The TViews Table for Storytelling and Gameplay

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1 Introduction

Over the past several decades, digital media interactions, such as playing games, sharing photo collections, and communicating across distances with remote friends and family have evolved from simple single-user applications to complex network games and media sharing programs. Yet still today, our interactions with these systems remain dominated by the all-prevailing single-user desktop computers, laptops or handheld devices.

As digital entertainment applications continue to evolve, there is an increasing need for new kinds of platforms that can support a diverse range of sociable media interactions for everyday consumers, including media asset management and story construction, digital game play and multimedia learning. In recent years, this need has resulted in the development of several technical approaches including touch-sensitive surfaces and prototypes of multi-object tracking platforms coupled with overhead projected displays. In this article, we describe our research and development efforts to create a general purpose, economically viable tangible media table platform, called TViews.

The TViews table provides tangible interaction through real-time tracking of multiple objects on an interactive sensing surface with an embedded display. An important element in the innovation is the sensing and enumeration approach used to locate objects on the table's surface. The design can generalize across diverse applications and physical contexts, ranging from home living rooms, to classrooms or public settings. The input to the table is an almost unlimited set of uniquely identified wireless objects that can be used on the surface of any similar table. These objects can be physically customized in order to suit particular applications, and can provide additional functionality through external input and output elements on the objects themselves. The output of the tabletop platform is provided by a coincident display embedded within the table itself. The sensing solution can scale to fit the appropriate display size for particular settings or physical locations.

The following sections provide a background context for our research and discuss related work on tangible media tables and sensing technologies. We then discuss our research prototype and the storytelling applications and workshops that helped us define the requirements for creating an extensible media table platform for tangible object interaction. We describe our design of the TViews table based on these requirements, providing an overview of the current hardware and software implementation. We also provide a comparison of different technical approaches for tangible media tables, and conclude with a brief look at some of the gaming applications we have been developing for the TViews table.

2 Beyond Desktop Computing

To address some of the limitations of existing computer interfaces, which typically provide single-user continuous control via mouse, touch or pen-based input, the past decade of human-computer interaction research has shown a growing interest in emerging areas such as ubiquitous and pervasive computing, and tangible user interfaces [20, 6]. Rather than moving more of our daily tasks out of the physical world into the limited interaction space provided by desktop computer interfaces, these domains seek to seamlessly integrate the digital and physical worlds in order to enable sensory-rich interactions with digital information across a broad range of contexts and environments. Tangible interfaces in particular, are characterized by the coupling of controls and representations of digital information within manipulable physical artifacts, surfaces and spaces [18]. This interaction technique differs significantly from mainstream computer interfaces such as keyboards and mice, which act as input devices alone and are intended as controls for the visual representations of digital information provided by screen-based displays.

2.1 Tangible Interfaces

As a relatively new field, tangible interface research has thus far focused largely on the search for new metaphors and approaches for physical-digital interactions through graspable objects. The prototypes created have capitalized on the rich sensory space that surrounds us in the physical world, which provides a vast variety of possible interaction styles that can be applied to a range of different application domains, including digital media entertainment and gameplay. But while the degrees of freedom in human physical-world interactions are extremely high, the forms of physical objects are rigid and fixed in a way that constrains each one to a small set of uses and applications. What if we could make a space that could recognize and track an almost infinite number of objects? Would making such a space lead us to a clutter of single purpose objects that are costly to manufacture and maintain? In order to reconcile the fixed form of physical objects with the malleable nature of digital contents, we need to think of ways in which the objects within a combined physical/digital interaction space can be reused across different kinds of digital applications.

The research described here seeks to address some of the scalability issues faced by tangible computing through the formulation of an approach that enables the creation of extensible tangible media platforms for shared spaces. The work builds on past research on tangible object tracking tabletops described in the following section. The approach considers how the combination of carefully coordinated object sensing, object identification and management, and visual display can form the integral elements for such a platform. If designed to work together, these elements can allow tabletop platforms to scale across many individual (and potentially connected) instances in different physical settings, and to support multi-user media interactions across a broad range of application domains, including interactive storytelling and gameplay.

2.2 Tangible Media Tables

Tables provide an ideal space for people to engage in shared and sociable interactions. Digital tabletops that provide interaction through tangible objects can serve as a platform for multi-player digital games and other media content applications in shared physical contexts, such as the home, school classrooms, cafes, shops or museums.

Some of the early research on tangible tabletop interaction took place at the MIT Media Laboratory, with the metaDesk and I/O Bulb projects [17, 19]. Designed for collaborative use, these systems provided prototype applications for geographical visualization, simulation of holographic setups, and urban planning. In both systems, the tracking of multiple objects was achieved through computer vision, and the display was accomplished with projected graphics from the rear (metaDesk) or the front (I/O Bulb).

