The tangiBook: A Tangible Display System for Direct Interaction with Virtual Surfaces

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Figure 1: *Image sequence showing a painting model being displayed on the tangiBook. The tangiBook is based on an off-the-shelf laptop computer that incorporates an accelerometer and a webcam as standard equipment. Custom software allows the orientation of the laptop screen and the position of the observer to be tracked in real-time. Tilting the laptop (as shown) or moving in front of the screen produces realistic changes in surface lighting and material appearance.*

Abstract

In this paper we introduce the tangiBook, a tangible display system that allows realistic simulation and direct interaction with virtual surfaces. The tangiBook is based on an off-the-shelf laptop computer that incorporates an accelerometer and a webcam as standard equipment. Custom software allows the orientation of the laptop screen and the position of the observer to be tracked in real-time. Using this information, realistic images of surfaces with complex textures and material properties, illuminated by environment-mapped lighting, are rendered to the screen at interactive rates. Tilting the laptop or moving in front of the screen produces realistic changes in surface lighting and material appearance. Thus the tangiBook allows virtual surfaces to be observed and manipulated as naturally as real ones, with the added benefit that the material properties of the surfaces can be changed in real-time. We demonstrate the potential utility of the tangiBook in three application areas: material perception research, computer-aided appearance design, and enhanced access to collections in digital libraries and museums. With its unique capabilities and commodity roots, the tangiBook can be broadly deployed and should be useful in a wide range of applications.

Introduction

Advances in computer graphics technology have provided the capabilities for realistic image synthesis, allowing images of virtual objects to be rendered that are indistinguishable from photographs of real-world objects [1]. The ability to create realistic renderings of virtual objects has proven to be valuable in a variety of application domains including the film and game industries, computer-aided design and manufacturing, medical imaging and digital libraries and museums.

With standard computer graphics systems, a user is a step removed visually and physically from the virtual objects they are interacting with. The screen acts as a window separating the real and virtual worlds, and the user does not interact directly with the virtual objects, but instead uses indirect means, such as a mouse or keyboard, to manipulate the objects or shift the point of view.

Our objective is to remove these barriers between the real and virtual worlds by developing a tangible display system, which we call the tangiBook, that gives users much of the same experience they would have if the virtual object were situated in a real environment (see Figure 1). Instead of providing a view into a virtual world, this system presents the virtual object, situated in the real world, at the physical location of the display. It supports natural interaction with the object, through direct manipulation of the object's orientation by rotating the display, and dynamic viewpoint changes through observer tracking.

The tangiBook is based on an off-the-shelf laptop computer that contains a triaxial accelerometer and a webcam as standard components. Through custom software that integrates these devices, we are able to actively sense the orientation of the laptop display and dynamically track the observer's viewpoint with camera-based head-tracking. This information is used to drive a physically-based rendering algorithm that generates an accurately oriented and realistically shaded view of a virtual surface to the laptop's display. The custom rendering system also allows the user to change the material properties of the rendered virtual surface in real-time, a capability that allows the tangiBook to be used in psychophysical experiments and computer-aided appearance design applications.

Related Work

There has been a strong interest in developing natural interfaces for viewing virtual objects and scenes since Sutherland and colleague's pioneering work on the design of a see-through

head-mounted display (HMD) and 3D input wand in the 1960's and 1970's [2, 3]. Significant advances have been made in both display systems [4, 5, 6], and 3D input devices [7, 8, 9] for virtual environments. The focus in these systems is on immersing a user in a virtual world delivered through a HMD.

An alternative approach is represented by the CAVE system [10] that surrounds a user with projection screens on which virtual content is displayed. Further innovations in this projection-based approach include the shaderLamps and iLamps systems [11,12, 13] that project pre-warped images on real three-dimensional objects to create physical objects whose appearance can be changed under computer control. Bimber and colleagues have also been early innovators in this area (see [14] for a comprehensive review).

A third major approach to bridging real and virtual worlds incorporates spatially aware displays and tangible interfaces. The Chameleon systems [15,16] coupled 6 DOF trackers with computer displays to create spatially aware display systems whose content changes depending on its position and context. The Virtual Mirror system [17] took the spatially aware display concept a step further by incorporating a video camera pointed toward the user holding the display to create the impression of a real mirror. The device also allowed interactive viewing of reflective daguerreotype images [18]. 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 affordances of the object (in these cases lifting, tilting, and rotating the display) support rich and natural modes of interaction with the virtual world.

