Tangible imaging systems

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ABSTRACT

We are developing tangible imaging systems[1-4] that enable natural interaction with virtual objects. Tangible imaging systems are based on consumer mobile devices that incorporate electronic displays, graphics hardware, accelerometers, gyroscopes, and digital cameras, in laptop or tablet-shaped form-factors. Custom software allows the orientation of a device and the position of the observer to be tracked in real-time. Using this information, realistic images of three-dimensional objects with complex textures and material properties are rendered to the screen, and tilting or moving in front of the device produces realistic changes in surface lighting and material appearance. Tangible imaging systems thus allow virtual objects to be observed and manipulated as naturally as real ones with the added benefit that object properties can be modified under user control. In this paper we describe four tangible imaging systems we have developed: the tangiBook – our first implementation on a laptop computer; tangiView – a more refined implementation on a tablet device; tangiPaint – a tangible digital painting application; and phantoView – an application that takes the tangible imaging concept into stereoscopic 3D.

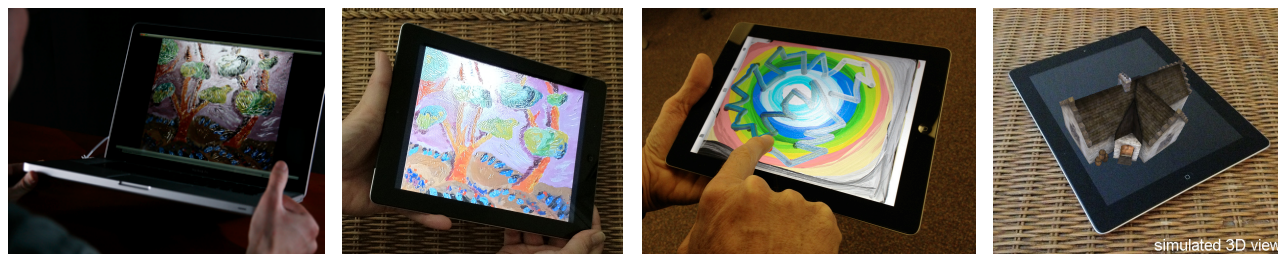**Keywords:** augmented reality, tangible user interfaces, 3D interaction, 3D displays

Figure 1: Tangible imaging systems (left to right): The first generation tangiBook system developed using an off-the-shelf laptop computer; the tangiView system implemented on a tablet device; the tangiPaint application that allows the creation of paintings with rich surface properties; the phantoView system that allows tangible interaction with three-dimensional object models.

1. INTRODUCTION

When an observer interacts with an object they typically engage in a complex set of behaviors that include active manipulation and dynamic viewing. These behaviors allow the observer to experience how the object looks from different perspectives and under different lighting conditions. This experience provides rich visual information about the object's shape and surface properties.

Modern computer graphics methods provide the ability to render realistic images of the shapes and surface properties of complex objects at interactive rates. This has enabled great advances in fields such as digital cinema, computer gaming, medical imaging, and cultural heritage archiving. However in standard interactive graphics systems, the observer is always one step removed from the object. Viewing is typically of an image on a screen, and interaction is typically mediated through interface devices such as keyboards and mice.

We are developing *tangible imaging systems*[1-4] that merge the power of computer graphics with the direct interaction capabilities of modern mobile devices to create rich digital representations of three-dimensional objects that can be viewed and manipulated as naturally as real ones, with the added benefit that the shapes, surface properties, and lighting of the objects can be changed under user control. Figure 1 shows examples of the four systems we have developed that will be reviewed in this paper: tangiBook – our first implementation of the concept on a laptop computer; tangiView – a

more refined implementation on a tablet device; tangiPaint – a tangible digital painting application that allows users to directly create paintings with rich surface textures and material properties; and phantoView – an implementation that takes the tangible imaging concept into stereoscopic 3D.

2. RELATED WORK

There has been a strong interest in developing natural interfaces for interacting with virtual objects since Sutherland and colleagues' pioneering work on see-through head-mounted displays (HMDs) and 3D input devices[5,6]. Significant advances have been made since that time in both HMDs[7-9], and 3D input[10-12] for virtual environments.