Today, digital tables with tangible interaction are being explored by an increasing number of researchers for a broad range of applications and physical settings. The Sensetable project at the MIT Media Laboratory has been used for applications in a number of areas, including supply-chain visualization and musical performance [13, 14]. Other tables that are being developed at university research labs include the reacTable from the University of Pompeu Fabra which is used as a musical instrument [7], and the InteracTable and STARS platform from Fraunhofer IPSI which have been used for multi-player games [9]. Examples of tangible media table research from industry include the Entertaible from Philips Research, which uses an optical approach to track both fingers and objects on the surface of a horizontally placed LCD [22], and the vision-based PlayAnywhere table from Microsoft Research [21].

A related area of research focuses multi-touch tabletops that can simultaneously track multi-user interactions through touch alone. Notable examples include the DiamondTouch table from Mitsubishi Electric Research Labs which enables up to four users to be uniquely identified [3], and the IR frustrated total internal reflection based Multi-Touch table designed by researchers at New York University [4].

2.3 Sensing Technologies

This section provides a brief overview of the primary approaches that have been used for locating objects on relatively small-scale horizontal surfaces, such as tabletops or single-room floors. For the most part, these fit into three broad categories: optical, electromagnetic and acoustic.

Optical. Objects can be tracked on a horizontal surface using computer vision algorithms, as in the metaDesk and I/O Bulb systems [17, 19] and the PlayAnywhere table [21]. In contrast to these, the Entertaible system by Philips Research is based on a series of LEDs and photodiodes mounted around the perimeter of an LCD screen, which can track both fingers and objects placed on its surface [22]. Optoelectronic triangulation systems are widely used for tracking mobile robots. These typically involve a scanning mechanism that operates in conjunction with fixed-location receivers placed in the operating environment.

Electromagnetic. Other approaches to object tracking use electromagnetically actuable tags. The Sensetable project mentioned above [13] is based on Wacom's tablet and pen technology that uses an antenna grid within the sensor board to track pens containing coil-and-capacitor resonant circuits. While a typical Wacom tablet can track only two pens at a time, the Sensetable project modified the system using a duty cycling approach in order to allow a greater number of objects to be tracked at once. Another example of an electromagnetic position detection system was developed by Scientific Generics and licensed by Zowie Intertainment for use in a couple of children's toys [15]. This technology was used in the first prototype of the tabletop media interaction platform described in the following section, and also by later versions of Patten's Sensetable work. Since electromagnetic systems require sensors to be embedded within the interaction surface, coincident display of graphics must be projected from overhead.

Acoustic. Objects can be located using an acoustic approach by embedding ultrasonic transmitters inside the tracked objects. Ultrasonic receivers placed around the sensing area pick up the short acoustic signals emitted by the objects and triangulate the object's location based on the time-of-flight of the signal from the transmitter to each receiver. The acoustic signal is typically transmitted through the air, which can result in errors if there are objects in the way between a transmitter and receiver. This approach has been used to locate performers on a stage [16] as well as in a number of electronic whiteboard systems such as Mimio by Virtual Ink, in which an ultrasonic tracking array is positioned along the upper left edge of the board, and the acoustic signals are transmitted from special sleeves that hold the whiteboard markers [1]. In another system from the MIT Media Lab, ultrasonic positioning has been used to track knocks or taps on large glass surfaces [12]. In this case, the receivers are affixed to the back of the glass panel and the acoustic signal travels through the glass rather than through the air, which eliminates potential problems of occlusion. This method provided the inspiration for the approach used in TViews, but differs in that the TViews system places the receivers in the objects in order to allow the system to scale to larger numbers of tracked objects. In the commercial realm, two companies from France, Intelligent Vibrations [2] and Sensitive Object [5], have both developed systems for tracking taps on large flat surfaces such as windows and tables, and their approaches are similar to the work by Paradiso described above. Canon has developed a similar approach for tracking a vibrating stylus on the surface of a display tablet using the acoustic propagation time of the signal through a glass plate placed above the display surface [8, 23].

3 Research Prototype

This section presents work leading to the development of a general purpose tangible media table technology and design. The research approach followed an iterative design process, beginning with the development of a research prototype and several media applications. The goal of this preliminary work was to better understand how tabletop platforms could be used for shared media and story interactions, and to determine the technical requirements for constructing an extensible and robust technology for object sensing on tabletop displays.

3.1 Storytelling Applications

The research prototype is a small tabletop interaction platform, which uses an inductive sensing technology that was licensed by Zowie Intertainment for use in a couple of digitally enhanced children's toys [15]. The coincident display of graphics on the horizontal interaction surface is provided by overhead projection.

Two narrative-based applications focusing on multiple viewpoint and spatial storytelling were constructed for the system [10]. These applications supported interactive story navigation through the manipulation of graspable pawns and other tangible tools on the sensing and display surface. Each application was used as part of a storytelling workshop that served as a test-bed for identifying the limitations of the prototype platform and the design principles for the final design.

