Experiences with Interactive Multi-touch Tables

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Abstract. Interactive multi-touch tables can be a powerful means of communication for collaborative work as well as an engaging environment for competition. Through enticing gameplay we have evaluated user experience on competitive gameplay, collaborative work and musical expression. In addition, we report on our extensive experiences with two types of interactive multi-touch tables and we introduce a software framework that abstracts from their technical differences.

Keywords: Interactive table display, User and developer experience.

1 Introduction

One of the promises of Ambient Intelligence (AmI) is to have intelligence embedded in our environments, whether it is the home environment, an office environment or public spaces. Intelligence is embedded in walls, floors, furniture, wearables, and other objects. The available intelligence is ubiquitous and pervasive. It can perceive activities and interactions. It can support, both in a reactive and pro-active way, the humans that inhabit or visit these environments. Natural implicit and explicit interaction with the environment requires an awareness of the activities and preferences the human inhabitant. Also, the environment and its interfaces should inform and communicate with their human partners using various modalities. Interactive surfaces where touch can be used to issue commands and to manipulate virtual objects are essential for natural interaction and for natural collaboration and entertainment activities. In this paper we report about our research on using interactive multi-touch displays for collaboration and entertainment applications. User experience is a main issue in our investigations.

The research reported here fits in our research on multimodal interaction in entertainment environments [1]. Touch is the main modality that we want to see explored in this work. Interactive surfaces that allow touch for multiple users and are connected with other touch-sensitive interaction surfaces can be expected to take flight in home, educational, professional and recreational environments. Multi-touch technology makes it possible for artists, designers, gamers and office workers to (jointly) interact with responsive surfaces, such as tables and walls. Interactive tables have already been introduced in restaurants, in museums, and at exhibitions to entertain visitors.

We are designing various applications for multi-touch tables with a particular interest in embedding such interactive surfaces in AmI and ambient entertainment environments. This requires research on how to embed such surfaces, how users want or are

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willing to interact with them and user experiences with diverse applications ranging from artistic and entertainment to decision making and crisis management.

The remainder of this paper is structured as follows. Section 2 provides an overview of multi-touch technology that possibly limits the interaction and defines research challenges for interactive tables. Section 3 introduces a software framework that abstracts from the interactive table hardware so that applications can run on any interactive table. Section 4 reports on our own experiences with two distinct multi-touch devices: a DI back projection table and the DiamondTouch [2]. With five distinct applications, we evaluated multi-touch interactions based on their fun factor, on performance and on the overall user experience in interacting with table displays. We conclude our paper in Sect. 5 with a discussion of our experiences and an outlook on open challenges for interactive surfaces in ambient intelligent environments.

2 Related Work

Previous multi-touch experiences. Interactions with interactive tables are influenced greatly by the application and its setting. Is the interaction time crucial [3]? Do users collaborate or do they compete with each other [4]? Do users casually interact with the table in passing [5] or do they perform complex and more time-consuming tasks [6]? How can hesitance to touch the table simultaneously be overcome [7]? Do we need to transfer the floor explicitly in collaborations [6] or can users operate cooperatively [8]?

Tse et al. [3] studied deictic input signals based on whole hand interaction with speech commands. Through collaborative time crucial tasks (Warcraft 3) and tasks where completion time was no issue (The Sims, Google Earth), Tse et al. showed that interactive table collaboration benefits from a shared view where users can communicate with each other directly through verbal utterances and manipulating the visualizations. Hardware and software limitations influenced the interaction greatly, resulting in coarse, counter-intuitive gestures. A later study found that users would actively engage in each other's tasks even insofar that tasks were jointly performed [8]. Also, deictic commands were observed to double as implicit communication between subjects.

A room furniture layout application (RoomPlanner) has been used for exploring interaction techniques that take advantage of multi-touch and hand shape input on table displays [9]. Two users on opposite sides of the table fitted furniture in a room. Private information could be projected on hands and objects by virtue of using a top-projection table. Three types of interactive table territories have been observed in both casual and formal interaction settings [5]. The personal territory allowed users to perform independent activities, the group territory served as a joint blackboard and the storage territory held unused icons in out-of-the-way spaces on the table.

