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Selective Stylization for Visually Uniform Tangible AR

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Abstract
In tangible user interfaces, physical props are used for direct interaction with a computer system. Tangible interaction applications often use augmented reality display techniques in order to overlay virtual graphical objects over the interaction area. This typically leads to the problem that the virtual augmentations have a distinct, simple computer-generated look, which makes them easily distinguishable from the real environment and physical props. Here, we present a new style of tangible interaction, which seamlessly combines real objects and graphical models. In the tangible user interaction zone of our system, physical objects and virtual models are displayed in the same technical illustration style. Regions outside of the interaction zone, and also the user's hands, are shown unaltered in order to maintain an unmodified visual feedback in these areas. Our example application is a tangible urban planning environment, in which the placement of both real and virtual building models affects the flow of wind and the casting of shadows. We describe the real-time rendering pipeline which generates the selectively stylized output images in the tangible interaction system and discuss the functionality of the urban planning application.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Computer Graphics]: Interaction techniques; H.5.1 [Information Interfaces and Presentation]: Artificial, augmented, and virtual realities

1. Introduction

Tangible user interfaces use physical objects (props) for direct, immediate input [IU97]. These physical props correspond to virtual components in a computer-generated virtual space. Whenever the user manipulates a prop, this change is recorded and fed back into the current state of the virtual space, and it typically also leads to some updated graphical representation. Such user interfaces are often combined with augmented reality (AR) displays, which overlay computer-generated graphics on top of the real world using head-worn displays, video see-through mobile devices, or projectors [ABB*01].

The drawback of conventional augmented reality systems is that virtual models are usually represented in the typical style of real-time computer graphics. The underlying real-time rasterization methods rely on simplified assumptions for illumination and shading, and the resulting renderings tend to look artificial. This graphical style makes them stand out visually from the physical environment, which in video see-through systems is represented by captured video frames of the real surroundings. As a possible solution for this problem, it was proposed that illustrative or artistic stylization filters should be applied to virtual models as well as the real-world view [FBS05c]. This approach creates a more similar visual realism for virtual and real objects in augmented reality environments.

Here, we introduce the use of stylization in a tangible user interface, with the help of the principle of *selective stylization*. Unlike earlier approaches, our video see-through system does not stylize the entire combined real-virtual image. Instead, we adaptively define a *stylization domain* comprising only those regions where stylization is useful. The stylization domain includes physical props as well as virtual graphical models, rendering them in an equivalent visual style. However, regions outside of the tangible interaction zone, and also the user's hands, are excluded from the stylization process. This way, the system maintains an unmodified, direct visual feedback to the viewer in areas not immediately belonging to the tangible application (see Fig. 1).

As an example application, we present a tangible urban planning simulation inspired by the Augmented Urban Planning Workbench developed by Ishii et al. [IUC*02]. In our system, cardboard props representing buildings and purely virtual building models are placed on a street map (i.e., the interaction zone). The user can interactively manipulate the placement of the real props, as well as change simulation parameters, e.g., wind and sunlight direction. In order to achieve a seamless visual integration of physical building props, virtual buildings, and the street map, the image regions they cover are stylized. The stylization filter we use in this application creates a suitable uniform look resembling a technical illustration.