Tangible Viewpoints. In this application, the content clips of a multi-viewpoint story are organized according to the character viewpoint they represent, and their place in the overall flow of the narrative. The physical pawns are used to represent the different character viewpoints in a story, and when placed on the interaction surface thumbnails of associated story clips hover around them. Users can explore the different viewpoints and story threads by playing the clips that cluster around the pawns using a small lens-shaped selection tool. Clip playback causes the narrative to advance and new clips to become available, drawing users forward through the multi-threaded story space.

Tangible Spatial Narratives. This application explores the notion that physical spaces can become an arena for story construction and narrative development through the human actions, conversations and memory creation that unfold throughout them. The application recreates the physical space of a story on the

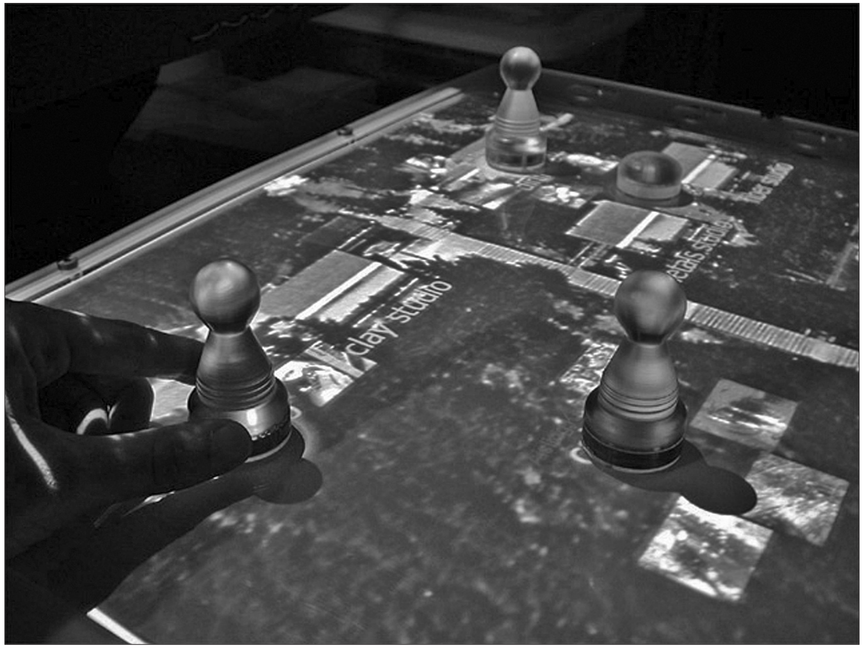

Fig. 1. Tangible Spatial Narratives running on the prototype platform. Three pawns are placed at different locations on the map, with content clips projected around them.

tangible platform, allowing audience members to navigate a story map using tangible objects such as pawns and clock tools. These interactions gradually reveal the many pieces of a complex spatially structured story (see Fig. 1).

3.2 Storytelling Workshops

The research prototype and applications provided a means for exploring questions of tangible media table design and use: in particular, who might use such a platform and how, and what are the technical requirements for deploying such a platform in shared settings? The applications described above both allow small groups of users to share multimedia stories created about their personal experiences in an informal and social manner. To explore this idea of sociable storytelling on a shared tabletop platform, the multi-viewpoint and spatial applications were used to support two different personalized storytelling experiences in which the community of story authors was also invited to become the audience members of their own stories. Through iteration between story creation and story engagement, participants were able to watch their own story grow and evolve, and as a result became engaged in an active process of story revealing and personal reflection.

The first experience took the form of a ten day storytelling workshop at the Boston Museum of Science Computer Clubhouse. This after school learning environment provides a safe space for young people from underserved communities to engage in creative activities and skill building through the use of technology. Workshop participants worked together to develop a structure for their story, and decided to create a documentary piece chronicling one day in each of their lives in their East Boston community. They used digital still cameras to record images for their stories, and provided voice-overs and metadata information before adding their clips to the content database. The tabletop interaction platform was set up in a central area of the one-room Clubhouse environment, and members of the community were free to interact with the stories created by workshop participants.

The second storytelling workshop was based around the Tangible Spatial Narratives application and was held at the Digital Dialogues: Technology and the Hand symposium at the Haystack School of Mountain Crafts in Maine in September 2002. The symposium focused on the creation of artistic pieces in a studio-based environment, and the 65 participants were invited to use their hands in collaboratively forming materials, media, and ideas. Participants used digital video and still cameras to record their activities and experiences in the studio spaces. These clips were then annotated with the appropriate metadata and loaded into a database that could be queried according to different keywords or combinations of keywords. The tabletop media platform enabled participants to collaboratively engage with their story as it was still being created. As people experimented with the tangible interface, their engagement with the video clips was enhanced by the fact that they were familiar with the people and events portrayed, and the social nature of the platform allowed them to share and reflect on this experience with others. As we observed at the Computer Clubhouse, the tangible platform drew users around it to jointly engage with their media collection during coffee breaks and leisure time.

