

---

# CapWidgets: Tangible Widgets versus Multi-Touch Controls on Mobile Devices

**Sven Kratz**

Mobile Interaction Lab  
University of Munich  
Amalienstr. 17, 80333 Munich  
Germany  
sven.kratz@ifi.lmu.de

**Michael Rohs**

Mobile Interaction Lab  
University of Munich  
Amalienstr. 17, 80333 Munich  
Germany  
michael.rohs@ifi.lmu.de

**Tilo Westermann**

Deutsche Telekom Laboratories  
TU Berlin  
Ernst-Reuter-Platz 7, 10587 Berlin  
Germany  
tilo.westermann@telekom.de

**Georg Essl**

EECS & Music  
University of Michigan  
Ann Arbor, MI 48109  
USA  
gessl@eecs.umich.edu

**Abstract**

We present CapWidgets, passive tangible controls for capacitive touch screens. CapWidgets bring back physical controls to off-the-shelf multi-touch surfaces as found in mobile phones and tablet computers. While the user touches the widget, the surface detects the capacitive marker on the widget's underside. We study the relative performance of this tangible interaction with direct multi-touch interaction and our experimental results show that user performance and preferences are not automatically in favor of tangible widgets and careful design is necessary to validate their properties.

**Keywords**

User Interfaces, Tangibles, Mobile Devices, Capacitive Sensing, Touch Screens, User Study

**ACM Classification Keywords**

H5.2. Information interfaces and presentation, User Interfaces: Input devices and strategies.

**General Terms**

Design, Experimentation, Human Factors, Measurement, Performance

---

Copyright is held by the author/owner(s).

CHI 2011, May 7–12, 2011, Vancouver, BC, Canada.

ACM 978-1-4503-0268-5/11/05.



**Figure 1** The rotary knob CapWidget is made from aluminum and is attached to a PCB that creates artificial touch points by conveying the user's ground potential to the surface of the touch screen.

The unique arrangement of the artificial touch points for this CapWidget can be seen in the lower image.

## Introduction

Mobile devices rely increasingly on finger-based input using capacitive multi-touch screens. Capacitive multi-touch screens are nowadays very precise and responsive input devices. Sample rates for touch input are usually above 60Hz. A problem with touch-based interfaces is that the flat glass panel of the touch screen replaces all the physicality of traditional button-based device interfaces. Touch-based interfaces lack variation in tangibility and physical behavior of interface controls must be simulated on-screen through software.

We present CapWidgets, an exploration of the idea of bringing physical controls back into the world of mobile multi-touch interfaces. CapWidgets are designed to function with off-the-shelf mobile devices that have a capacitive multi-touch screen. It is possible to create artificial touch points at arbitrary locations on the bottom of a CapWidget. These points are detectable by the mobile device's capacitive touch screen when the CapWidgets are touched. Our technique allows the creation of a multitude of physical controls for capacitive touch screens, ranging, for instance, from simple styli to rotary knobs or sliders.

## Related Work

Fitzmaurice et al. introduced tangibles in surface computing using self-contained 6D input devices [3]. More recent approaches have used RFID [5] tags or visual tags [4]. Weiss et al. [9] added complex mechanical functions to their tangibles, creating, amongst other tangibles, a fully featured physical keyboard usable with a standard FTIR tabletop setup. Tracking of tangible building blocks [1] based on fiber optics was presented by Baudisch et al. Very little work

on sensing of tangibles on capacitive touch screens has so far been published. Orientation-aware "Capacitance Tags" have been previously described [8]. The tracking technique employed in this paper has been used to implement commercially available (single-point) styli and joysticks. An alternative, frequency-based tracking technique is proposed in [7]. To our knowledge, no previous work has analyzed the usability of tangibles on mobile devices with capacitive touch screens.