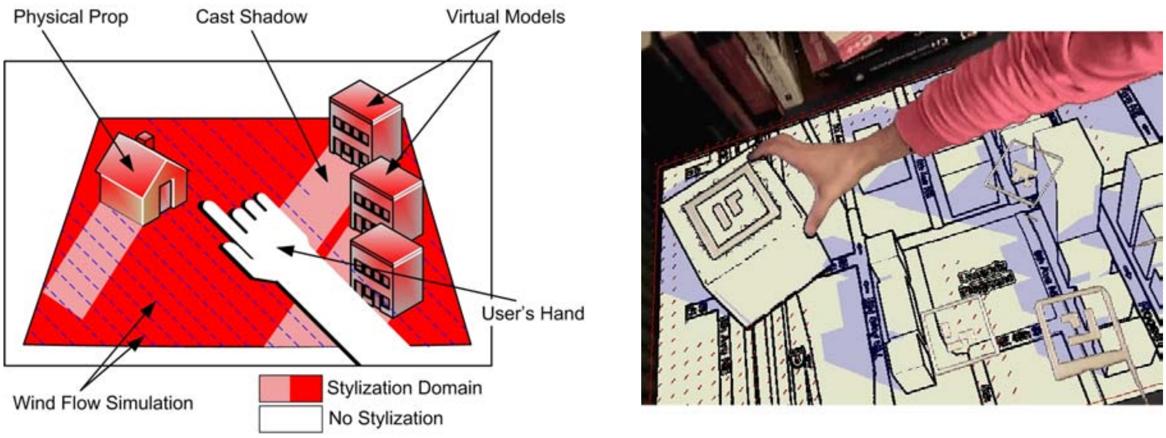

Figure 1: *Selective stylization for visually uniform tangible augmented reality. In the interaction zone of the tangible application, both real props and virtual models are shown in the same technical illustration style, making them practically indistinguishable. The user's hand and arm, as well as outside regions, are displayed without modifications. Our example application is a tangible urban planning system, which simulates wind flow and shadows cast by buildings. Left: Concept sketch. Right: Screenshot of the example application.*

A multi-pass rendering method generates the selectively stylized output images. We use a segmentation step based on color space distances to determine the areas covered by the user's hands and arms. (In our experiments, we assumed that both hand and arm/sleeve have a similar, skin-like color.) Both the hand segmentation and the stylization filter were implemented as shaders running on the programmable graphics processing unit (GPU). Overall, the system achieves real-time frame rates, allowing for a fluid tangible interaction. The implementation and example application presented here demonstrate that selective stylization makes real and virtual objects less distinguishable.

2. Related Work

In 1997, Ishii and Ullmer described the concept of Tangible Bits as a vision for tangible human-computer interfaces [IU97]. Since then, the design, implementation, and evaluation of tangible user interfaces has become an ever-growing area of research. Ishii et al. later presented the Augmented Urban Planning Workbench [IUC*02]. This tangible urban planning simulation inspired our example application, which is described in this paper. More recent examples of tangible interaction techniques include the Augmented Foam presented by Lee and Park [LP05], which combines physical foam mock-ups with virtual phantom models. Fiala developed a system for the automatic acquisition of tangible user interaction elements using a large number of optical tracking fiducials [Fia05]. The Shared Design Space, a large augmented table top setup integrating tracked pens and various tangible interaction props, was presented by Haller et al. [HBL*06]. Toney and Thomas examined the influence of reach on the design of tangible and table top interaction spaces [TT06].

As its main motivation, this paper seeks to create an equalized visual representation for physical props and graphical objects. Conventional approaches to this problem try to adapt the visual realism of virtual objects to the camera image appearance. This process is called *photometric registration*; it is defined as the task of adapting illumination conditions and overall visual appearance of two images to one another. An early method for the correct automatic illumination of virtual objects added to real images was described by Debevec [Deb98]. Research has also been done into methods of analyzing the real illumination in interactive mixed reality, for instance by Gibson et al. [GHH01].

A different method for equalizing the visual realism of real and virtual scene elements is to apply artistic or illustrative stylization to both the camera image and the computer-generated graphics. This approach, called stylized augmented reality, generates a more homogeneous visual appearance in the output video stream [FBS05c]. Algorithms for a cartoon-like [FBS05b] and a painterly stylization [FBS05a] of mixed reality video streams have been presented. It was reported that the application of a stylization filter in augmented reality significantly reduced the discernability of virtual objects in a psychophysical study [FCB*06]. Haller et al. developed a method for displaying both the camera image and virtual objects in AR in a "loose and sketchy" style [HLB05]. The potential drawback of previous stylized augmented reality systems is that they filter the entire combined real-virtual image, which is not desirable in many applications. The concept of selective stylization introduced here excludes those parts of the image from the stylization process, for which an unmodified visual feedback is reasonable in a given application.

The system described in this paper uses a straightforward color-based segmentation step in order to detect hand and arm pixels. This approach has several limitations (e.g., we assume that the hand and arm/sleeve have approximately the same color) and is to be considered a prototype method for demonstrating the principle of selective stylization. Similar color-based hand segmentation techniques have been used before, for instance by Tang et al. [TNG06]. An example of an advanced method for hand-based interaction in virtual environments is the approach described by Duca et al. [DFF07].

3. Selective Stylization for Tangible Interaction

In this paper, we present a method for selective stylization of physical props and virtual scene elements in a tangible user interface. Fig. 2 shows an example of a tangible interaction setup used by our demonstration application. The user interaction zone is defined by a base plate, on which cardboard props representing buildings, tracked interaction elements, and virtual augmentations (not shown here) are located. We use a video-see through approach to generating the augmented reality display. Therefore, the view of the tangible interaction zone is captured by a digital video camera. We use an optical marker tracking system based on the ARToolKit library [KB99].