3.3 Platform Requirements

The storytelling workshops served as exploratory evaluations for the prototype platform, bringing to light a number of important limitations and helping to identify the particular requirements for a tangible tabletop media interaction platform. Ultimately, these observations lead to the development of the TViews media table architecture described in the following section. The design requirements identified are as follows.

Scalability of the Display and Interaction Space in Size. In working with users, it became evident that the size of the prototype platform was too small to accommodate more than two or three users at once. This was not a problem in the small and crowded Clubhouse environment, where typically no more than three people were actively involved in story creation or exploration at a time. In contrast, the Haystack space would have benefited from a much larger interaction platform that could have enabled larger subsets of the 65-person community to interact with the system at once. The lesson to be drawn here is that different physical environments and application contexts benefit from different sizes of media interaction table, hence the need for a platform that can scale in terms of size.

It is also worth noting that the overhead projection, which was accomplished using a specially constructed stand, proved cumbersome as it blocked one side of user access to the interaction surface and was difficult to transport and set up. Since hanging a projector from the ceiling does not allow for the system to be easily movable or portable, the sensing technology should allow for the incorporation of an embedded display.

Extensibility of the Object Namespace. Another major limitation of the prototype platform was the small number of interactive objects that the sensing technology was able to support. Even though the spatial application provided the ability to associate a physical pawn to different characters through a menu-style interface, a larger number of objects would have enabled a broader range of interactions. With a limited number of tools, it becomes necessary to give the tool a very generic shape if it is to be used across different kinds of application areas. A larger object namespace would allow for objects to take on a different physical form depending on their function within the media space and the particular application with which they are typically used.

Portability of Interactive Objects between Platforms. If separate tangible media table instances are employed in different physical locations at once, portability of objects between these platforms becomes an important factor. For example, if two friends each have a media table in their living room, they might want to take their interactive objects or game pieces to play on each other's tables. In another scenario, a naval simulation game that comes packaged with its own set of interactive objects should be able to run on any instance of the tangible media table. Tangible media tables thus need to be able to identify and locate any interactive object from the global set, regardless of their size or location.

Extensibility of the Application Space and Management of Objects and Applications. A modular software framework designed for the prototype platform separated the tracking technology from the end-user applications, allowing the set of applications for the platform to be easily extended. During the workshops, switching between applications still needed to be done through the windows operating system using a keyboard and mouse, which proved to be tedious for users. While it may at times still be useful to wirelessly connect a keyboard and mouse to a tangible media table, it became clear from our observations that basic interactions should be done without them. An application manager is needed to keep track of the applications installed on the table and the particular objects associated with each one, and to support easy switching between different applications. For instance, if one user is running a paint program when another user places an object from a naval simulation game on the table, the event could be handled by asking the users whether they would like to switch applications or stay within the current one.

4 TViews Table

The requirements identified above form the basis of our extensible architecture for tangible media tables. Based on this architecture, we have designed the TViews Table, a media interaction platform for shared living spaces within the home environment [11]. We have constructed two complete TViews tables, which can work both independently and together as a networked system. One TViews table is located at the MIT Media Laboratory, while the other is located around the world at Samsung's research center in Suwon, Korea (see Figure 2).

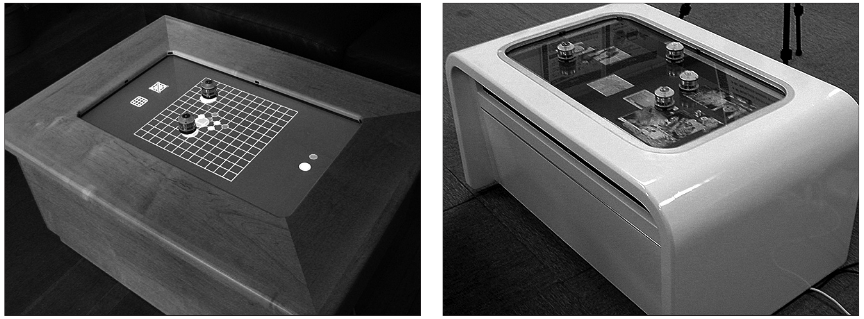

Fig. 2. Two different styles of TViews media table constructed at the MIT Media Lab (left) and Samsung Research (right).

TViews uses a novel combination of acoustic sensing and infrared communication technologies, coupled with distributed processing both in the interaction objects themselves and in the table's central processor to achieve these objectives. Here we provide a brief overview of the technical features that we have used to fulfill these requirements.