An alternative approach to support direct interaction with virtual objects is represented by the CAVE system[13] that surrounds users with projection screens that display the virtual content. Stereoscopic rendering and eyewear, and user head-tracking and gesture interfaces have been added to increase feelings of "immersion". Further innovations in projection-based approaches include the shaderLamps and iLamps systems[14-16] as well as projects by Bimber and colleagues[17]. In these systems pre-warped images are projected onto real three-dimensional objects to create physical objects whose appearance can be changed under computer control.

A third major approach to bridging real and virtual worlds incorporates spatially aware displays and tangible interfaces. The Chameleon systems[18,19] coupled 6 DOF trackers with computer displays to create a spatially aware display whose content changes depending on its context and position. The Virtual Mirror system[20] took the spatially aware display concept one step further by incorporating a video camera pointed toward the user to create the impression of a real mirror. The device also allowed interactive viewing of reflective daguerreotype images[21]. A significant feature of these systems is the capability to grasp and directly manipulate the display to change the viewpoint on the virtual environment. The virtue of tangible interfaces such as these, is that the affordances of the systems (lifting, tilting, and rotating the display) support rich and natural modes of interaction with the virtual objects[22,23].

3. THE TANGIBOOK

To recreate the experience of interacting with real objects, tangible imaging systems require two main capabilities: realistic rendering of virtual objects, and direct tracking of user interaction (both manipulation and viewing). Our goal in designing the tangiBook was to create a proof-of-concept tangible imaging system that supported these goals. The tangiBook was based on an off-the-shelf laptop computer (Apple MacBook Pro) that incorporated all the necessary components. The laptop's high-resolution LCD display screen backed by graphics rendering hardware and software supported realistic rendering, and its built-in accelerometer and camera were used to support direct object manipulation and user tracking. The following paragraphs detail how these components were harnessed to create the system.

Since we were engaged in a project to create rich digital representations of fine art, for the tangiBook project we choose to focus on modeling and rendering paintings. Paintings are true three-dimensional objects that often have complex

Figure 2: The tangiBook system – tilting the display (top row) or moving in front of it (bottom row) produces realistic changes in the appearance of the rendered surface.
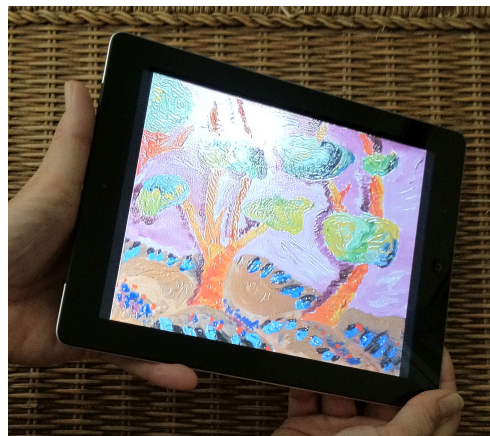

Figure 3: tangiView – an implementation of the tangible imaging concept on a tablet device. The natural form-factor facilitates direct interaction.

surface textures and material properties, but they are also near-flat and can be rendered so they appear coincident with the display screen. We model a painting's geometry as a tessellated polygon in three-space and use normal maps[24] captured with 3D scanners to represent surface texture. Surface colors and gloss values derived from reflectance data are represented using the Ward light-reflection model[25]. A custom GPU-based surface shader implemented using OpenGL[26] provides real-time rendering of the painting model under different lighting conditions. Both point light and illumination-mapped lighting environments are supported.

To enable direct interaction, both the orientation of the display and the relative positions of the display and user need to be tracked. To achieve this we use the laptop's accelerometer hardware and the SMSLib software library[27] to establish a gravity-referenced coordinate framework for the laptop. We then calculate the 3D pose of the display screen relative to this framework. We track the user's head position relative to the display using the laptop's built-in webcam and the head tracking functions in the OpenCV software library[28]. Lighting for the painting model is defined with respect to the gravity-fixed coordinate system, so tilting the laptop's screen or moving relative to it produces realistic changes in surface shading and the movement of glossy highlights.

The capabilities of the tangiBook system are illustrated in Figure 2. The images show a three dimensional model of an oil painting being rendered in real-time to the laptop's display screen. The surface normal maps and light reflection model used in conjunction with the OpenGL shader provide realistic surface color, shading, and highlights for the pose of the painting relative to the virtual lighting environment. The images in the top row in Figure 2 show how tilting the screen/painting produces realistic changes in surface appearance. The images in the bottom row show the corresponding changes that occur when the observer moves relative to the screen/painting. Taken together the realistic rendering and direct interaction capabilities of the system provide an experience that is similar to interacting with the real painting.