Hardware. The most popular technique for optical recognition is Frustrated Total Internal Reflection (FTIR) is similar to fiber optics [4,10]. FTIR displays project IR light into an acrylic sheet. The internal reflection is frustrated by touching the surface, so that the refracted IR light can be detected with an IR-sensitive camera. FTIR scales up successfully but cannot support passive fiducials [4]. Active markers, however, might be used for FTIR displays [11]. Alternatively, Diffuse Illumination (DI) does support passive fiducials [12,13]. DI displays diffuse illuminate the surface so that a camera can detect all IR reflecting objects on and hovering over the surface: hands and fiducials alike. FTIR typically requires less computer vision (CV) filtering than DI.

The Apple iPhone is a well-known example of a capacitive coupling touch screen. This technology relies on the conductive properties of the human skin. A grid of electrically polarized transmitters and receivers can detect the small changes in capacitance triggered by a touch. Implementations vary: the iPhone is based on mutual capacitance, SmartSkin [14] has its receivers and transmitters under perpendicular angles and the DiamondTouch [2] touch panel contains two arrays of transmitters only with users standing on receiver mats. By design, the SmartSkin can detect conductive objects on its surface while The DiamondTouch can identify users through the receiver mats [6]. The signals received by the DiamondTouch are code division multiplexed which results in ambiguity of n^2 possibilities for n touches of the same user.

3 Abstract Software Layer - μ^3

Our multi-touch experiences are based on two distinctly different interactive tables, see Fig. 1, a DI back projection table and a DiamondTouch [2] top projection table. These two distinct platforms each have their pros and cons. The DI table can detect fiducials and hovering over the table while the DiamondTouch can identify users. Extracting touches is, due their distinct designs, quite different for each of our two interactive multi-touch tables. DI tables typically use the *tbeta*[1] framework which produces TUIO messages that hold information on location, orientation and recognized states [15]. TUIO cannot, however, handle multi-user information. The DiamondTouch can be accessed with the DiamondSpin toolkit [16]. DiamondSpin focuses on multi-user interaction and cannot handle multi-touch input adequately. Other similar frameworks such as TouchLib, reacTIVision [12] and LibTisch [17] have their own limitations so that there is no uniform framework that spans interactive multi-touch tables sufficiently.

The strengths of DI tables and capacitive coupling tables are combined in μ^3 which stands for *mu*lti-touch *mu*lti-tangible *mu*lti-user. With μ^3, we aim to overcome the shortcomings of existing multi-touch software. For multi-touch, we represent all possible touch points on a table in a 2D array (the table surface) as states. Each point is touched, untouched, a ghost touch[2] or an untouchable point (e.g. for non-rectangular tables). We generalize all touched points as tangible objects so that tangible object identification is made possible, also encompassing tracked fiducials [12]. Multiple users are also represented as the owners of tangible objects. Every ‘tangible’ can be assigned to at most one user for identification. The input arrays that represent touch point states and tangibles are combined into frames that, in turn, represent all touch activity on the table. To resolve overlapping touch points we use a collection of frames.

μ^3 can track, join and split touches. Developers need only to implement a preprocessing step to convert raw input to μ^3 frames, see Fig. 2. To illustrate, the DiamondTouch

[1] *tbeta* framework available: `http://tbeta.nuigroup.com/`, checked february 2009.

[2] Recall from Sect. 2 that the DiamondTouch suffers from touch ambiguity when 1 user touches the panel on 2 or more points.

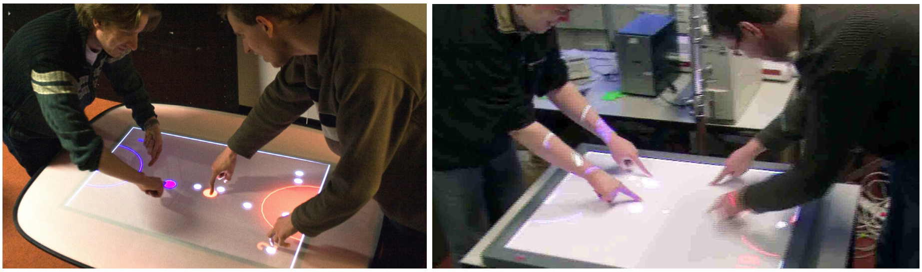

Fig. 1. Two distinct interactive multi-touch tables with our AirHockey game on a diffuse illumination table (left) and on the MERL DiamondTouch table (right)

