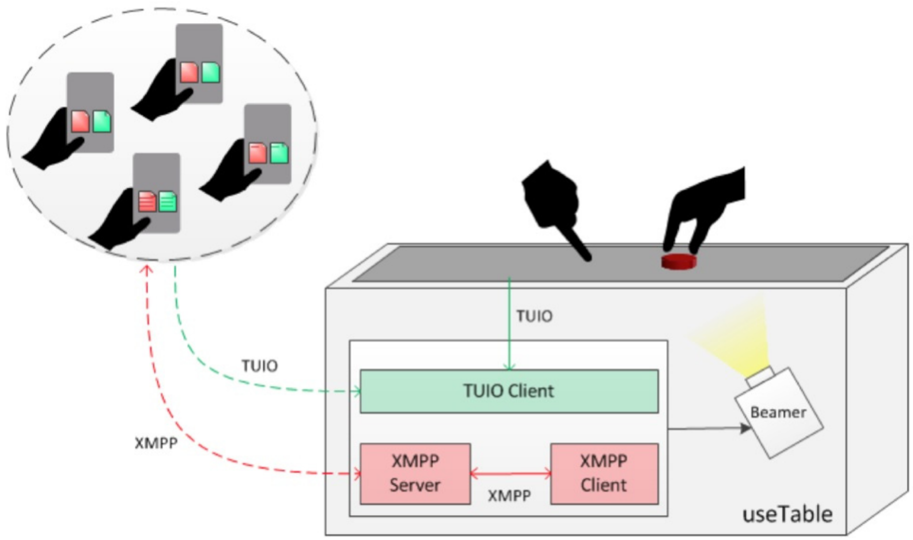

Fig. 3. SmartPhoneControl Framework

[5] We use a Samsung Omnia 7, a LG Optimus 7 and a HTC Mozart.

4 Evaluation

In this section we present two early user studies we held in our laboratory in order to compare the previously described interaction techniques and to evaluate the group work. Even though the number of participants is low the results show interesting trends and we gathered important think-alouds from the users.

4.1 Single User Study

The goal of the first user study was to analyze the effort and precision of the interaction techniques as well as the user experience. Therefore we asked five colleagues from our laboratory to perform a docking test and answer an INTUI [26] questionnaire. This questionnaire allows an evaluation of the intuitiveness of different interaction techniques. All questions have to be answered on a scale from 1 (very low) to 7 (very high).

Fig. 4. Docking Task in the Single user Study

In the docking test the users had to dock a virtual armchair onto another one (see figure 4). The test consisted of six tasks. It began very simple but got more complicated after successfully completing a task. In Task 1 (T1) users only had to translate the object along the x axis (1 DOF), in T2 users had to translate the object along the x and the y axis (2 DOF), in T3 users had to move the object along the z axis (1 DOF), in T4 users had to rotate the object around the z axis (1 DOF), in T5 users had to rotate around all three axes (3 DOF) and finally in T6 users had to control all six DOF. Every participant had to use all three interaction techniques but in an alternating order. The smartphone device offered the possibility to translate and rotate the object via the accelerometer sensor values and a switch button (translation/rotation) on the touchscreen. All task completion times can be found in tables 1 to 3. Some users had not been able to complete a task. This is indicated with a ”-” in the tables.

It can be seen that for the simple tasks (T1, T3) multitouch and tangible interaction are very fast. This might be caused by the fact that the smartphone interaction requires learning while the other tasks are more or less known from state of the art approaches. In T2 it took the users very long to complete the z-translation using multitouch. This can also be interpreted as a learning artifact because we invented a new three-finger technique as described previously. In the rotation tasks (T4, T5) the smartphone interaction was fastest. This shows that using accelerometer sensor data is very effective for rotation tasks. In the combined task T6 multitouch and tangible interaction are again faster, mainly caused by the very good translation performance. However the standard deviation values of T6 show that completion times vary strongly. Analyzing the INTUI questionnaire answers (tables 4 to 6) it can be seen that users rated the learning effort of the multitouch interaction highest (4.0, tangible interaction: 2.0, smartphone: 2.2). We think that this is mainly caused by the complicated three finger interaction techniques. Users further on rated the precision of the smartphone highest (4.8, multitouch: 2.6, tangible interaction: 4.6). Also the fun factor (enjoyment) was rated best with the smartphone approach (5.6, multitouch: 5.0, tangible interaction: 5.4). The INTUI results (visualized in figure 6) have large deviation values therefore this results can only be seen as first trends but further studies including a larger number of participants have to be performed. However, these early results helped us designing a multiuser application for the collaborative design of an office lobby. Here our hypothesis was that smartphones are very suitable due the embedded storage and the private display. The interaction techniques for the smartphones have been slightly adapted according to the results of the single user study. The application as well as the results of a multiuser study are presented in the next section.