4. TANGIVIEW

While the capabilities of the tangiBook and the experience it provides are novel and compelling, the laptop-based implementation is awkward, since one has to manipulate the whole device to interact with the system. Tablet computers provide a much better form-factor for developing tangible imaging systems since they are typically lighter and are shaped much more like the nearly-flat surfaces the system is typically used to simulate.

Our port of the system to an Apple iPad 2 tablet computer (which we called tangiView) is shown in Figure 3. All the rendering and display capabilities are the same as those of the tangiBook system. In the implementation shown, only accelerometer-based surface orientation tracking is implemented, since the processing power of the device is limited, and the field of view of the front-facing camera is too small to support observer face/position tracking under typical use conditions However there is no reason that with more processing power and wide-field camera optics this feature could not be implemented in future versions of the system.

The tangiView implementation also improves on the versatility of the system for simulating different surfaces by providing a standard format for surface models in which surface textures and material properties are represented as four standard 24-bit RGB images, with one each used to code surface normals, diffuse colors, specular (gloss) intensity, and specular (gloss) dispersion. New surface models coded in this way can be loaded using standard Apple iOS photo library applications.

5. TANGIPAINT

Given the direct touch interaction capabilities of tablet devices, we thought an exciting possibility would be to develop an application that would allow users to create tangible content rather that just view existing models. This application, known as tangiPaint, allows users to create virtual "oil paintings" using their fingers on the tablet's touch screen. All the rendering and direct manipulation capabilities of the tangiView system are included, but users can select different textured "canvases" to paint on, and can work with "paints" and "brushes" that can produce realistic-looking paintings with complex variations in surface color, gloss, and texture.

To simulate the experience of working with real artist's materials we scanned paper and canvas samples and used normal maps to model their surface textures. We simulated the painting process using paint/brush/substrate models inspired by the work of Baxter et al.[29] that interact to produce realistic stroke behavior. To start, the color and gloss properties of the paints can be selected through a color/material dialog. Brushes of different sizes and shapes can then be selected and loaded with different quantities of paint. Dragging a brush/finger across the screen will then deposit the paint on the
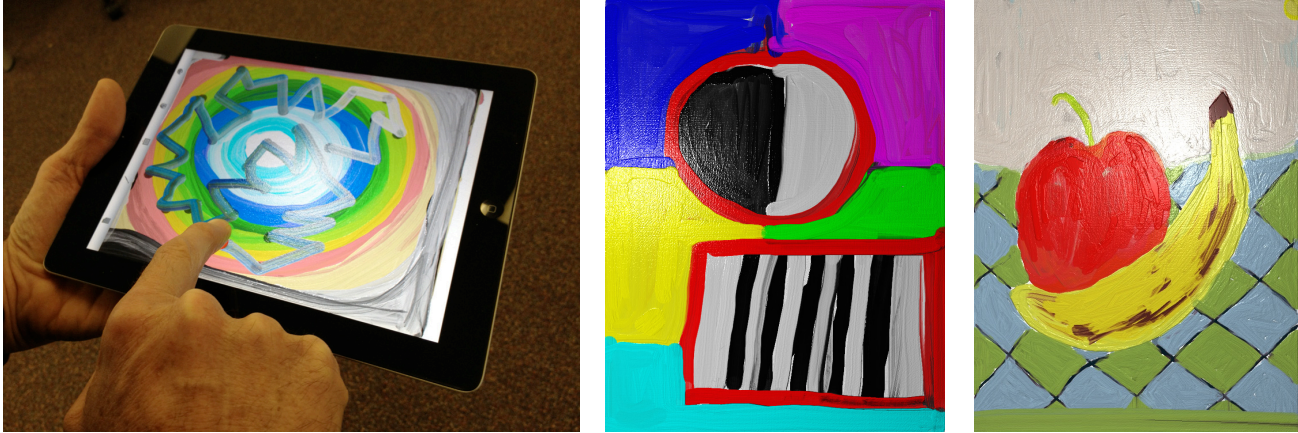
Figure 4: tangiPaint – With a finger on the tablet users can create digital "oil paintings" that have rich three-dimensional surface textures and material properties. Tilting the tablet changes the lighting on the painting to reveal these features.

canvas. A stochastic 3D brush model spreads the paint with realistic texture and color effects that include layering, mixing, run-out, and interactions with the canvas. Paintings can saved for later re-working and/or exported in a 4xRGB format similar to that used in the tangiView application. Paintings can also be "dried" and exported in standard image formats to the iOS photo library.