## CapWidget Implementation

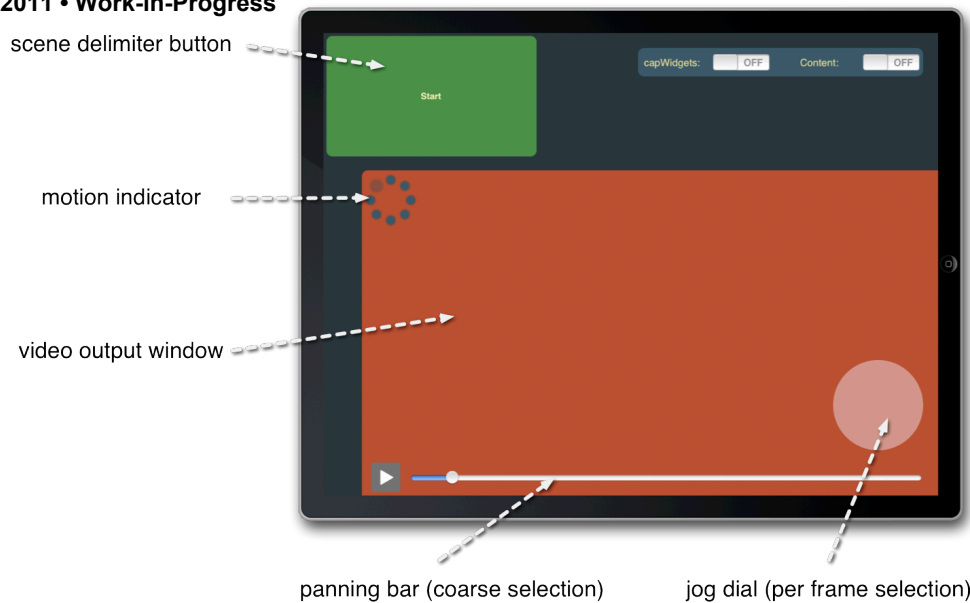
To understand why physical widgets can simulate touch points on a capacitive touch screen let us briefly review how capacitive sensing works.

### Capacitive Sensing

Capacitive touch screens use the electrical property of capacitance to determine the proximity of the user's fingers. Capacity is defined as:

$$C = \frac{\epsilon_0 \epsilon_r A}{D}$$

This shows that the capacitance (of a capacitor or equivalent object) is proportionally dependent on the Area  $A$  of the capacitor and the distance  $D$  of the capacitor's "plates". Capacitive sensors usually determine  $C$  indirectly by measuring the properties of an RC oscillator. Since a capacitor's (charge or discharge) current over time can be described as  $i = C dv/dt$ , it is possible to calculate the capacitance by measuring the time to reach the oscillator's threshold voltage or alternatively, the oscillator's frequency. To determine the exact location of a user input, capacitive touch screens usually make use of a grid arrangement of driving and sensing lines that act as individual



**Figure 2** The user interfaces implemented for iPad used in the study. Both interfaces are currently showing the artificial video. The screen on the left shows the touch-based interface, the screen on the right the interface for the physical control.

capacitors at discrete points on the screen, or are built from an array of individual capacitive sensing plates. Because the user is usually grounded with respect to the touch screen, a touch will influence the electrical (fringe) field of the capacitors in the touch screen at the touch location and modify the overall capacitance at that location, thus the touch is detected.

#### *How CapWidgets Create Distinct Touch Points*

Since CapWidgets usually have a physical knob or handle, it is necessary to transfer the user's ground potential to the capacitive touch screen. In our approach, we use physical controls made from a conductive material attached to a dual-sided PCB. The top of the PCB is electrically connected to the bottom of the PCB using a via, which is connected to tin-coated contact points. The contact points have about the same area as the contact area of a user's finger on the touch screen (Figure 1, bottom).

#### *Discerning between CapWidgets and Finger Tips*

When the user manipulates them, CapWidgets create a unique fixed touch pattern on the touch screen. It is thus a relatively simple task to discern CapWidgets from normal user touches by analyzing the geometric relationships of groups of touch points. A further advantage of the CapWidget fiducial pattern is that we are thus able to distinguish between multiple types of CapWidgets. In our demonstration implementation, object recognition is achieved by identifying the unique alignment of points of contact. In case of two or three points, the distance between these points identifies the object. The distances and diagonals in the resulting rectangle identify a widget with four contacts.

#### *Working CapWidget Prototype*

Our first working prototype CapWidget is a rotating knob (Figure 1). The aluminum knob is attached to a base PCB using superglue. Conductivity between the control and the PCB is ensured through the use of aluminum foil on the base of the Control. Our prototype