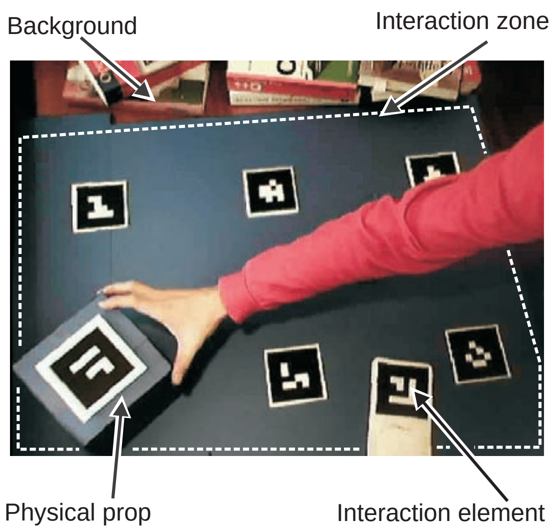

Figure 2: *Example setup used for tangible interaction.*

Two main tasks have to be performed in order to generate the selectively stylized output images. First, the stylization domain has to be computed. The stylization domain is defined as the union of those areas in the image where stylization is useful. It is determined by combining image-space information with knowledge about tracked props and virtual objects. Subsequently, the stylization filter is applied. We use a real-time image stylization process working on the composited real-virtual images. It creates a stylized look resembling a technical illustration in image areas belonging to the stylization domain and leaves the remainder of the image unaltered.

3.1. Determining the Stylization Domain

The stylization domain can be thought of as a binary image containing the value 1 at each pixel location where the stylization filter is to be applied, and 0 elsewhere. (Note, however, that in our current system implementation, this map is never explicitly generated in its entirety, but is instead evaluated on the fly by a shader program.) As mentioned above, selective stylization aims at applying the stylization filter only to image areas which are an immediate part of the application. Therefore, we propose the following properties for the definition of a useful stylization domain in a tangible user interface, as also illustrated in Fig. 1 (S = stylized, U = unstylized):

- (S1) Stylize the base plate of the interaction zone.
- (S2) Stylize virtual objects, e.g., graphical building models.
- (S3) Stylize physical props, which represent relevant elements in the tangible application.
- (U1) The background, i.e., areas outside of the interaction zone, should not be stylized.
- (U2) The user's hands and arms, which are not an immediate part of the tangible application, should not be stylized.

The first two conditions can easily be satisfied. The geometry and placement of the base plate and virtual objects are known to the application. Moreover, the current position and orientation of the digital video camera is estimated by the marker tracking system. The corresponding geometry can therefore be easily projected into camera image space, and the regions they cover are recorded. Since the associated virtual models, as well as the base plate, are typically displayed as virtual augmentations anyway, the desired information can be obtained from the rendering process by accessing the information in the z-buffer of the graphics card. Fig. 3 shows graphical augmentations overlaid over the same view of the tangible interaction setup as in Fig. 2. Note that the base plate of the interaction zone is drawn as a textured quadrangle.

We also want to stylize physical props in the tangible application. In order to achieve this, the image regions they cover have to be determined. For the example application presented here, we assume that all physical props are tracked using tracking fiducials, and that their shape and size are known. This makes it possible to define invisible *phantom models* corresponding exactly to real props. When phantom models are rendered, only the z-buffer is modified, whereas the color buffer is not altered. As a result of these rendering processes, we obtain the binary image Bin_{Depth} containing a value of 1 for all pixels covered by virtual augmentations or prop phantoms.

Figure 3: *Tangible interaction zone with superimposed graphical augmentations. This image shows the same view as Fig. 2. Note that the base plate is rendered as a textured quadrangle depicting a street map. (In this rendering, the phantom model used for the physical prop is represented as an overlaid black wireframe mesh.)*

The stylization domain is initialized with the binary image Bin_{Depth}. In this image, the background (i.e., regions outside of the interaction zone) are automatically excluded, fulfilling condition (U1) listed above. Finally, the user's hand and arm also have to be excluded from the stylization domain. In our demonstration system, the user's hand and arm are detected with a color segmentation step. We assume that both the hands and the arms have a similar, skin-like color. The input camera image is converted into YUV color space, which has proven to produce more stable segmentation results. This means that the original camera image pixels Cam_{rgb} are converted into pixels $Cam_{yuv} = (Y_{Cam}, U_{Cam}, V_{Cam})$. In this representation, Y_{Cam} encodes the brightness of a pixel, and U_{Cam} and V_{Cam} represent its color. Assuming that limits (Y_{min}, Y_{max}), (U_{min}, U_{max}), and (V_{min}, V_{max}) for the color components of skin-colored pixels have been defined, the segmentation step can easily performed:

$$Bin_{Hand}(x,y) = \begin{cases} 0, & Y_{min} < Y_{Cam}(x,y) < Y_{max} \quad \wedge \\ & U_{min} < U_{Cam}(x,y) < U_{max} \quad \wedge \\ & V_{min} < V_{Cam}(x,y) < V_{max} \\ 1, & otherwise \end{cases}$$