System Design

Our objective in designing the tangiBook was to create a low-cost-of-entry tangible display system for interacting with virtual surfaces. The tangiBook is based on an off-the-shelf laptop computer (Apple MacBook Pro) that incorporates all the components necessary to create a tangible display system: an LCD display, an accelerometer, and a webcam. The accelerometer is used to estimate the orientation of the display, and the camera provides a means to estimate the observer's viewing position with computer vision-based head tracking. This information is used within a custom 3D shader to dynamically render a realistically shaded view of the virtual surface to the laptop's display. By integrating these components in a custom software system, virtual surfaces can be observed and manipulated in the same manner as real surfaces, such that tilting the laptop or moving in front of the screen produces realistic changes in surface appearance. An additional capability is that the material properties of the virtual surface can be changed in real-time. In the following sections we describe the implementation of each of these capabilities.

Interaction

Coordinate System

Two coordinate systems are used for performing calculations and representing interactions with the tangiBook system (Figure 2). The first is the world coordinate system, where the **x**, **y**, and **z** axes remain fixed relative to the physical direction of gravity. The second is the laptop-object coordinate system **uvw**, which is affixed to the laptop and has its axes defined by the directions
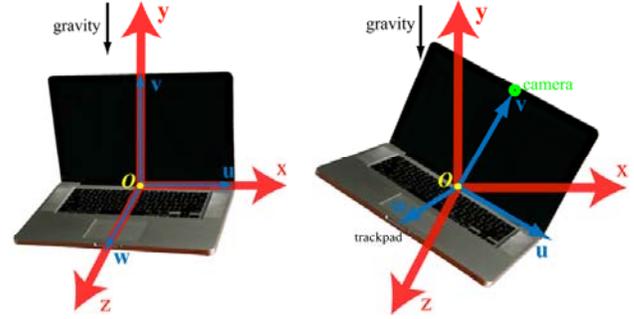
Figure 2: The ***xyz*** *axes define a world coordinate system that is fixed with respect to gravity. The **uvw** axes define an object space coordinate system that is fixed with respect to landmarks on the laptop (the directions along the screen-base hinge, from the origin to the webcam, and origin to trackpad). Left, the two coordinate systems are aligned in the laptop's initial state. Right, the laptop has been rotated relative to the world coordinate system.*

between landmarks of the laptop. With the screen adjusted to be at a right angle to the base, an orthogonal set of axes is formed with the **u** axis defined by the intersection of the laptop screen and base, the positive **v** axis by the direction from the bottom to the top of the screen, and the positive **w** axis by the direction from the base of the screen to the trackpad.

With the laptop in its initial state, resting on a horizontal surface (Figure 2, left), the laptop's **uvw** axes are aligned with the **xyz** axes of the world coordinate system. As the laptop is manipulated, the **uvw** axes are rotated relative to the **xyz** axes (Figure 2, right). Because the system does not track translation of the laptop, it is convenient to maintain a common origin point between the two systems and represent orientation changes as rotations relative to that origin.

Orientation tracking

The orientation-tracking component of the system provides information on how the laptop screen has been rotated by the user. Tracking is implemented using the accelerometer in the laptop's Sudden Motion Sensor (SMS) and the open source SMSLib library [19]. The SMS accelerometer provides the necessary information for tracking the laptop's orientation (relative to the world) by relating the laptop's three affixed axes (**u, v,** and **w**) to the direction of gravity (the **y** axis of the world coordinate system).

Data from the SMS define a vector **s** that has known coordinates in both the **uvw** and **xyz** systems. The three coordinates (u_s, v_s, w_s) of **s** in **uvw** are reported by the sensor, and are known to correspond to the **y** axis, $(x_s, y_s, z_s) = (0, 1, 0)$, of the world coordinate system. The **xyz** coordinates of this laptop-affixed vector are also known for the initial state, prior to any rotation (represented by a vector **r**). Because the two coordinate systems are aligned for the initial state, the vector **r** has the same (x,y,z) components as **s** has (u,v,w) components:

$$\mathbf{r} = (x_r, y_r, z_r) = (u_s, v_s, w_s). \qquad (1)$$

The relationship between **r** and **s** in **xyz** is used to calculate a 4 x 4 matrix **R** that defines the current orientation of the laptop-object frame in terms of world coordinates (the underlying mathematics can be found in [20]). The **xyz** space homogeneous coordinates of

the laptop's three axis vectors in their initial state, $\mathbf{u_0} = (1,0,0,0)$, $\mathbf{v_0} = (0,1,0,0)$, and $\mathbf{w_0} = (0,0,1,0)$, are multiplied by $\mathbf{R}$ to specify the laptop's current orientation in world coordinates:

$$\mathbf{u} = \mathbf{R}\mathbf{u_0}, \; \mathbf{v} = \mathbf{R}\mathbf{v_0}, \; \mathbf{w} = \mathbf{R}\mathbf{w_0}. \qquad (2, 3, 4)$$

A limitation of using a triaxial accelerometer like the SMS to track orientation is that it is invariant to rotations around the axis aligned with gravity (**y**-axis). This limitation is partially overcome by dynamic viewpoint tracking, which responds to changes in the viewing angle between the eye-point and screen normal as the laptop is rotated. This maintains some dynamic interactivity, though of a different kind, for rotations around the y-axis.

Viewpoint tracking

Webcam-based viewpoint tracking is used in conjunction with orientation tracking to provide enhanced 3D interactivity. As the observer moves, the head tracking system estimates the observer's viewing position relative to the laptop. This information, along with information about the camera's orientation and position determined from orientation tracking, is used to estimate the position of the eye-point in world coordinates.

The position of the head center and the head radius in each webcam image is determined using Lienhart's Haar cascade algorithm from OpenCV [21]. The location of the eye-point in the image is estimated by offsetting the head center position by a percentage of the head radius. The size of the head radius in the image is also used as an approximate method for estimating the physical distance of the viewer from the laptop.

The first step in estimating the 3D world coordinates of the eye-point from the camera data is to determine the camera's position in **xyz.** The physical distance from the origin point to the camera, d_{cam}, has been measured, and the camera falls on the **v**-axis (Figure 3), allowing the camera position ($\mathbf{p}_{cam}$) to be found by:

$$\mathbf{p}_{cam} = d_{cam}\mathbf{v}. \qquad (5)$$

Starting from the camera position, the eye-point position in 3D space is determined from the camera tracking data using an ideal pinhole camera model (see [22] for a description of camera models for computer vision). The distance along the camera's principal ray to the perpendicular plane containing the eye-point is estimated from the size of the viewer's head radius in the camera image, $d_{rad,pix}$. Using the effective focal length of the camera in image pixels (f_{pix}), calculated from calibration data, and an estimate of the physical vertical radius of the viewer's head ($d_{rad,cm}$), the distance along the principal ray to the plane ($d_{plane,cm}$) is determined from the head size in the image using the pinhole camera equation:

$$d_{plane,cm} = d_{rad,cm}\left(f_{pix}/d_{rad,pix}\right). \qquad (6)$$

The position in world coordinates where the principal ray intersects the plane containing the eye-point is found by moving along the principal ray direction (which corresponds to the **w**-axis) a distance $d_{plane,cm}$ from the camera:

$$\mathbf{p}_{pr,plane} = \mathbf{p}_{cam} + d_{plane,cm}\mathbf{w}. \qquad (7)$$
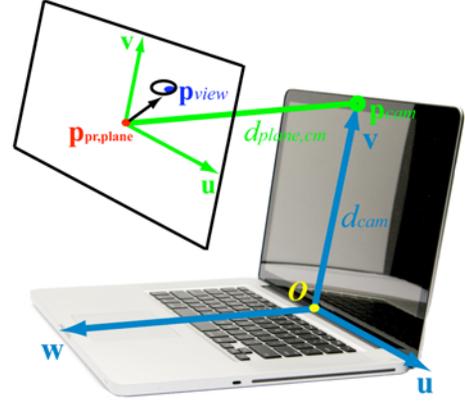
Figure 3: *Diagram of the geometry for viewpoint tracking. The camera position ($\mathbf{p}_{cam}$) is located a known distance (d_{cam}) from the origin along the v axis of the laptop coordinate system. The principal ray emanating from the camera points in the same direction as the w axis. The point $\mathbf{p}_{pr,plane}$, where the principal ray intersects the perpendicular plane containing the eye-point, is found by moving along the principal ray a distance, $d_{plane,\,cm}$, determined from the pinhole camera equation. The viewpoint ($\mathbf{p}_{view}$) is found by moving away from the intersection point in the u and v directions, based on the offset of the eye-point in the captured image relative to the image center.*