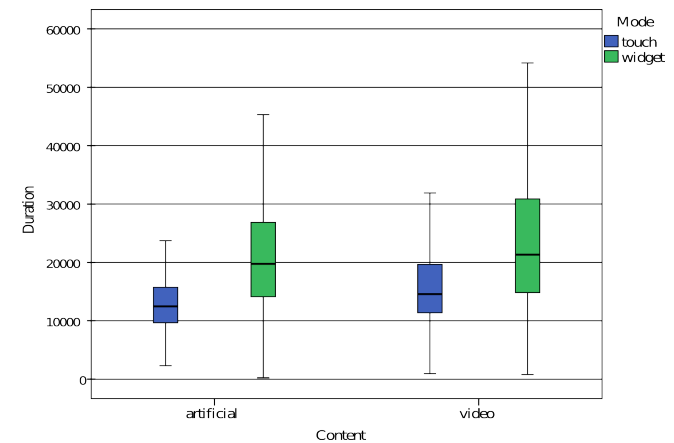
supports two basic input operations. By moving the control on the touch screen's surface the user can input translation commands. Rotation commands can be accomplished by turning the control. We have so far tested our prototype CapWidget on Apple's iPhone 3GS and iPad as well on the HTC Desire smartphone. All software for the user study was implemented for the iPad.

### User Study

In order to assess the relative performance of the CapWidget prototype, we conducted an explorative study of the usability of tangible controls on mobile devices. Our prototype CapWidget primarily affords rotary gestures, which are suitable for precise selection tasks, for example when browsing media. We hypothesize that the added tangibility of physical controls can improve the speed and precision of such tasks, for instance by allowing the user to focus on the presented content rather than the touch location on the screen. For the study, we implemented a video player that allows the user to jog between individual frames using either a standard jog dial on the touch screen or a CapWidget rotary control (Figure 2). The interface also includes a standard panning control, which allows the user to skip to a part of the video timeline directly. The panning control can be used with touch as well as the rotary control.

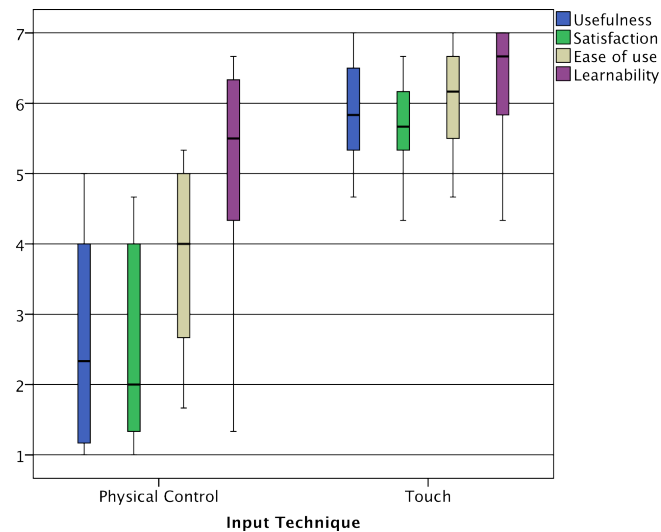
#### Task and Measured Variables

The task of our experiment was to mark each scene transition of a video shown by the video player. To accomplish this, the user was required to use the panning control for coarse positioning and the jog dial or CapWidget rotary knob for fine selection. For all tasks, the iPad placed on the surface of a level table.



**Figure 3** Boxplot of the task duration time vs. the input technique x video shown.

The users had to perform the task on two different videos for each input technique, touch (I1) or physical control (I2). Figure 2 shows screen shots of the user interface we employed in the experiment. Two types of videos were shown to the user. The first video type (V1) was an excerpt from the animated movie "Big Buck Bunny" [2] with a length of 4100 frames (about 170s at 24 frames per second). V1 contains a total of 30 scene transitions. The second type of video (V2) was purely artificial. The artificial video contained no meaningful content other than a motion indicator and clear scene transitions. V2 had the same length and number of scene transitions as V1. Furthermore, the locations of the scene transitions of V2 were identical to those of V1. We used a 2x2 factorial design, measuring the total task execution time as well as the input precision, i.e. the average amount of frames away from the true scene transition (missed frames), for every combination of input technique and video type. To



**Figure 4** Boxplot of the qualitative results for usefulness, satisfaction, ease of use and learnability, obtained from questionnaires. Ratings were given on a Likert scale from 1 (worst) to 7 (best).

avoid biasing due to learning effects, we used a Latin Square design to determine the order of videos and input techniques. We also gathered qualitative feedback about usefulness, satisfaction, ease of use and learnability, based on the USE Questionnaire [6] for each input technique. Additionally we allowed the users to comment on the positive and negative aspects of each technique.

#### Results

We conducted our study with 8 female and 8 male subjects, with an average age of 27.5 (SD=5.28). All subjects received monetary compensation for their participation in the study.