Bin_{Hand} is a binary image containing the value 1 in all pixels not belonging to the user's hand or arm. In our current system implementation, the color component limits are selected manually and typically remain valid as long as the illumination conditions and camera parameters do not change drastically. In order to generate more stable color segmentation results, we apply a 3x3 box filter to the input camera image beforehand. By combining the model information about virtual objects and physical props with the color segmentation results, the final stylization domain $SD(x,y)$ is computed. The stylization filter is to be disabled in regions outside of the interaction zone, as well as in areas showing the user's hand or arm:

$$SD(x,y) = Bin_{Depth}(x,y) \;\; AND \;\; Bin_{Hand}(x,y)$$

Fig. 4 shows an example of a stylization domain computed for the tangible interaction setup. In this image, the stylization domain is represented by white pixels.

Figure 4: *Example of a stylization domain with the user's arm reaching across the interaction zone. Pixels belonging to the stylization domain (i.e., $SD(x,y) = 1$) are shown as white.*

3.2. The Illustrative Stylization Filter

Our demonstration system uses a stylization algorithm which generates a visual style similar to a technical illustration. This visual style is very suitable for the urban planning application presented here. The stylization process is a purely image-based postprocessing filter inspired by the cartoon-like stylization technique described in [FB05]. The generated output images consist of a uniformly colored bright background and black silhouette lines representing objects (both virtual and real). Since the method is designed as a postprocessing step and real-time performance is desired, the filter is executed on the programmable GPU.

An edge detection image filter is applied for finding the location of silhouette outlines. Our system uses the Sobel filter in order to approximate the partial derivatives of the 2D image function. Assuming that the composited real-virtual image is contained in the 2D image $Comp$, the Sobel filter computes the partial derivatives $Comp_x$ and $Comp_y$ in the horizontal and vertical directions, respectively. By computing the vector norm of the two components $Comp_x$ and $Comp_y$, the gradient magnitude $|\nabla Comp|$ is determined. As in the hand segmentation step (see Sec. 3.1), we convert the composited image into the YUV color space before the edge detection filter is applied. This means that gradient magnitudes $|\nabla Y_{Comp}|$, $|\nabla U_{Comp}|$, and $|\nabla V_{Comp}|$ are calculated for the three color channels. This way, the local contrast in the brightness and color of the image can be separately evaluated. We have found that a weighted summation of brightness and color gradients leads to improved silhouette detection results compared to simple averaging:

$$edge_{Comp} = (1-\alpha)\cdot|\nabla Y_{Comp}| + \alpha\cdot\frac{|\nabla U_{Comp}| + |\nabla V_{Comp}|}{2}$$

The parameter $\alpha \in [0;1]$ determines the relative influence of brightness and color contrasts. The selection of this parameter depends on the type of scene captured by the digital camera, as well as properties of the camera itself. However, in our experience a constant value delivers good results under most circumstances. The computed edge detection response $edge_{Comp}$ is then compared with an absolute threshold value in order to decide which pixels are part of a silhouette outline. Pixels not containing a silhouette edge are diplayed in a bright, paper-like color. Fig. 5 shows an example of a stylized composited image consisting of real and virtual objects.

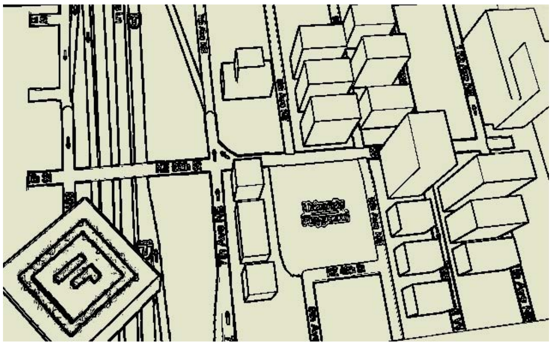

Figure 5: *A stylized image of the tangible interaction setup. This image contains both virtual models and a real object (the physical prop in the lower left corner). In this example, no stylization domain was taken into account, and the entire image was processed.*