Figure 4 shows screenshots of the tangiPaint system in action and some paintings created with the system. Note the mixing of the colors, the glossy highlights and the textures of the brush strokes. The screenshots also show that the tangiPaint system incorporates the key capabilities of our other tangible imaging systems. Thus by tilting the device the artist can change the relationship between the digital painting and the virtual light source that illuminates it. The artist can also re-position the light source with a simple hand gesture akin to moving a real light source. We believe the tangiPaint system represents a significant first step toward developing digital painting tools that allow artists to work with digital media that look and behave like real materials.

6. PHANTOVIEW

The tangible imaging systems described above have been well received, but a frequent question has been - "Could the systems be used to interact with three-dimensional objects?" At one level the question misses the point that the surfaces being displayed do have three-dimensional properties, that in fact provide the rich appearance properties of the renderings, but at another level the question raises the interesting issue of whether tangible interfaces could be developed to allow direct interaction with three-dimensional "objects" in addition to three-dimensional surfaces.

To explore this issue we have developed an tangible imaging application called phantoView that supports direct interaction with digital models of three-dimensional objects. As with the tangiView and tangiPaint systems, phantoView takes advantage of the form-factors, graphics, and tracking capabilities of tablet devices (in the case shown, an Apple iPad 2), to render the objects and support interaction. The unique feature of phantoView is its use of a special kind of stereoscopic rendering known as a phantogram[30] to create compelling 3D visualizations of the objects.

The principles of phantograms are shown in Figure 5. Like other stereoscopic renderings, separate images are created to represent views of the object that would be seen by an observer's left and right eyes. Like standard anaglyphs, the left/right views are composited into a single image using red/blue coding, and the image is viewed by an observer wearing glasses with corresponding red/blue filters. However the key attribute of phantograms is that the perspective projection used to create the image is off-axis, which means when the images are viewed off axis as shown in the Figure, the object appears to sit on the image plane rather than being seen in the virtual space behind it.

Figure 6 illustrates the phantoView application in action (the views of the object are simulated because of the problems of photographing anaglyphs). To begin, an object model is loaded from standard Wavefront OBJ file. A phantogram of the first object is then rendered to the screen in real-time. To see the object from different viewpoints, the user simply rotates the tablet around a vertical axis. The experience is of directly manipulating an object that is sitting on the tablet.
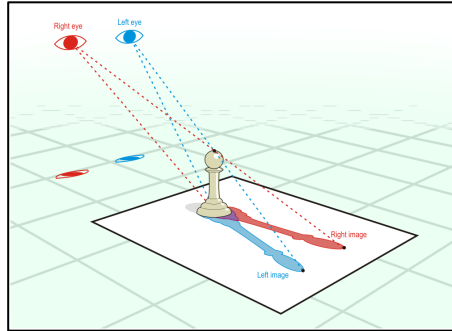
Figure 5: Principles of phantogram anaglyphs – off axis stereoscopic projection and viewing cause the virtual object to appear to be situated on the image surface.[30]

Figure 6: The phantoView system – 3D object models loaded into the system are rendered in real-time as phantograms to the tablet's display. A rendered object appears to be sitting on the tablet's surface. Rotating the tablet about the vertical axis allows the object to be seen from other viewpoints.

A pinch gesture scales the object. A two-finger swipe changes the azimuth and elevation of the scene lighting. A single-finger swipe switches between loaded object models. The phantoView application provides a unique new tool that allows tangible interaction with virtual objects.

7. CONCLUSION

We are developing tangible imaging systems that merge the power of computer graphics with the direct interaction capabilities of modern mobile devices to create rich digital representations of three-dimensional objects that can be viewed and manipulated as naturally as real ones, with the added benefit that the shapes, material properties, and lighting of the objects can be changed under user control. We believe tangible imaging systems provide a powerful and meaningful new approach to merging the real and virtual worlds. There is still much work to be done in to develop this technology, but the systems described in this paper represent some promising first steps. At the time of writing, versions of some of the applications described are available at www.tangibleimagingsystems.com.

ACKNOWLEDGEMENTS

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