A MANOVA on task duration and precision shows that touch input (I1,  $M=15.3s$ ,  $SE=2.45s$ ) was significantly faster than input using the rotary control (I2,  $M=24.5s$ ,  $SE=5.1s$ ),  $p < 0.001$ ,  $F_{3,1920}=100.738$ , whereas there was no significant difference for precision. A box plot of the task time ordered by input technique is shown in Figure 3.

A MANOVA on the USE questionnaire results shows a significant effect of the type of input method on all measures of the USE questionnaire ( $p < 0.001$  for usefulness, satisfaction and ease of use,  $p < 0.08$  for learnability). As can be observed in Figure 4, touch was consistently rated higher than the physical control for all measures of the USE questionnaire.

#### Discussion of Experiment Results

The results of our experiment clearly show that our original hypothesis, the assumption that physical controls on a multi-touch screen of mobile devices would lead to lower task completion times and a higher precision, were not confirmed. Excluding other factors, such as noisiness of the touch point locations obtained through our implemented controls or possible problems in our software implementation, our results may indicate that physical controls on mobile- or tablet-sized devices with multi-touch screens may not be as advantageous as presumed. However, we do have some assumptions why the performance difference between touch and physical widget was so large and we wish to improve on these aspects in the future. A big factor in the execution time difference between the two modalities could be that the touch-based jog dial allowed continuous navigation between frames, whereas the physical control needed a repositioning of the fingers after a certain number of frames. What may

have additionally contributed to longer execution times was our decision to implement separate panning and selection areas when using the physical control. This approach, initially seeming simpler than allowing panning and selection at the same time, may have caused significant delays by forcing the users to repeatedly lift and place down the physical control in the two different input areas. Several positive user comments, for instance “*I liked to use the knob because of its retro style*” or “*the control was very easy to figure out*” indicate physical controls for touch-screen based mobile device have the potential to be a useful and engaging technology. However, there were also negative observations, the most important one being that ergonomic (i.e. neck strain) issues could be raised due to the requirement of the mobile device to be in a stationary and level position (e.g. on a table) in order to prevent the controls from sliding off the screen. Physical controls that adhere to the screen while at the same time remaining movable could be a solution to this problem.

### Conclusion and Future Work

We have shown a method of creating tangible input controls for mobile devices equipped with a capacitive touch screen. A preliminary user study we conducted has highlighted some potential issues with this approach, and indicates that for certain tasks, physical controls for such mobile devices may not yield the expected performance gains.

In the future we wish to create additional types of CapWidgets with a range of affordances and expand to user studies that explore the trade-off between multi-touch and tangible physical interface elements for portable devices, including the influence of using such

widgets on the go. This will require techniques to fixate the widgets sufficiently and hence we plan to explore suitable widget constructions.

### References

- [1] Patrick Baudisch, Torsten Becker, and Frederik Rudeck. 2010. Lumino: tangible building blocks based on glass fiber bundles. In ACM SIGGRAPH 2010 Emerging Technologies (SIGGRAPH '10).
- [2] Big Buck Bunny, Blender Foundation, 2008, <http://www.bickbuckbunny.org>
- [3] G.W. Fitzmaurice, H. Ishii, and W.A. Buxton, “Bricks: laying the foundations for graspable user interfaces,” Proc. CHI 1995.
- [4] Sergi Jordà. 2010. The reactable: tangible and tabletop music performance. In Proceedings of the 28th of the international conference extended abstracts on Human factors in computing systems (CHI EA '10).
- [5] James Patten, Ben Recht, and Hiroshi Ishii. 2002. Audiopad: a tag-based interface for musical performance. In Proceedings of the 2002 conference on New interfaces for musical expression (NIME '02).
- [6] A.M. Lund, “The need for a standardized set of usability metrics,” Human Factors and Ergonomics Society Annual Meeting Proceedings, 1998.
- [7] Neng-Hao Yu, Li-Wei Chan, Lung-Pan Cheng, Mike Y. Chen, and Yi-Ping Hung. Enabling tangible interaction on capacitive touch panels. Proc. UIST '10.
- [8] Jun Rekimoto. SmartSkin: an infrastructure for freehand manipulation on interactive surfaces. In Proc. CHI '02.
- [9] Malte Weiss, Julie Wagner, Yvonne Jansen, Roger Jennings, Ramsin Khoshabeh, James D. Hollan, and Jan Borchers. 2009. SLAP widgets: bridging the gap between virtual and physical controls on tabletops. Proc. CHI '09.