3.3. The Final Image Composition Step

In the last step of our rendering pipeline, the final, selectively stylized output image is generated. Based on the value stored in the stylization domain, the color of each output pixel is determined. If the stylization domain has a value of 1, the color of the stylized composited real-virtual image is used (see Fig. 5). Otherwise, the color of the original camera image, Cam_{rgb}, is displayed. Note that this means that in areas outside of the stylization domain, not only is the stylization filter disabled, but the display of virtual objects is completely suppressed. Assuming that the user's hand and arm are always in front of the virtual elements, this process therefore constitutes a form of image-based occlusion handling. A selectively stylized output image for the tangible user interaction setup is depicted in Fig. 6. In this image, the user's arm occludes the virtual building models and the street map at the base of the tangible interaction setup. This is a correct representation of the spatial relationships in the scene.

Figure 6: *Selectively stylized view of the tangible interaction setup. Both virtual and real objects in the interaction zone appear in a technical illustration style. (The physical prop is visible in the lower left corner.) The real background and the user's arm and hand, however, are shown without modifications. Note that the user's arm also correctly occludes the virtual building models.*

4. Example Application: Urban Planning Environment

In order to demonstrate the concept of selective stylization, we have developed an example application inspired by the Augmented Urban Planning Workbench (see [IUC*02]). Our demonstration system is not a complete, fully functional environment for urban planning. However, it emulates some typical functionalities found in this type of application. Moreover, it integrates tangible interaction, application-specific simulation, and graphical augmentations in a single system.

Our urban planning application is capable of rendering shadows cast by buildings, and it performs a simple simulation of wind flow between them. The user can change the placement of physical building props and manipulate parameters of the simulation. For the manipulation of simulation parameters, additional user interface elements are provided directly in the interaction zone. Tracking fiducials are printed on these user interface elements, which makes a feedback of information into the system possible. An example of an interaction element is shown in Fig. 2.

4.1. Simulation of Shadows Cast by Buildings

We use a shadow volume technique on the basis of stencil buffer tests for rendering the shadows cast by buildings. Fig. 7 illustrates the concept of this shadow computation method. A detailed description of the shadow volume algorithm was given by Heidmann [Hei91]. Based on the output computed by the shadow volume algorithm, the brightness of image regions lying in shadow is decreased during the rendering process.

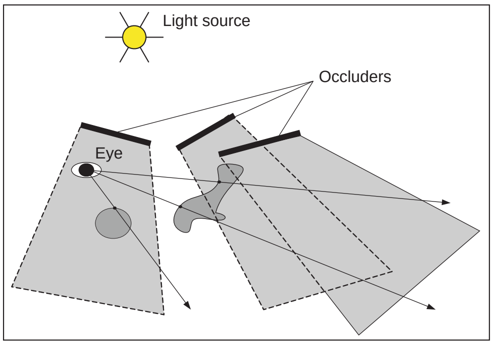

Figure 7: *The shadow volume technique used in the example application. Portions of the scene lying in the shadow of light source occluders (i.e., other buildings) are rendered darker.*

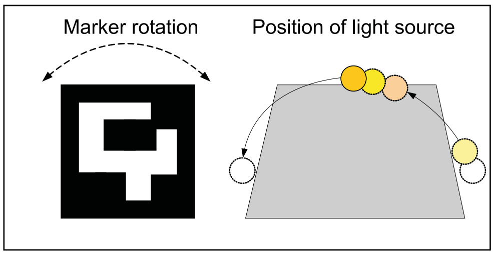

Figure 8: *Interaction element for changing the position of the virtual sun.*

A user interaction element is provided, so that the user can change the position of the virtual sun as light source for the shadow computation. By rotating the tracked element on the base plate of the interaction zone, the virtual time of day is changed (see Fig. 8).

The position, orientation, and geometry of virtual building models as well as physical building props are known to the system. In the case of physical props, this is possible thanks to the registered phantom models described in Section 3.1. Therefore, both types of buildings can cast and also receive shadows. Fig. 9 shows examples of simulated shadows rendered in our urban planning system.

4.2. Simulation of Wind Flow

The urban planning demonstration system also provides a simple simulation of wind flow. Wind is represented by animated line segments moving over the base plate of the interaction zone. The direction and speed of these "wind particles" can be influenced by the user. A user interaction element is provided for the wind simulation, and its rotations and movements are translated into simulation parameters (see Fig. 10).