Scalability of the Display and Interaction Space in Size. In order to allow scalability of the interaction surface in size, the object positioning technology must function independent of the size and scale of the interactive surface. This can allow the surface to be constructed in smaller or larger versions and at different scales to accommodate different types of displays. We based the TViews object tracking technology on the acoustic time-of-flight of positioning signals transmitted through the glass display surface itself, and passively monitored by the interaction objects. Since this acoustic positioning system does not require antenna grids or other materials covering the interactive surface, it is possible to provide a coincident display without suffering from occlusion or other problems inherent in other technologies, regardless of the size or aspect ratio of the display surface. Furthermore, by broadcasting positioning signals from the display surface to all interaction objects simultaneously, there is no inherent limit to the number of interaction objects that may be used simultaneously on the same surface, and the position update rate is independent of the number of interaction objects. Our initial TViews prototypes have shown 100Hz update rates and millimeter scale position measurement accuracy, essentially invariant to the number of tracked objects.

Extensibility of the Object Namespace. In order to provide an extensible object namespace, TViews uses a globally unique digital identification number for each interactive object. The current 64-bit number allows an extremely large object namespace that is used in a hierarchical fashion to permit different object types to be differentiated through fields in the ID namespace. This ID space could be extended to a larger numbering space if necessary.

Portability of Interactive Objects between Platforms. Supporting portability of interactive objects from one table to another requires two properties. First, a table must be able to identify any object from the entire namespace as soon as it is placed on its interaction surface. Second, any table regardless of its size needs to be able to determine the position of any object placed on its interaction surface. To accomplish the first property, we developed an enumeration strategy for the singulation and identification of all objects that are currently on a given table, even when the number of objects and their identities are not known a priori. To accomplish the second property, the position solution based on time-of-flight data is performed by the computational system within the table rather than on the objects themselves. This way, the objects do not need to know anything about the size of the table on which they have been placed, and only need to be able to measure signal flight times and communicate them to the table.

Extensibility of the Application Space and Management of Objects and Applications. In order to support an extensible set of applications, TViews provides an API (Application Programming Interface) layer based on an event model that sends events when objects are added to, moved on, or removed from the table. TViews applications register themselves to receive input events from the table's control system. TViews also provides an application and object manager to support multiple applications on the table and to keep track of interaction objects associated to the different applications.

4.1 Hardware Implementation

TViews uses a combination of acoustic and infrared communication technologies to implement the feature set outlined above. Inside the table, a master control board connected to the interaction surface manages the communication and tracking of the large set of interaction objects (known as pucks) as they are placed and moved

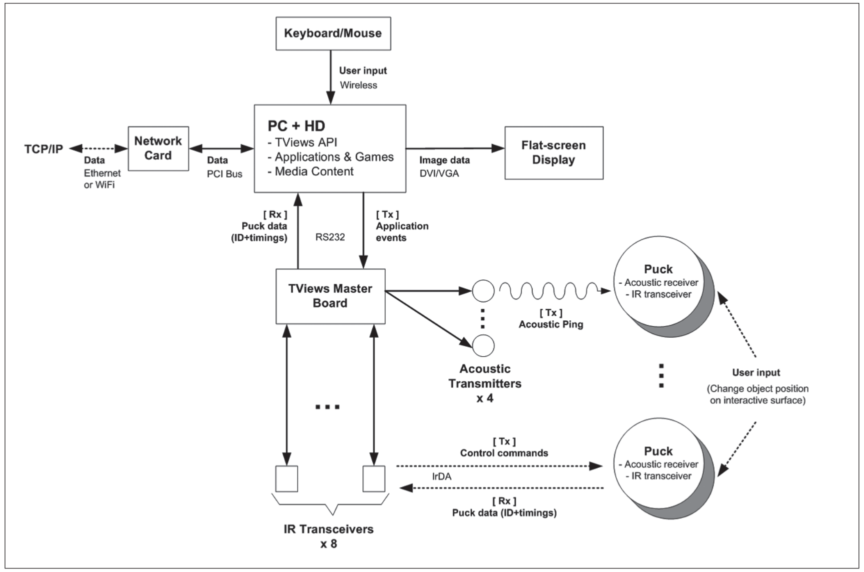

Fig. 3. Block diagram illustrating the various components of the TViews system.

on its surface. Each puck is powered by a rechargeable lithium polymer battery. The prototype pucks last 8-12 hours on a single charge, although further work on the puck circuitry should result in weeks or months of operation on a charge.

Acoustic ranging pings are used to locate the pucks, while object identity, time of flight, and object manipulation information is communicated bidirectionally between the master control unit and each puck by means of infrared transceivers. To transmit acoustic ranging pings, piezoceramic transducers are affixed to the bottom-side four corners of the display glass. These transducers launch ultrasonic acoustic waves at a frequency of 200 Khz into the glass surface in a bulk longitudinal acoustic wave mode. A frame consisting of eight infrared transceivers is placed around the edge of the interaction surface for communication. An excess number of inexpensive infrared transceivers are placed around the edge of the display surface so that hand occlusion or object occlusion do not block communication between interaction objects and the TViews table. Future versions of the TViews system will employ RF communication to avoid this problem entirely. Each puck (interaction object) is equipped with an ultrasonic receiving sensor to pick up the