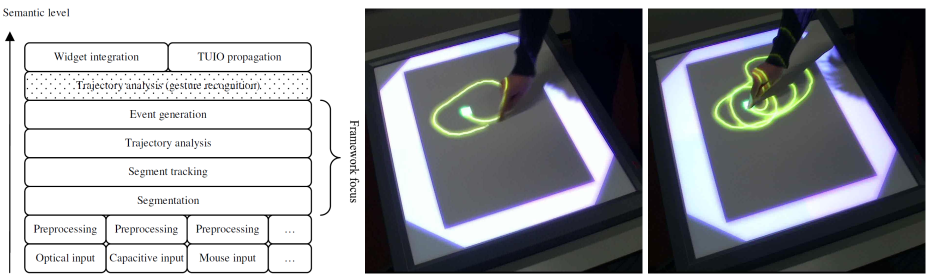

Fig. 2. The μ^3 framework architecture and our FeelSound musical application (see Sect. 4.4) build on top of μ^3 and composing on the DiamondTouch

is accessed in under 200 lines of code with μ^3. Adjacent points in the input are identified into a concave hull using marching squares and polygon simplification. Tracking searches for the best matching touch for each segment using a confidence measurement based on segment size and location. When exceeding a predefined threshold these segments are passed to the trajectory analysis where touches are possibly split or joined. Note that μ^3 is not capable of recognizing fiducials directly and expects this information from a preprocessing layer. μ^3 can also take TUIO messages as input.

4 Multi-touch Experiences

We present four applications for our interactive tables with which we explored the touch modality. First, turn taking is explored in manipulating a 3D molecule, based on [6]. Second, competitive and engaging behavior was explored with our AirHockey game. Third, MT-Pong crowds the table with competitive gamers. Fourth and final, we enticed creativity in passers-by to compose a musical performance in FeelSound.

4.1 Collaboration – 3D Molecule

Interactive tables are extremely suited for collaboration while users stand or sit around the table, sharing a common display [6]. We have evaluated collaborative behavior with

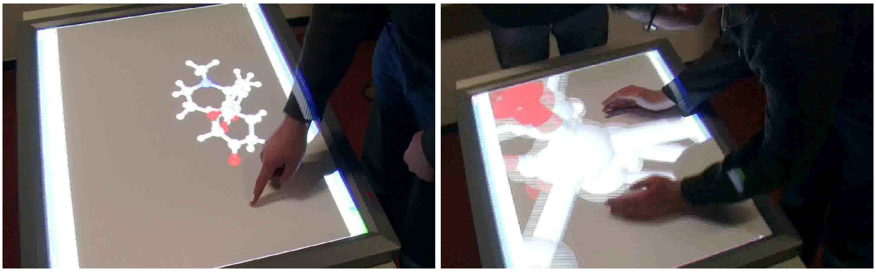

Fig. 3. One finger to rotate and two fingers or hands to zoom into and out of the 3D molecule

a biological visualization tool that fills the table with a 3D molecule. Bioinformaticians stand around the table to discover function from form. The interface is multi-user and multi-touch but only one task should be performed at any one time. Multi-touch and multi-hand gestures were implemented to control the molecule so that users can perform a task alone or together with a partner [8]. We were especially interested to find out how turn taking would take place: would users wait for their partners to finish?

Observations with two groups with no biological knowledge of the depicted molecules simply moved, rotated and resized the molecule. These users let a self-appointed chairman control the display. They argued that the simple goal did not require input from each of the participants. The chairman stood centralized, see Fig. 3. A group of three biologists jointly answered form-related questions; they located active sites on various simple and complex proteins. These biologists took turns to control the molecule by switching places and thinking out loud to solve the task.

4.2 Competition – AirHockey

What happens when the nature of the interaction shifts from collaborative to competitive? Our AirHockey game, based on the arcade version, is played by two gamers. The gameplay was tuned to this digital version, for example, touches in the goal area were discarded. In addition, we experimented with the number of balls, amount of friction and responsiveness to touches. Adding too many balls panicked gamers so that they tried to beat away as many balls coming towards them instead of applying some tactics. Players commented that they misjudged how fast the table would respond; the output initially lagged behind input, making real-time gameplay difficult. Players physically pushed the arms of their opponents out of the way to be able to score goals. This fast-paced game did entice gamers to great extent, making them very eager to win the game by any means possible.