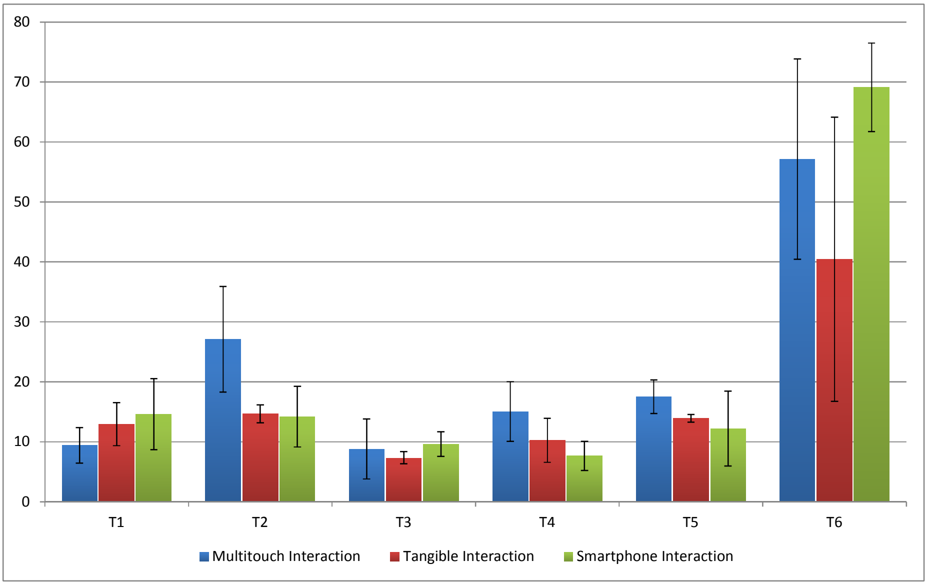

Fig. 5. Average Task Completion Times and Standard Deviations

Table 1. Task Completion Times for Multitouch Interaction (Values in Seconds)

Participant	T1	T2	T3	T4	T5	T6
1	6.9	17	17.3	13.7	17.9	80
2	5.9	37.6	5.4	14.6	14.9	-
3	11.5	20.3	8.8	-	-	44.9
4	12.8	34.2	7.7	21.9	21.3	44.5
5	9.9	26.4	4.9	10	15.9	59.2
Avg. Time	9.40	27.09	8.80	15.04	17.51	57.15
Std. Deviation	2.95	8.80	5.00	4.99	2.81	16.70

Table 2. Task Completion Times for Tangible Interaction (Values in Seconds)

Participant	T1	T2	T3	T4	T5	T6
1	9.7	13.4	6.9	13.7	14.4	32.0
2	8.9	16.5	6.6	14.2	-	-
3	13.9	16.0	7.5	8.8	13.2	75.3
4	14.6	13.3	6.6	5.6	14.1	32.3
5	17.5	14.0	9.0	8.9	-	22.2
Avg. Time	12.92	14.64	7.31	10.23	13.90	40.45
Std. Deviation	3.58	1.50	1.02	3.66	0.62	23.70

Table 3. Task Completion Times for Smartphone Interaction (Values in Seconds)

Participant	T1	T2	T3	T4	T5	T6
1	9.1	7.9	11.0	7.0	15.2	-
2	13.1	13.6	12.1	11.6	17.9	73.6
3	23.0	20.9	7.9	6.2	12.2	60.0
4	13.1	17.2	9.9	8.0	-	76.4
5	-	11.3	7.2	5.4	3.5	66.5
Avg. Time	14.58	14.17	9.62	7.64	12.20	69.13
Std. Deviation	5.92	5.06	2.05	2.41	6.25	7.37