In the final step, the position of the eye-point in the camera image is used to determine the eye-point position in the world. The up-vector of the camera coincides with the direction of **v**, and is the physical direction corresponding to a vertical offset from center in the camera image. The **u** vector is the physical direction corresponding to a horizontal offset from center in the camera image. The eye-point offsets in image pixels are scaled to physical units using the pinhole camera equation and are applied as physical offsets from the principal ray-plane intersection point, giving a final viewing position, $\mathbf{p}_{view}$, of:

$$\mathbf{p}_{view} = \mathbf{p}_{pr,plane} + d_{plane,cm}\left(\left(x_{img,eye} - x_{img,ctr}\right)/f_{pix}\right)\mathbf{u} \\ + d_{plane,cm}\left(-\left(y_{img,eye} - y_{img,ctr}\right)/f_{pix}\right)\mathbf{v} \qquad (8)$$

Modeling and Rendering

Using the orientation and viewpoint tracking information, the tangiBook renders a realistically shaded view of a virtual surface to the laptop's display. The virtual surface is modeled in such a way that it appears to be at the physical location of the laptop screen, and it is rendered from a camera position that makes it respond to orientation and viewpoint changes as a physical surface would.

Surface modeling (geometry, texture, material)

The geometry of the virtual object is modeled as a rectangular surface that coincides with the physical surface of the laptop screen in the world coordinate system. The surface normal for the rectangular virtual object is aligned with the **w** axis. Spatially varying object-space normal maps are used to adjust this surface normal to provide mesoscale texture [23]. The (*ix,iy*) image positions of the map are associated with locations on the surface by anchoring the corners of the map image to the object vertices. At each (*ix, iy*) image position, the object space normal map provides

a set of scalars describing the mesoscale normal in **uvw** coordinates ($u_{map(ix,iv)}$, $v_{map(ix,iv)}$, $w_{map(ix,iv)}$). After applying the map, the spatially varying normal vector for the object's surface ($\mathbf{n}_{(ix,iv)}$), in world coordinates, becomes:

$$\mathbf{n}_{(ix,iy)} = u_{map(ix,iy)}\mathbf{u} + v_{map(ix,iy)}\mathbf{v} + w_{map(ix,iy)}\mathbf{w}. \tag{9}$$

In addition to mesocale texture, spatially varying material properties can also be specified for the virtual object. The diffuse, specular, and roughness properties of the material are specified by a set of maps corresponding to the three components of the Ward BRDF model [24]: ρ_d, ρ_s, and α.

Illumination and Shading

A custom OpenGL shader was developed to render the object's surface with its specified material properties and mesoscale texture. The surface is shaded to show the reflections that an observer would see from his or her current viewing position, for the laptop's current orientation relative to virtual environmental illumination. Our shader, based on the Ward model shader described by Rost [25], implements an isotropic form of the Ward model:

$$\rho_{brdf}\left(\theta_i,\phi_i,\theta_r,\phi_r\right) = \frac{\rho_d}{\pi} + \rho_s \frac{1}{\sqrt{\cos\theta_i \cos\theta_r}} \frac{e^{-\tan^2\left(\theta_h/\alpha^2\right)}}{4\pi\alpha^2} \tag{10}$$

where ρ_d is the diffuse reflectance parameter, ρ_s is specular reflectance, α is the standard deviation of surface slope, and θ_h is the angle between the surface normal vector (**n**) and the halfway vector (**h**) defined by the bisector of the surface-to-light source and surface-to-viewing point vectors. θ_i represents the angle between the surface normal and a vector from the surface to a light source. θ_r is the angle between the surface normal and the vector to the viewing position.