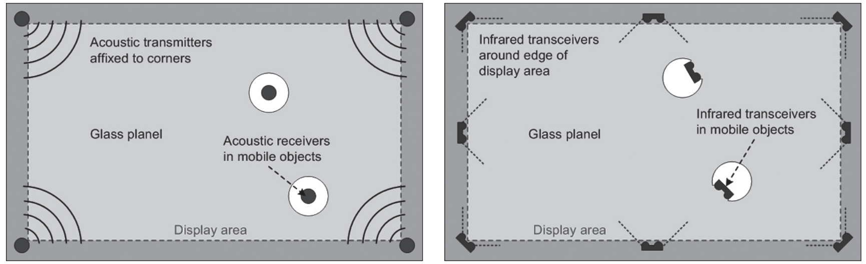

Fig. 4. Top view of the sensor layout on the surface of the TViews table.

acoustic waves as they travel through the glass display surface beneath, as well as an infrared transceiver for bidirectional data communication with the table. Figure 3 illustrates the components of the TViews system.

This position sensing approach was inspired in part by the Tap Window project, a system for tracking taps and other impacts on large glass surfaces [12]. An important difference between the TViews sensing approach and previous work on acoustic tracking systems such as the Tap Window is that TViews simultaneously tracks many objects on the table rather than one object or tap at a time. Another important distinction is that the Tap Window is a passive system, used to track impacts on glass from inactive interaction objects such as metal objects or human fists, while the TViews table is used to track active objects equipped with sensing and computation capabilities. Furthermore, the acoustic receivers in the TViews system are located in the interaction objects themselves, while acoustic transmitters are affixed to the corners of the glass (see Figure 4). This reversal of the past approach endows the TViews display surface with a positioning utility, which enables the TViews system to scale to an essentially unlimited number of interaction objects on the table without a significant reduction in the refresh rate or accuracy of object positions.

4.2 Application Programming Interface

The application programming interface (API) for the TViews platform is implemented in Java and runs on a computer housed inside the media table. It allows developers to create different kinds of tangible media table applications that

Functionality	Technologies for Interactive Tables						
	Optical		Electromagnetic		Acoustic		
	Vision-based object tracking	Infrared light curtain	Actuated RFID tag tracking	Multi-touch systems	Through-air ultrasonic triangulation	Through-glass tap tracking	Through-glass object tracking
Object Sensing							
Supports multiple objects	✓	✓	(Limited)	(Touch Only)	✓		✓
Avoids interference and occlusion		(Partially)	✓				✓
Scalable in size	✓	(Difficult)	(Difficult)	(Difficult)	✓	✓	✓
Object Management & Identification							
Global and extensible object IDs	(Difficult)						✓
Objects are portable	✓	✓					✓
Objects are customizable	(Difficult)		(Limited)				✓
Table Setup & Display							
Self-contained sensing		✓	✓		✓	✓	✓
Self-contained display		✓			✓	✓	✓

Table 1. Technologies for tangible media tables include optical, electromagnetic and acoustic approaches. Each technology has specific properties and capabilities with respect to its support for object sensing, object management and identification, and tangible media table setup and display. This table provides an overview of the most commonly used approaches.

make use of the combination of real-time object tracking and embedded display. The TViews software underlying the API keeps track of the incoming messages from the master control board and parses them into three main types of events: puck added, puck removed and puck metadata (e.g. position, button state, etc.) updated. The API employs a Java event model to distribute events to applications that have registered themselves as listeners. These events can be extended to incorporate additional event notifications to subscribing applications about user actions that make use of any external I/O devices that might be attached to a puck, such as a button press.

The TViews API is being extended to support bidirectional messaging, which will allow applications to send messages to or control specific properties for each puck. For instance, a puck used as a game piece might flash to draw attention to alert the player of their turn. Or if the puck is equipped with a small add-on display, the application might send a text, picture or video message to a puck. Future pucks might even contain actuators to allow them to move, vibrate, or provide haptic input or output.

5 Technical Approaches Compared

The need for display surfaces that can support multi-user media interactions in shared spaces has yielded a variety of technical approaches and prototypes. Our own prototype system helped us to identify the functional criteria for constructing tangible tabletop platforms, which can be grouped into three categories: (1) object sensing, (2) object management and identification, and (3) table setup and display. Table 1 provides an overview of the most commonly used technologies for interactive and tangible tables and shows the specific functionality enabled by each with respect to these categories. The last column indicates the TViews acoustic-based sensing approach. Below we compare of the strengths and limitations of these different techniques and briefly discuss their effects on application and game design.

5.1 Object Sensing

Precisely locating objects on the surface of a table is a difficult technical problem. The approaches tried have ranged across optical, acoustic or radio-frequency sensing. Many optical or acoustic approaches that are done through the air can pose problems of occlusion if one or more objects are blocking the view of a receiver or transmitter. In these cases, it becomes difficult to support multiple continuously interactive objects. Another problem that arises in object sensing is the scalability of the interactive surface in terms of size or shape. Approaches that use antenna grids rather than a small set of fixed receivers or transmitters generally require tiling in order to scale in size. This can be costly and result in additional complexity in the design of the electronics.