Table 4. Questionnaire Results for Multitouch Interaction

Participant	Motion Effort	Learn Effort	Precision	Enjoyment
1	2	4	1	4
2	5	2	3	5
3	6	6	2	3
4	5	6	2	7
5	2	2	5	6
Avg.	4.0	4.0	2.6	5.0
Std. Deviation	1.87	2.00	1.52	1.58

Table 5. Questionnaire Results for Tangible Interaction

Participant	Motion Effort	Learn Effort	Precision	Enjoyment
1	2	1	7	6
2	4	3	3	5
3	2	2	6	5
4	2	2	1	5
5	3	2	6	6
Avg.	2.6	2.0	4.6	5.4
Std. Deviation	0.89	0.71	2.51	0.55

Table 6. Questionnaire Results for Smartphone Interaction

Participant	Motion Effort	Learn Effort	Precision	Enjoyment
1	2	2	4	6
2	2	2	3	3
3	1	1	6	6
4	6	4	5	6
5	1	2	6	7
Avg.	2.4	2.2	4.8	5.6
Std. Deviation	2.07	1.10	1.30	1.52

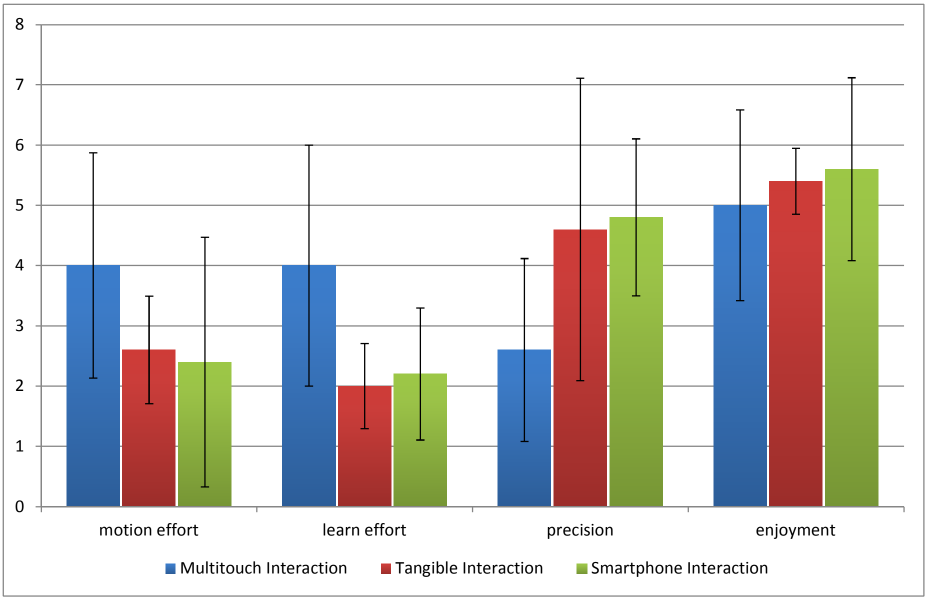

Fig. 6. Results of the INTUI Questionnaire

4.2 Multiuser Study

After getting first insights about the quality of the developed interaction techniques we applied some improvements based on the measurements, questionnaires and recorded think-alouds. For example we realized the possibility to change the camera perspective of the 3D scene. This enables a translation with one finger and rotation with two fingers to control all six DOF since the affected axes can be switched. So no three-finger techniques are required anymore (even though still working). Further on the smartphone interface now enables the rotation around a single axis by disabling the other two. The task in the second study was to collaboratively design a lounge for an office. 15 people participated in this study divided into five groups, three participants each. All users got a short training of all three interaction techniques and five minutes time to get familiar with them. Then the design task was assigned to the participants and we asked them again to think-aloud. We used video and audio recording for later analysis and after completing the task every user had again to fill out an INTUI questionnaire. The participants got a smartphone as personal display and personal interaction device. Via the smartphone and our framework the users were able to add new pieces of furniture to the scene and to remove them. Figure 7 shows the 3D scene and figure 8 three users with their smartphones designing a lounge. Figure 9 shows the personal display of the smartphone (left: select the kind of interaction performed through the accelerometers, center: furniture menu, right: different perspectives of a selected armchair).