Shading calculations are performed in the **xyz** world coordinate system. The known laptop-object space positions of the surface's vertices are transformed into world coordinates in the vertex shader, and the resulting interpolated positions of the surface fragments in **xyz** coordinates are sent to the custom fragment shader where the reflectance calculations are performed. Each interpolated surface position is subtracted from the tracked viewing position, $\mathbf{p}_{view}$, to find the Ward model's surface-to-viewing point vector. The surface normal at each fragment position is found using the object-space normal map and the **u**, **v**, and **w** vectors from orientation tracking. The properties of the material are provided to the shader with either single values of ρ_d, ρ_s and α to describe a surface with uniform properties, or maps of these parameters are provided to specify values at each fragment position to describe materials with spatially varying BRDFs.

Two methods are available in the shader for illuminating the surface. For applications where complex patterns of illumination are critical, such as soft-proofing of a glossy print, the surface is illuminated with image-based cubic environment maps [26]. The surface normal and the direction from the surface to viewpoint are used to calculate the direction of the specular reflection. A small number of angles around the specular reflection direction are then uniformly sampled, used to index the cubic environment map to find the illumination color at that location, and the contribution of

each to the overall sum, based on its direction, is calculated with the Ward model. A diffuse cubic map of the environment is also used and indexed by the surface normal. The amount of diffuse light reflection is weighted relative to specular reflectance and the light from the two is summed to determine the fragment color.

Due to sparse sampling of the specular lobe, the reflections calculated using the environment map technique may not be accurate enough for certain applications, such as psychophysical testing. In this case, a discrete set of lights specifying the direction and color of points of illumination may be used.

Viewing Position for Rendering

When rendering to the display, we want to treat it as a physical object with virtual material properties and not as a window into a virtual scene. The key is to use a different viewing position for calculating the fragment colors in the shader than is used for rendering the surface to the screen's viewport. When shading, the dynamically-tracked viewing position and its true relationship to the laptop's current orientation needs to be used to calculate the light reflecting toward the viewer from each position on the virtual object's surface. However, a different viewpoint must be used for rendering. To treat the display as a physical object, the virtual object's surface must stay affixed to the viewport on the screen. This requires that the camera point for rendering always remains a fixed distance from the virtual object's surface, along a ray normal to the object that intersects the center of the object's surface.

System Capabilities

The tangiBook system provides a unique set of capabilities that create a powerful and flexible tangible interface tool for interacting with virtual objects. These capabilities are described in the following sections.

Dynamic interaction

As shown in Figure 1, the tangiBook supports dynamic, natural interaction with virtual surfaces. As the laptop is manipulated by the user, the changes in its physical orientation are tracked and used to dynamically update the rendering of the virtual object. The updated rendering displays the surface reflections for the virtual object's new orientation relative to the specified lighting environment. As the laptop is tilted from its orientation in the left image (of Figure 1) to its orientation in the far right image, the painting's surface catches the reflection from one of the virtual lights when the change in the direction of the painting's surface normal causes the viewing position to near the specular angle with respect to the light's position.

Dynamic viewing

The tangiBook also provides the capability to dynamically track the observer's viewing position relative to the display and update the rendered image accordingly. As shown in Figure 4, as the viewer's head position moves relative to the display, the rendered reflections off the painting's surface change to reflect the new relationship between the viewpoint, surface normal, and the virtual illumination environment.

Figure 4: *Dynamic viewing: The three screenshots illustrate the dynamic viewpoint control capabilities of the tangiBook. The insets show the output of the webcam-based headtracking software as the observer moves from left to right. The large images show the corresponding movement of surface reflections.*

Dynamic control of material properties

The tangiBook provides dynamic control of material properties specified in terms of the diffuse reflectance, specular reflectance, and roughness of the object's surface. These parameters can be adjusted dynamically, while the user is interacting with the virtual surface, and will immediately produce changes to the surface's appearance. This is demonstrated in Figure 5, where the material being rendered is changed from matte to glossy while the tangiBook is actively being used.
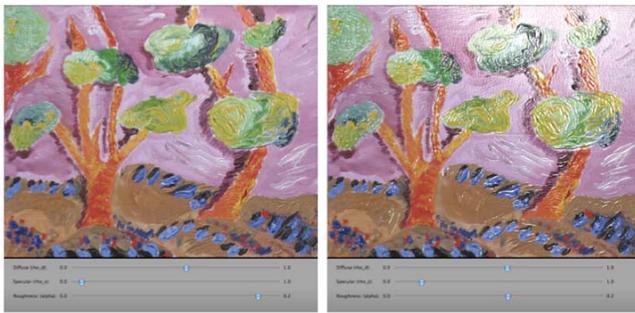
Figure 5: *Dynamic control of material properties: The two renderings of the painting illustrate the tangiBook's ability to dynamically change the material properties of a displayed surface. The surface on the left has a relatively low specular reflectance (ρ_s) and a high roughness (α) giving a matte appearance. Using the sliders, these two parameters have been altered in the surface on the right to produce glossy reflections.*