4.3 Crowding – MT-Pong

Interactive tables are currently quite small. Multiple users easily crowd the display, inhibiting their own movements and those of others. We implemented a competitive game, MT-Pong which was similar to Gross' [4] Puh game. Up to four players would score points by playing balls in an opponent's goal. Players placed up to two paddles with two or more fingers; single touches were ignored, following [4]. Placing a third paddle would remove the first and paddles had a maximum length to prevent spanning the whole table. The game ended after a set time. An informal evaluation took place with passers-by gamers who played MT-Pong in our coffee room. These gamers initially started waving around their hands erratically at the balls, hoping to change their direction. They quickly caught on that two touches were needed to play. Most players noticed a minor delay in placing the paddles due to the update frequency of the DiamondTouch but found it of little influence to the gameplay as it was not as fast-paced as AirHockey. Like AirHockey, we observed that gamers physically pushed each other out of the way in order to win. MT-Pong was 'fun', 'engaging' and 'tiring' to play. Crowding the display is mostly fun for the gamers involved in competitive settings. Pushing opponents was not considered to be an issue, on the contrary, it added to the fun-factor.

4.4 Artistic Expression – FeelSound

Following reacTIVision [12] we explored how users would compose a musical performance on an interactive table using touches alone. FeelSound synthesizes real-time sounds based on touch trajectories, see Fig. 2. Composers draw shapes on the table to add samples to the performance. The horizontal and vertical axis represent the sample frequency and amplitude; complex shapes result in complex, long samples. Drawn shapes collapse into an icon on the table that can then be configured along the edge of the table to start replay. FeelSound can current only construct simple music samples for the performances. More complex samples such as singing and instruments is work-in-progress. During a public exhibition a large audience (50+ people) walked up to the table and started composing music with FeelSound; it was easy to entice passers-by to start composing. The interface proved to be not very intuitive; most users were unsure what to do without instruction. Often, composers would start out by tapping the table to see what would happen, cluttering the table with lots of brief sample icons. After receiving instructions, the composers found FeelSound very engaging for creating music.

5 Discussion and Future Work

Our experiences with interactive multi-touch tables are colored by the specifics of our two tables. Each table has its own, mutually exclusive strong points, see also Sect. 2. DI tables can detect hovering and fiducials while a capacitive coupling table can identify users and requires limited processing to access. Weak points were present in both tables. First, touch-calibration proved to be very fragile. The DiamondTouch is easily pushed aside, especially when leaning over the panel, because it simply lies on top of a table with minimal anti-slip precautions. In addition, when mounting the beamer on a tripod users tend to bump into it by accident as occurred often in our FeelSound exhibition. Similarly, the mirror set-up in the DI table is fragile and susceptible to users (unintentionally) banging against the table thus requiring recalibration. Second, the update frequency is rather limited. The DiamondTouch operates at 30 Hz while a DI table is limited by its camera. For both MT-Pong and AirHockey, players commented that the interface responded unexpectedly slow. Third, interactive tables are still rather small;

our tables are both roughly a meter across. However, our users typically did not experience lack in their freedom of movement due to this size.

We found that a DiamondTouch user not standing on a receiver mat can interact with the table by touching a user who is standing on a mat. This might offer some interesting forms of explicit collaboration on interactive tables taking into account that users can complement each other's commands as noted by [8].

A specific weak point of the DiamondTouch is its limitation to detect individual touch points by default. Touch ambiguity of n touches results in n^2 potential touches that the developer needs to handle. Tse et al. [3] worked around this by performing multiple selection with large bounding boxes and precise control with small ones. Our games required more precision that we were able to implement using μ^3. Our μ^3 framework abstracts from the table's underlying hardware so that developers can focus on applications rather than handling multi-touch hardware. μ^3 can track, join and split touches that originate from identifiable users or tangibles. μ^3 is under active development.

An extensive insight in developing for and using our DI table and DiamondTouch was given through informal evaluations of four very different applications. Through competitive gameplay (AirHockey) we found an eagerness to win that extended even beyond the interface by physically hampering opponents. This was intensified even more when the display was crowded (MT-Pong). Artistic expression was explored through composing music (FeelSound) and proved to be engaging in a public exhibition even though the interface was not very intuitive. In a collaborative setting (3D molecule) we observed that the display is controlled from a central spot from which the visualization can be observed upright. Turn-taking, in various forms, proved to be a very important aspect of the interaction with interactive tables. We showed the appreciation of physical interaction between users cooperating (jointly performing tasks) or frustrating other users in competitive gameplay (by pushing opponents away).

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