The most interesting result of the multiuser study is that nearly all users mainly decided to use the smartphone for 3D interaction. We believe that this is caused by two facts: First, the users had to use the smartphone to chose a furniture they like to add to the scene via the smartphone display, therefore it is obvious to seamlessly continue the use of the device for object manipulation. Second, the user experience with this kind of interaction is really good, proven by the fact that after the experiencing phase the users rated the smartphone interaction as the easiest one.

Fig. 7. Virtual 3D Scene of an Office Lounge

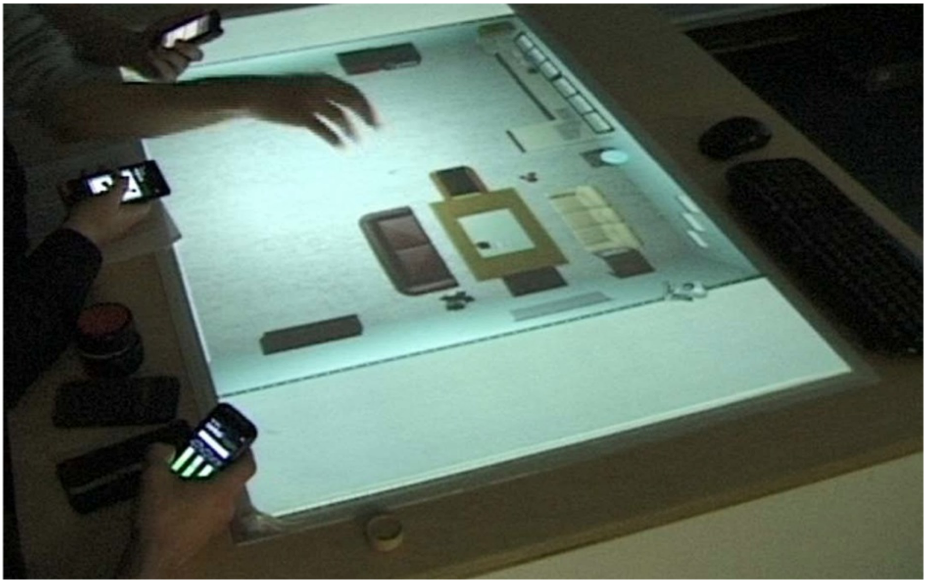

Fig. 8. Collaborative Design on the useTable using Smartphones, Multitouch and Tangible Interaction

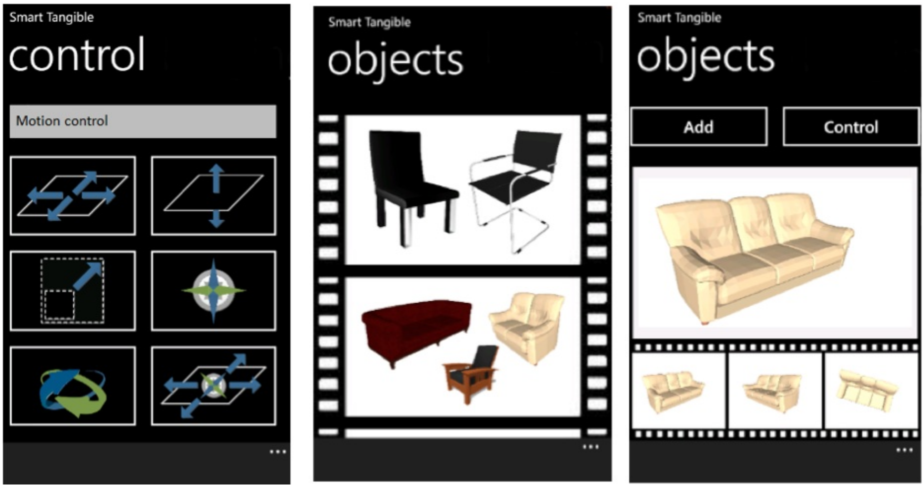

Fig. 9. Private Display of the Smartphone

We observed that there was much discussion going on during the design task. Often users discussed general ideas before they split the virtual room into three regions. After that they proceeded individually and each user designed one region on her own. This single user process was often shortly interrupted by group discussions about the general ideas including critical comments about already completed things. Another interesting aspect is that even though it was introduced at the beginning only one group decided to make use of the possibility to switch camera perspectives. We observed that many users tried to change their position on the table to get a different perspective but then recognized that this had no effect on the 3D perception.