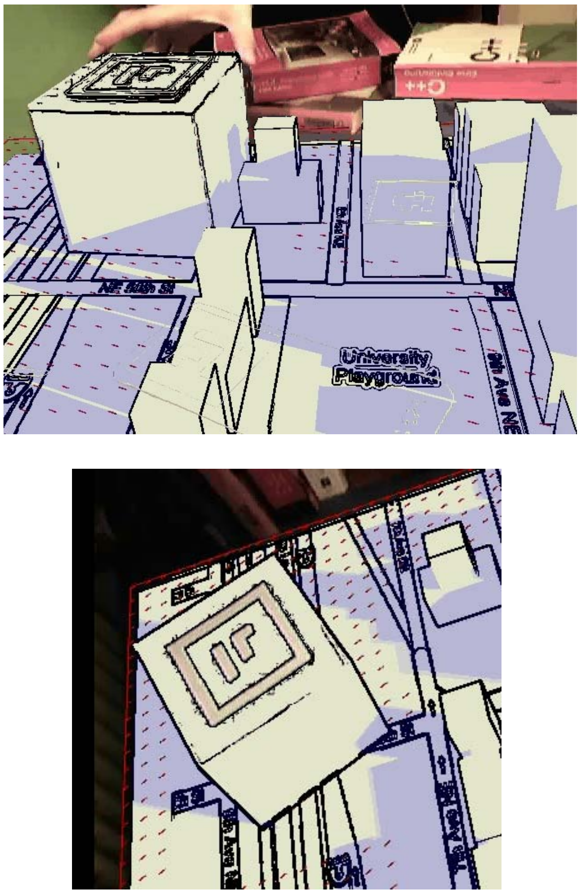

Figure 9: *Examples of shadow casting rendered in the urban planning environment. The bottom image illustrates that shadows are also cast by physical props (visible to the left of the prop).*

The wind particles move linearly across the interaction zone. Whenever a wind particle encounters a building, it enters the area that the building shelters from the wind (i.e., its "wind shadow"). The function of our simple wind flow simulation is to visualize this wind-sheltered area (see the concept sketch in Fig. 11). Fig. 12 shows example images illustrating the wind flow simulation.

Note that the wind particles are superimposed after the stylized image has been generated. This way, they are exluded from the stylization process. Their simple, sketch-like appearance was chosen so that they blend in well with the technical illustration style of the urban planning environment. The wind shadow visualization described here is relatively simple and only a very coarse approximation of a more complete, physically-based wind flow simulation. However, like the shadow casting simulation discussed above, the display of animated wind particles is an additional functionality of the urban planning example application. Therefore, it helps to demonstrate the benefits of tangible interaction and the selective stylization presented here.

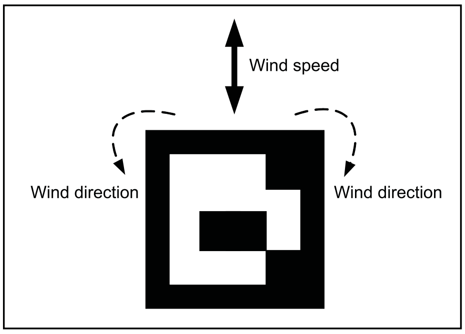

Figure 10: *Interaction element for manipulating the direction and speed of the virtual wind.*

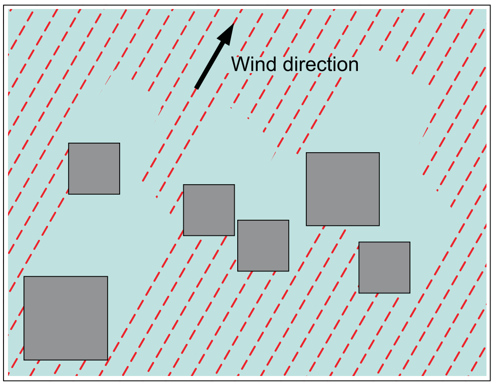

Figure 11: *Visualization of the areas that buildings shelter from the wind in the urban planning environment.*