Applications

The unique capabilities of the tangiBook should enable a wide variety of applications where natural interaction with virtual objects is desired. In the following section we provide examples of three potential application domains: the psychophysical study of material appearance, visualization and soft proofing of coatings and printed materials, and interactive access to digital library and museum collections.

Psychophysics of material appearance

Understanding the psychophysics of material appearance has important implications for both basic science and industry [27, 28, 29]. Traditionally, a major impediment to material appearance research has been the difficulty of creating physical sample stimuli that vary systematically in the parameters of interest. Recently, the study of material appearance has been facilitated by the ability to use 3D computer graphics to create and display physically accurate simulations of objects and scenes with complex geometries, materials and illumination [30, 31,32, 33, 34]. However a significant limitation of computer-based studies is that images on a screen do not allow for the natural modes of interaction, such as direct manipulation and differential viewing, that one would typically use when evaluating material properties. Another limitation is the inability to dynamically control material properties, which has prevented the use of adjustment and matching procedures in experiments. Both of these limitations can be overcome with the capabilities of the tangiBook.

It is well known that the apparent gloss of a surface varies with its diffuse reflectance due to changes in the visual contrast of surface reflections [28]. Figure 6 shows a screen shot from a sample psychophysical experiment designed to investigate this phenomenon using the tangiBook. The two patches of the central target have the same physical gloss properties (Ward ρ_s and α), yet differ in apparent gloss due to differences in their diffuse reflectances (ρ_d). The tangiBook interface allows an observer to tilt the surface and observe it from different viewing positions, while interactively varying ρ_s and α to produce a visual gloss match. These capabilities enable a greater level of naturalness and control in computer-based experiments.
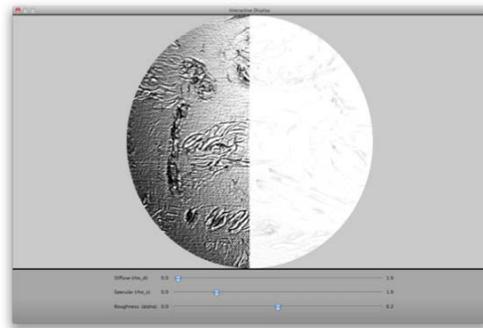
Figure 6: *Psychophysics of material appearance. Figure 6 shows how the tangiBook can be used to study the effects of color on gloss perception. The left and right patches of the target have the same physical gloss properties (ρ_s and α) but differ in perceived gloss. The observer's task is to change the Ward parameters of the left patch until the two match in apparent gloss.*

Computer-aided appearance design

In photographic printmaking and desktop publishing, it is useful to be able to simulate the appearance of a hardcopy image before printing by soft proofing on a computer display [35, 36]. Recently, soft-proofing systems have started to model the glossiness of photographic prints and render them in 3D graphics simulations [37, 38]. The simulated images are mapped to 3D

planes and shown as objects on a standard display system. Some interactivity is provided through Quicktime VR sequences created in an offline process.

Figure 7 shows a prototype of an interactive soft-proofing system implemented on the tangiBook. In addition to selecting the gloss and texture properties of the paper in real time, the system allows the user to directly manipulate the simulated print and view it from different orientations to anticipate how it will look under different lighting geometries. The real-time control and natural interactivity provided by the tangiBook should enhance the utility of soft-proofing applications. More broadly, the system provides important functionality for the emerging field of Computer-Aided Appearance Design (CAAD) of paints, coatings, and textiles [39].
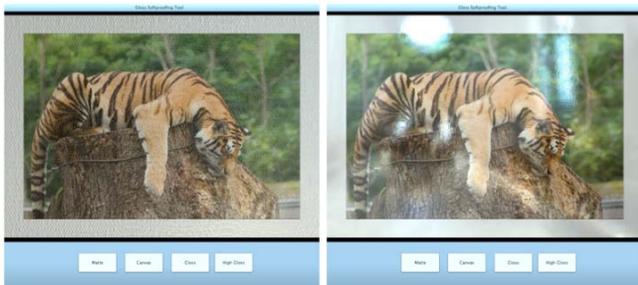
Figure 7: Soft-proofing: The images illustrate a photographic soft-proofing application. Buttons in the interface allow an image to be proofed on simulated photo papers with different colors, textures, and gloss levels (canvas (left) and high gloss (right), respectively).