All users who tried the manipulation with tangible objects switched back to smartphone interaction after a short while. They all moaned about the occlusion caused by the objects. In their think-alouds the participants presented good ideas for future improvements. E.g. one user asked for a reset button after his piece of furniture got lost in space. Another user recommended the use of a physic engine for collision detection to make the 3D interaction easier and more natural. A third user asked for the possibility to rotate in steps of 90 degrees since this is hard to do precisely with the implemented techniques. Further on he criticized that it is not possible to have more than one instance of a piece of furniture in the 3D scene.

The result of the INTUI questionnaire showed an overall intuitiveness value of 5.27. The fun factor of the application was rated with an average value of 5.8. This shows that with our smartphone approach we are on the right track to intuitive 3D interaction on tabletop devices that shows high usability.

5 Conclusion

In this paper we presented an ongoing research on 3D interaction techniques for tabletop devices. In two early user studies we evaluated multitouch, tangible interaction and especially sensor-equipped smartphones as external devices. The results show that multitouch 3D interaction requires a huge cognitive effort while tangible objects cause too much occlusion. Therefore we think that smartphones are very suitable and our study results show that they allow for easy, fast and intuitive usage, especially in rotation tasks. Even though virtual and real objects are no longer coupled in this approach, most participants rated the user experience of this indirect interaction as a very intuitive one. Further on the fun factor seems to be high.

Nevertheless, we got important insights for improvements. To support group work we also have to study the implications on the group awareness and dynamics our techniques cause. Therefore, after redesigning the interaction techniques and the overall workflows further studies and observations are needed in order to best fulfill all requirements for collaborative 3D tabletop scenarios. We also plan to integrate additional sensors of mobile devices like a digital compass.

References

1. Akaoka, E., Ginn, T., Vertegaal, R.: DisplayObjects: prototyping functional physical interfaces on 3d styrofoam, paper or cardboard models. In: Fourth International Conference on Tangible, Embedded, and Embodied Interaction (TEI), pp. 49–56. ACM Press, New York (2010)
2. Ishii, H., Ratti, C., Piper, B., Wang, Y., Biderman, A., Ben-Joseph, E.: Bringing Clay and Sand into Digital Design - Continuous Tangible user Interfaces. BT Technology Journal 22, 287–299 (2004)

3. Piper, B., Ratti, C., Ishii, H.: Illuminating clay: Illuminating Clay: A 3-D Tangible Interface for Landscape Analysis. In: SIGCHI Conference on Human Factors in Computing Systems, pp. 355–362. ACM Press, New York (2002)
4. Nebe, K., Klompmaker, F., Jung, H., Fischer, H.: Exploiting New Interaction Techniques for Disaster Control Management Using Multitouch-, Tangible- and Pen-Based-Interaction. In: Jacko, J.A. (ed.) Human-Computer Interaction, Part II, HCII 2011. LNCS, vol. 6762, pp. 100–109. Springer, Heidelberg (2011)
5. Nebe, K., Müller, T., Klompmaker, F.: An Investigation on Requirements for Co-located Group-Work Using Multitouch-, Pen-Based- and Tangible-Interaction. In: Jacko, J.A. (ed.) Human-Computer Interaction, Part II, HCII 2011. LNCS, vol. 6762, pp. 90–99. Springer, Heidelberg (2011)
6. Kaschny, M., Buron, S., von Zadow, U., Sostmann, K.: Medical education on an interactive surface. In: ACM International Conference on Interactive Tabletops and Surfaces (IST), pp. 267–268. ACM Press, New York (2010)
7. Conradi, B., Hommer, M., Kowalski, R.: From digital to physical: learning physical computing on interactive surfaces. In: ACM International Conference on Interactive Tabletops and Surfaces (IST), pp. 249–250. ACM Press, New York (2010)
8. McCrindle, C., Hornecker, E., Lingnau, A., Rick, J.: The design of t-vote: a tangible tabletop application supporting children's decision making. In: 10th International Conference on Interaction Design and Children, pp. 181–184. ACM Press, New York (2011)
9. Hornecker, E.: Tangible User Interfaces als kooperationsunterstützendes Medium, Doctoral Thesis, Elektronische Bibliothek, Staats und UniversitŁtsbibliothek Bremen (2004)
10. Shen, C., Ryall, K., Forlines, C., Esenther, A., Vernier, F.D., Everitt, K., Wu, M., Wigdor, D., Morris, M.R., Hancock, M., Tse, E.: Informing the Design of Direct-Touch Tabletops. IEEE Comput. Graph. Appl. 26, 36–46 (2006)
11. Shen, C., Everitt, K., Ryall, K.: UbiTable: Impromptu Face-to-Face Collaboration on Horizontal Interactive Surfaces. In: Dey, A.K., Schmidt, A., McCarthy, J.F. (eds.) UbiComp 2003. LNCS, vol. 2864, pp. 281–288. Springer, Heidelberg (2003)
12. Morris, M.R., Cassanego, A., Paepcke, A., Winograd, T., Piper, A.M., Huang, A.: Mediating Group Dynamics through Tabletop Interface Design. IEEE Comput. Graph. Appl. 26(5), 65–73 (2006)
13. Kin, K., Agrawala, M., DeRose, T.: Determining the benefits of direct-touch, bimanual, and multifinger input on a multitouch workstation. In: Graphics Interface, pp. 119–124. Canadian Information Processing Society (2009)
14. Yu, L., Svetachov, P., Isenberg, P., Everts, M.H., Isenberg, T.: FI3D: direct-touch interaction for the exploration of 3D scientific visualization spaces. IEEE Trans. Vis. Comput. Graph. 16(6), 1613–1622 (2010)
15. Hancock, M., ten Cate, T., Carpendale, S.: Sticky tools: full 6DOF force-based interaction for multi-touch tables. In: ACM International Conference on Interactive Tabletops and Surfaces (IST), pp. 133–140. ACM Press, New York (2009)
16. Martinet, A., Casiez, G., Grisoni, L.: The design and evaluation of 3D positioning techniques for multi-touch displays. In: IEEE Symposium on 3D User Interfaces, pp. 115–118. IEEE Press, New York (2010)
17. Reisman, J.L., Davidson, P.L., Han, J.Y.: A screen-space formulation for 2D and 3D direct manipulation. In: 22nd Annual ACM Symposium on User Interface Software and Technology (UIST), pp. 69–78. ACM Press, New York (2009)