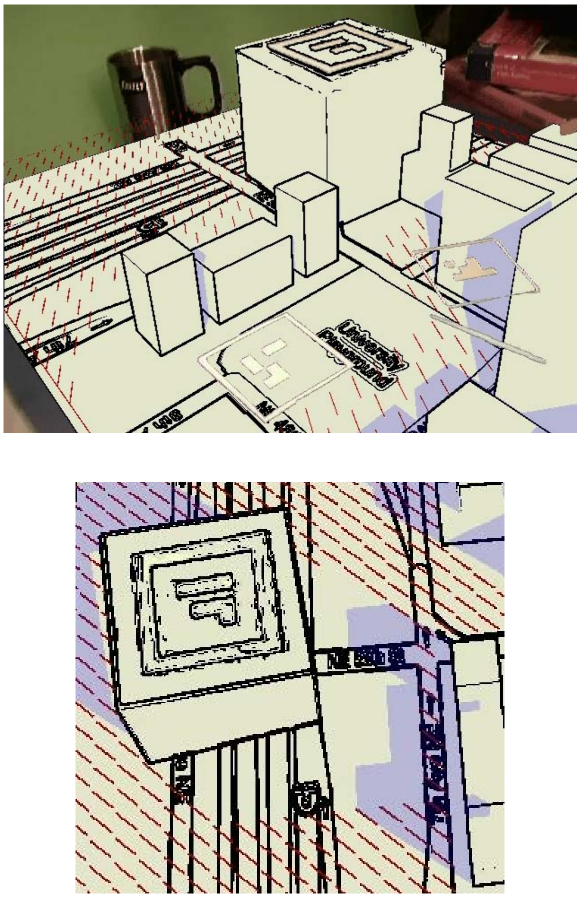

Figure 12: *Examples images of the wind flow simulation. The wind particles are displayed as red line segments. Their absence corresponds to the area sheltered from the wind by a building. The bottom image demonstrates that physical props also create a wind shadow (visible to the right of and below the prop).*

5. Implementation Details

We have developed an ID-based marker tracking extension for the ARToolKit library, which can automatically generate a large number of monochrome marker patterns [FF07]. With the help of this extension, we were able to quickly create the various fidicuals required by our example application for camera pose estimation, physical props, and additional interaction elements.

The image generation pipeline for selectively stylized output images was implemented as a multi-pass rendering algorithm. Intermediate images generated in the rendering pipeline are stored as textures bound to separate texturing units of the GPU. These intermediate textures are accessed by a final image processing stage, which generates the actual selectively stylized image. This image processing step is implemented as a single shader program executed on the GPU. We have implemented the shader program in the OpenGL Shading Language (GLSL). This shader decides whether to display the unprocessed input camera pixel or the stylized augmented pixel based on the result of the stylization domain computation.

Note that in the urban planning example application, two additional rendering passes are executed. One specialized rendering step generates an image containing the wind simulation line segments. Another application-specific step renders the shadows cast by buildings. Both steps generate additional texture images, which are then taken into account by the image processing shader.

During benchmark measurements, our system for selective stylization achieved an average frame rate of ca. 18 frames per second without the urban planning visualization. When shadow rendering and wind simulation were enabled, the performance dropped to approx. 13 frames per second. These values were determined as the averages of five benchmark sessions lasting at least 60 seconds for each of the two modes. (The measurements were made on a computer equipped with an Athlon XP processor running at 2.2 GHz and a graphics card based on an NVidia GeForce 6600 chipset. A Sony EyeToy USB Webcam was used for the acquisition of a video stream with a resolution of 640 by 480 pixels at a rate of 30 Hz.)

6. Conclusion

We have presented the novel concept of selective stylization for tangible user interfaces. By applying the same kind of artistic or illustrative stylization to both virtual models and physical props, they become practically indistinguishable. This creates a more integrated visual experience for the user. At the same time, the user's hand and arm, as well as the background, are shown without modifications, so that a total dissociation of the user from the observed scene does not occur.

A tangible, augmented urban planning environment was described as a demonstration of the concept of selective stylization. We have discussed the implementation of the newly developed rendering pipeline, and it was shown that interactive or near real-time frame rates are achieved even on a midrange computer system.

Potential directions for future work include the development of an improved segmentation approach for the user's hand and arm, and the exploration of additional types of stylization.

References

[ABB*01] AZUMA R., BAILLOT Y., BEHRINGER R., FEINER S., JULIER S., MACINTYRE B.: Recent Advances in Augmented Reality. *IEEE Computer Graphics and Applications 21*, 6 (November/December 2001), 34–47.

[Deb98] DEBEVEC P.: Rendering Synthetic Objects Into Real Scenes: Bridging Traditional and Image-Based Graphics With Global Illumination and High Dynamic Range Photography. In *Proc. of ACM SIGGRAPH* (July 1998), pp. 189–198.