The technical approaches used for object sensing on tangible media interaction tables influence the choices that application designers can make when building for the platform. If the object sensing is not continuous or is subject to frequent interference, applications must not depend on the persistent presence of physical objects on the table. This does not necessarily pose a problem for turn-based games, where the current state of the system is saved at each player's turn. In a continuous simulation game however, it might be problematic for objects to intermittently disappear from the playing field. In this case, using the physical objects as handles that can be attached to virtual objects might provide an alternative approach. The design considerations for tabletop object sensing can be summarized as follows:

Supports multiple objects. The sensing surface is capable of continuously tracking multiple objects at once.

Avoids interference and occlusion. Multiple sensed objects do not interfere with one another. Hands or external objects placed in the interaction area do not affect the sensing mechanism.

Scalable in size. The sensing surface can be easily scaled to different sizes and aspect ratios.

5.2 Object Management and Identification

Tangible media tables face the challenge of dealing with large numbers of physical objects across many different applications and platforms. While unique identifiers and an extensible namespace are common within the digital realm, getting computers to uniquely identify objects in the physical world is a difficult problem. Technical solutions such as barcodes and Radio Frequency Identification (known as RFID tags) give physical objects a unique identity that can be understood by a computer. This unique identity is retained regardless of where you move the object in the physical space.

On a tangible media table, different interactive objects might have different physical properties or shapes depending on their application and use, such as figurines, buildings or dice in a game for example. For this reason, the objects need to be uniquely and digitally identifiable, and the means of object identification must function together with the table's position sensing technology. Moreover, users might want to move their interactive objects from one table to another, meaning that all tables need to have a shared understanding of how the objects are identified. Finally, if different types of objects are to serve unique purposes within different application environments, an interactive table should ideally provide a means for application designers to customize or tailor interactive objects to their particular applications in terms of physical form or functionality.

Certain technical approaches for tangible tabletops have not been able to provide adequate support for object identification and management. Optical-based systems have generally not been able to provide an easily extensible set of interactive objects, and customizations are difficult to manage or scale. Approaches that employ actuated RFID tags typically provide only a small set of interactive objects. For example Wacom's pen tablets provide only two pens, while Zowie's interactive toys provide nine tags which are the same for every toy. The design considerations for tabletop object management and identification can be summarized as follows.

Global and extensible object IDs. Each object is given a unique identifier that is global across an extensible namespace.

Objects are portable. The tagged objects can be moved from one interactive surface to another and retain their unique identity when moved.

Objects are customizable. The functionality of the tagged object can be easily expanded by adding user input and output elements such as sensors or displays on the objects themselves. The physical shape and form of objects can be customized.

5.3 Table Setup and Display

Many of the technical approaches to tangible media tables have required a large amount of external infrastructure, such as sensors placed around the room or overhead projectors to provide a visual display on the table's surface. While these systems work well for prototyping or demonstration purposes within a research laboratory, they are not viable options for use within a home or other real-world settings. Real-world use requires a system that can allow both the sensing and display technologies to be encased within the interactive table itself. Ideally, the table should be a single integrated unit that is not encumbered by too many wires or external connections, and that can be easily moved around a typical living room. The design considerations for table setup and display can be summarized as follows.

Self-contained sensing. The sensing mechanism can be fully contained within the table, requiring no external infrastructure such as cameras or separate antennas.

Self-contained display. A display mechanism can be integrated inside the table with the interaction surface, requiring no external infrastructure such as an overhead projector.

6 Tabletop Games

With the advent of digital games, designers have made extensive use of emerging technologies to enhance gameplay by immersing viewers into virtual worlds with stunning graphics and complicated artificial intelligence based rule engines. While many of these games can be played in a networked mode with thousands of players at a time, they no longer provide the face-to-face social interactions common to more traditional games, such as tabletop board games. With the increasing digitization of our everyday lives, the benefits of these separate worlds can now be combined, for example on digital media tables that provide tangible interaction. In this case, the table provides an embedded display and a computer that can mediate multi-player interactions with the game through physical playing pieces.

Our initial application development for the TViews table included several games, such as simple Pente implementation and a custom game called Springlets. More recently, we have been developing TTRPG, a tabletop role-playing game based on the Dungeons & Dragons rule-set.

6.1 Pente

TViews Pente was implemented to demonstrate digital board game play on the TViews table (see Figure 5). The game can be played with two or three players, and the goal is to place five stones in a row on the grid or to capture five pairs of

Fig. 5. TViews table game interactions: players engaged in a game of Pente (left) and the capture of a virtual Springlet with a button press (right).

an opponent's stones. Each player receives a puck, allowing them to drop stones onto the grid. There are three different pucks used for the game: yellow, red and blue. The yellow puck comes with a yellow removable plastic icon-cap on top, and it can place only yellow stones on the table. This behavior demonstrates how the pucks can be physically customized for a particular application, and how the physical shape of the interactive objects can be permanently linked to different meanings or functionality within the virtual space of the application.