18. Klompmaker, F., Nebe, K.: Towards 3D Multitouch Interaction & Widgets. In: Workshop on Interaction Techniques in Real and Simulated Assistive Smart Environment, Workshop at the First International Joint Conference on Ambient Intelligence, AmI (2009)
19. Martinet, A., Casiez, G., Grisoni, L.: 3D positioning techniques for multi-touch displays. In: 16th ACM Symposium on Virtual Reality Software and Technology (VRST), pp. 227–228. ACM Press, New York (2009)
20. Hilliges, O., Izadi, S., Wilson, A., Hodges, S., Garcia-Mendoza, A., Butz, A.: Interactions in the air: adding further depth to interactive tabletops. In: 22nd Annual ACM Symposium on User interface Software and Technology (UIST), pp. 139–148. ACM Press, New York (2009)
21. Klompmaker, F., Nebe, K., Fast, A.: dSensingNI - A Framework for Advanced Tangible Interaction using a Depth Camera. In: Sixth International Conference on Tangible, Embedded, and Embodied Interaction (TEI), pp. 217–224. ACM Press, New York (2012)
22. Cuypers, T., Francken, Y., Vanaken, C., van Reeth, F., Bekart, P.: Smartphone Localization on Interactive Surfaces Using the Built-in Camera. In: Procams, p. 448 (2009)
23. Wilson, A.D., Sarin, R.: BlueTable: connecting wireless mobile devices on interactive surfaces using vision-based handshaking. In: Graphics Interface, pp. 119–125. ACM Press, New York (2007)
24. Schmidt, D., Chehimi, F., Rukzio, E., Gellersen, H.: Phone- Touch: a technique for direct phone interaction on surfaces. In: 23nd Annual ACM Symposium on User Interface Software and Technology (UIST), pp. 13–16. ACM Press, New York (2010)
25. Kaltenbrunner, M., Bovermann, T., Bencina, R., Costanza, E.: TUIO - A Protocol for Table Based Tangible User Interfaces. In: 6th International Workshop on Gesture in Human-Computer Interaction and Simulation (2005)
26. Ullrich, D., Diefenbach, S.: INTUI. Exploring the Facets of Intuitive Interaction. In: Mensch & Computer, p. 251. Oldenbourg Verlag (2010)