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Stylized Depiction in Mixed Reality

Jan Fischer, Michael Haller and Bruce H. Thomas

***Abstract*— The combination of real video images and virtual graphical objects is a basic principle in many computer graphics applications. In recent years, mixed reality has become a widespread technique for superimposing registered three-dimensional models on the real world. Whereas most mixed reality applications use conventional photorealistic rendering methods for overlaying their graphical content, alternative display methods are being developed. We discuss the use of artistic and illustrative rendering techniques for combined real-virtual environments. This concept has a dual purpose. Depending on the type of stylization used, a novel user experience can be created. For instance, the use of a technical illustration style can provide a more appropriate and useful display in a technical design application. Moreover, since the difference in visual realism between real and virtual scene elements is reduced, the environment can become more immersive for the user. In this article, we give a survey of methods for the artistic depiction of combined real-virtual environments and discuss potential applications.**

***Index Terms*— Mixed/Augmented Reality, Non-Photorealistic Rendering, Video Stylization**

I. Introduction

An increasing proportion of computer graphics applications uses real images or captured video streams in combination with computer-generated renderings. Special effects for movies, as well as image- and video-based rendering are some of the areas in research and practice, in which real world image data is processed along with three-dimensional model information. One research area dealing in particular with the overlay of three-dimensional computer graphics over real world video streams is mixed reality (MR). The defining feature of mixed reality systems is that they provide an estimation of the position and orientation of the viewer or the digital camera used in the setup. This makes it possible to superimpose virtual graphical models using a correct three-dimensional registration relative to the surrounding real environment [2].

The majority of mixed reality systems use standard computer graphics methods for displaying virtual models. While standard real-time graphics technology is fast and easy to use, it has some significant drawbacks in the context of combined real-virtual images. Illumination and material parameters are defined manually for graphical objects, and they typically do not correspond well to the conditions in the real environment. Unless advanced lighting and texturing are used, which can require laborious model creation and slow down rendering, the generated output images are relatively simple.

The application of new display styles inspired by artistic or illustrative depiction can be a useful addition to mixed reality systems. Such visual styles create a novel experience for the user. For instance, an artistic depiction can provide a more entertaining environment in mixed real gaming, while a display style emulating a technical illustration creates a more legible representation in a technical design task. Non-photorealistic rendering styles can be applied to different parts of the mixed reality environment. Artistic rendering could be limited to the virtual objects or even only parts of them. Alternatively, the entire output image including the captured video stream can be represented in the same, non-photorealistic style. For the latter concept, the term *stylized augmented reality* has been proposed [6].

As a consequence of using stylized augmented reality, the visual realism of real and virtual objects is equalized. This means that real and virtual scene elements become less distinguishable, and a better immersion into the represented environment can possibly be achieved. This article gives an overview of different types of artistic and illustrative stylization in mixed reality, and it presents several existing as well as possible future applications.

II. Related Work

Mixed reality (MR) research aims at developing technologies that allow the real-time fusion of computer-generated virtual scenes with real world imagery. The terminology was first introduced by Milgram et al. [23]. The use of mixed reality enhances the users' perception and the interaction with the real world [2]. Methods for achieving a more consistent level of visual realism in mixed reality have been an area of active research. Many researchers focus on how to merge the real and the virtual elements using consistent illumination [3]. Kanbara and Yokoya describe an approach of analyzing the distribution of real light sources in real-time, which is used for adapting the representation of graphical objects accordingly [16]. A similar technique for utilizing an acquired environment illumination map was proposed by Agusanto et al. [1].

This article discusses the use of non-photorealistic (NPR) display styles in order to generate a novel kind of mixed reality imagery. This principle is related to classical techniques for computer-generated artistic depiction such as real-time video stylization. Examples of related work on video stylization include the system introduced by Collomosse et al., which renders motion in an artistic style within video sequences [5]. Winnemöller et al. presented an algorithm for the real-time abstraction of video sequences using a cartoon-like style [27].