During game-play, we noticed that players would identify with their own piece, often holding onto it even when they were not using it to make a move on the game-board. This identification with physical playing pieces can also be seen with traditional board games. In Monopoly for instance, some players can be very selective when choosing their playing piece, preferring to be a car rather than a thimble, or an iron rather than a race-horse. Moreover, if the red puck is moved to a different TViews table running the Pente application, it will retain its identity as a red puck in the game. In addition to the basic game features, Pente can be played in a networked mode from two different tables at once. In this case, each player's moves show up on both tables at the same time. For instance, two players in the game might be located at one table, while the third player is located at a different physically remote table. The idea of networked tabletop game-play could eventually be extended to include many existing networked games, such as online role-playing or simulation games.

6.2 Springlets

The Springlets game was designed as an example of visual improvisation on the TViews table. Two virtual spring objects (masses connected together with springs) can be controlled by the pucks, leaving colorful trails behind them as they bounce around the display area. Users latch onto the masses with a button press, and drag them around the table, causing the attached masses to follow behind (see Figure 5). A second button press drops the masses, propelling them forward on their own. Once the spring objects are in motion, they dance around the table and users can engage in improvisational play as they try to trap the masses in order to control the movement and display of the colorful trails on the display area.

Many players turned Springlets into a competitive form of game play, where they would try to capture the bouncing masses with their pucks, sometimes even using two pucks at a time (one in each hand). Since the game was not originally designed to be competitive, players invented their own methods for scoring and kept track of the scores by shouting them aloud as they played. We also observed that players would frequently try to coordinate their movements with those of other players in order to gain a competitive edge. The TViews sensing technology will need to undergo additional refinement in order to support the rapid movements required by this form of gameplay. In the current implementation, there are two main sources of positioning inaccuracy. The first results from poor contact of the acoustic sensor to the surface of the glass, which can happen when players make sudden movements. The second inaccuracy is a lag in position updates if a puck is moved too quickly. We are continuing to further develop the TViews pucks to address these issues, and are testing possible solutions that would use non-contact or point-contact acoustic sensors. Furthermore, the position estimation algorithm is currently implemented in Java, which is marginally too slow to keep up with the calculations required to estimate in real-time the positions of all the pucks on the table when they are being moved around rapidly. A low-level system driver optimized for real-time performance should help in resolving this problem.

6.3 TTRPG

Still in the early stages of development at this date, TTRPG (TViews Table Role-Playing Game) explores the creation of digital tabletop role-playing games on the TViews table. The goal is to bridge the separate worlds of traditional table-based RPGs with the growing area of massively multiplayer online role-playing games. The game is based on the original Dungeons & Dragons rule-set and follows the traditional form of play, in which a Game Master helps coordinate the game-play for multiple players and also provides an improvised narrative as the game unfolds. The players at the table manipulate tangible objects that represent their characters (fighter, wizard or rogue) and other game objects such as a selection tool and options circle. Play on the tabletop environment consists of three different modes: character selection, free play, and fight.

So far, players have responded positively to the TTRPG concept, finding the game to be entertaining and the interaction with other players engaging. They commented that playing a role-playing game with real people at the table is more enjoyable than on a computer with other people they can't see. The tabletop format requires players to work together, and verbal and physical interactions are often necessary to move the game forward. For example, in a situation where players need to find their way out of a room, they must talk with each other in order to determine an appropriate plan of action. Early player feedback has revealed a number of ways in which the physical gameplay objects could be improved. For example, rather than providing an options circle for the selection of player moves, this could be accomplished using the character pawns themselves. In this case, the pawns might utilize the TViews extensible I/O features, perhaps by providing a dial and button to scroll through and select player actions. Miniature display screens on the pawns could be used to provide feedback about the results of game moves. Further developments for the system include a richer set of objects and interactions, improved visuals and a networked mode for gameplay across remotely located TViews tables.

7 Conclusion

We have presented the TViews architecture, an economic and scalable sensing architecture for tangible media tables. The system allows a broad range of games and an extensible set of interaction objects to be designed and run across multiple tables, alone or in a networked mode. Through tangible interactions on a shared display, the face-to-face sociability of traditional board games can be combined with the computational power, high-end graphics and vast player community of today's digital and online game worlds.

With an extensible method for tangible media table creation and a straightforward API for development, we hope to continue building the community of developers who can design and create games for the TViews platform. We have presented a few of our initial game designs and player interactions, and we plan to create many more. Together with the design of new games and media content applications, we hope to continue refining the sensing technology of the TViews table. We also hope to push forward the design of the tangible interaction objects themselves, by providing custom shapes for specific games and by incorporating additional add-on elements such as sensors or small displays to enhance the gameplay.

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