[DFF07] DUCA F., FREDRIKSSON J., FJELD M.: Real-Time 3D Hand Interaction: Single Webcam Low-Cost Approach. In *Proc. of IEEE VR Workshop on Trends and Issues in Tracking for Virtual Environments* (2007).

[FB05] FISCHER J., BARTZ D.: *Real-time Cartoon-like Stylization of AR Video Streams on the GPU*. Technical Report WSI-2005-18, Wilhelm Schickard Institute for Computer Science, Graphical-Interactive Systems (WSI/GRIS), University of Tübingen, September 2005.

[FBS05a] FISCHER J., BARTZ D., STRASSER W.: Artistic Reality: Fast Brush Stroke Stylization for Augmented Reality. In *Proc. of ACM Symposium on Virtual Reality Software and Technology* (November 2005), pp. 155–158.

[FBS05b] FISCHER J., BARTZ D., STRASSER W.: Reality Tooning: Fast Non-Photorealism for Augmented Video Streams. In *IEEE and ACM International Symposium on Mixed and Augmented Reality Poster Proceedings* (October 2005), pp. 186–187.

[FBS05c] FISCHER J., BARTZ D., STRASSER W.: Stylized Augmented Reality for Improved Immersion. In *Proc. of IEEE Virtual Reality* (March 2005), pp. 195–202.

[FCB*06] FISCHER J., CUNNINGHAM D., BARTZ D., WALLRAVEN C., BÜLTHOFF H., STRASSER W.: Measuring the Discernability of Virtual Objects in Conventional and Stylized Augmented Reality. In *Proc. of Eurographics Symposium on Virtual Environments* (May 2006), pp. 53–61.

[FF07] FLOHR D., FISCHER J.: A Lightweight ID-Based Extension for Marker Tracking Systems. In *Eurographics Symposium on Virtual Environments Short Paper Proceedings* (July 2007).

[Fia05] FIALA M.: The SQUASH 1000 Tangible User Interface System. In *IEEE and ACM International Symposium on Mixed and Augmented Reality Poster Proceedings* (2005), pp. 180–181.

[GHH01] GIBSON S., HOWARD T., HUBBOLD R.: Flexible Image-Based Photometric Reconstruction using Virtual Light Sources. In *Proc. of Eurographics* (September 2001), pp. 203–214.

[HBL*06] HALLER M., BRANDL P., LEITHINGER D., LEITNER J., SEIFRIED T., BILLINGHURST M.: Shared Design Space: Sketching Ideas Using Digital Pens and a Large Augmented Tabletop Setup. In *Proc. of International Conference on Artificial Reality and Telexistence* (2006), pp. 185–196.

[Hei91] HEIDMANN T.: Real Shadows, Real Time. *IRIS Universe 18* (1991), 23–31.

[HLB05] HALLER M., LANDERL F., BILLINGHURST M.: A Loose and Sketchy Approach in a Mediated Reality Environment. In *Proc. of ACM International Conference on Computer Graphics and Interactive Techniques in Australasia and Southeast Asia (Graphite)* (December 2005), pp. 371–379.

[IU97] ISHII H., ULLMER B.: Tangible Bits: Towards Seamless Interfaces Between People, Bits and Atoms. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems* (1997), pp. 234–241.

[IUC*02] ISHII H., UNDERKOFFLER J., CHAK D., PIPER B., BEN-JOSEPH E., YEUNG L., KANJI Z.: Augmented Urban Planning Workbench: Overlaying Drawings, Physical Models and Digital Simulation. In *Proc. of IEEE and ACM International Symposium on Mixed and Augmented Reality* (2002), pp. 203–211.

[KB99] KATO H., BILLINGHURST M.: Marker Tracking and HMD Calibration for a video-based Augmented Reality Conferencing System. In *Proc. of IEEE and ACM International Workshop on Augmented Reality* (October 1999), pp. 85–94.

[LP05] LEE W., PARK J.: Augmented Foam: A Tangible Augmented Reality for Product Design. In *Proc. of IEEE and ACM International Symposium on Mixed and Augmented Reality* (2005), pp. 106–109.

[TNG06] TANG A., NEUSTAEDTER C., GREENBERG S.: VideoArms: Embodiments for Mixed Presence Groupware. In *Proc. of the BCS-HCI British HCI Group Conference* (2006).

[TT06] TONEY A., THOMAS B.: Considering Reach in Tangible and Table Top Design. In *Proc. of IEEE International Workshop on Horizontal Interactive Human-Computer Systems (TABLETOP)* (2006), pp. 57–58.