Access to digital collections

Digitization has had an enormous impact on libraries and museums. Manuscripts, paintings, and other collections that were only accessible by physical visit, or were not accessible at all due to concerns about wear and tear, are now documented and accessible worldwide though digital images. The positive impact of digital libraries on teaching and research is widely acknowledged. However for many objects, still images are not enough. For example, a digital image of a painting does not fully convey its true appearance, because its appearance changes due to interactions of the materials used, the environmental illumination, and the observer's own movements. The situation is similar with a wide range of cultural heritage objects.

The tangiBook can be used to provide enhanced digital access to collections of these objects. Figure 8 shows an example of an illuminated manuscript digitized by Gardner et al. [40]. A museum visitor or library scholar could pick up this page, move it around to see the glints off the gold leaf and look at it from different angles to see the texture of the vellum. The tangiBook provides a rich, tangible interface that allows direct access to digital collections and suggests the advances in teaching and scholarship that might be possible if digital objects are available that can be viewed, analyzed, and manipulated like the objects themselves.

Conclusions

In this paper we have introduced the tangiBook, a laptop-based tangible display system that allows realistic simulation and direct manipulation of virtual surfaces. Based on an off-the-shelf computer containing an accelerometer and webcam, it incorporates
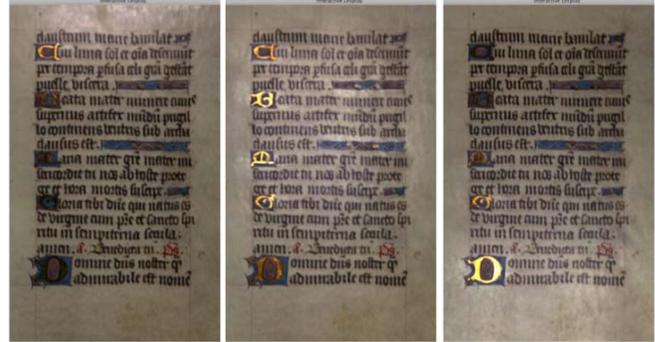
Figure 8: A virtual illuminated manuscript: The images show sections from a manuscript model displayed on the tangiBook. Note how the highlights in the gold leaf and vellum change from the left image to the right image as the display is tilted.

software that tracks the display's orientation and the observer's position in real-time to render realistically-shaded images of surfaces with complex texture and material properties. We have illustrated how the tangiBook could be used to advantage in a wide range of applications including psychophysics of material appearance, soft proofing, and enhanced access to digital collections in libraries and museums. Its relatively low cost and commodity hardware base should allow widespread implementation and application.

Although we think the tangiBook has great current utility and greater promise, in its current implementation it has several important limitations that suggest future work. One current limitation is that the laptop's accelerometer only registers changes with respect to gravity. Therefore rotations of the display around a vertical axis produce no change in lighting. One approach for overcoming this limitation would be to add a 6 degree-of-freedom tracker. There are also areas where the tangiBook's current rendering capabilities could be improved. First, explicit geometry could be included in addition to the normal maps currently used to represent surface texture. Second, with more powerful hardware or through software optimizations, it would be possible to improve upon the relatively sparse sampling of the Ward lobes or use other, more computationally intensive shading models to more accurately model complex materials. Third, there is a need to add HDR illumination maps to provide more realistic lighting. Finally, there is a need to incorporate accurate tone mapping algorithms and to compensate for changes in the colors and contrast of the LCD display at off-axis viewing angles.

Tangible interfaces offer a powerful and meaningful approach to merging the real and virtual worlds. The availability of commodity hardware with multimodal input, sensing, and display capabilities provides new opportunities to develop and use tangible interfaces in a wide variety of applications. The tangiBook represents some promising first steps in this direction.

Acknowledgements

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