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2.1 Outdoor Mixed Reality

Mixed reality systems designed for outdoor use pose a number of specific challenges for the rendering of virtual objects. In some cases, a slightly stylized representation of graphical objects has proven to be superior compared to standard rendering techniques. This is often achieved by adapting their color or opacity. In this section, we describe the impact of graphical style on the following two projects: ARQuake, an outdoor AR version of the Quake first person shooter game, and ARVino, a video-based outdoor AR system to support collaboration about a display in the field.

ARQuake: ARQuake [26] was developed with a digital compass for orientation information, a GPS receiver for positioning, and with a portable, lightweight head-mounted display (HMD). The design of the visuals for the game had a large impact on the users' acceptance of the augmented reality experience. The choice of colors is important for outdoor AR applications, as some colors are difficult to discriminate from natural surroundings or in brilliant sunlight, see Fig. 1. The original Quake game color design is "dark and gloomy". Dark colors appear translucent with a see-through HMD. A purple sky background jarred a user's eyes; it did not match with the physical sky. A blue, transparent virtual sky was deemed to be better suited to the game, as it blends in with the physical sky. Monsters and items require different colors to be more visible outdoors. We informally investigated, which colors are best suited to texture large areas of game monsters and items. The ambient sunlight has a major impact on the choice of colors, areas of bright and deep shadows. Nine colors appeared to work well, whether the user was viewing into or standing in bright light or deep shadow: three shades of purple, two shades of blue, two shades of yellow, and two of green. There were eight colors that scored a poor; these are as follows: bright yellow, bright red, bright pink, bright magenta, bright orange, bright cyan, and dark cyan.

Fig. 1. Screenshot from ARQuake.

ARVino: The ARVino system is an AR platform for visualizing viticulture data in 3D outdoors using a movable tripod-mounted notebook computer that can be viewed by small groups of people [17]. The system was evaluated by an expert viticulturist, and they reported the number of colors required for their data was only three or four, as crops are normally only divided into high, medium, or low yields. Transparency of virtual objects is employed to fuse these with the physical. The use of transparency proved difficult to balance between the ability to view clearly both the virtual objects and the physical world, and direct outdoor sunlight exaggerated this problem. We found the best results were obtained by using bright simple colors (pure red, green, and blue and mixes such as cyan, magenta, and yellow). The 3D graphics were configured to 100% ambient lighting to remove shading that made the objects darker. The expert felt the system provided better visualization for the viticulturist than available with traditional methods.

III. Stylized Rendering in Mixed Reality

One of the first systems that used non-photorealistic rendering in mixed reality was presented by Haller and Sperl [14]. This system applied artistic rendering techniques only to the virtual objects and showed the camera image in its original, unprocessed form. The graphical objects could be displayed using varying types of brush stroke rendering.

More recent approaches have sought to deliver a more integrated experience by applying stylization techniques to the camera image as well as the virtual models. One of the main challenges when rendering combined images consisting of both real and virtual image elements is their different level of visual realism. In a typical mixed reality scene, virtual objects clearly stand out from the background due to mismatched lighting parameters and rendering artifacts like aliasing. Although various approaches to a more photorealistic display of virtual models in mixed reality have been proposed, they are often computationally expensive, complex to implement, and can typically only provide partial solutions to the problem.

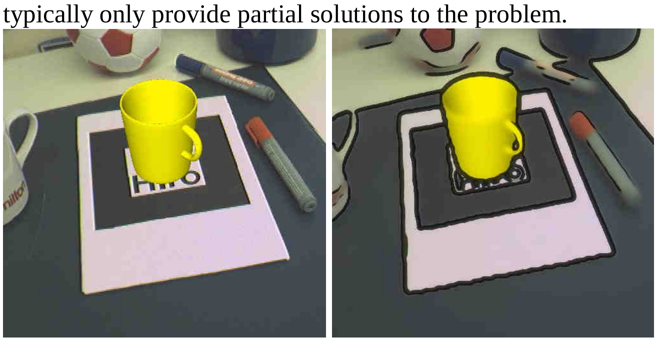

Fig. 2. Comparison between conventional and stylized augmented reality. In the image on the left, the yellow virtual cup clearly stands out. The cartoon-like stylization shown in the right image makes real and virtual objects look more similar.

As an alternative technique for providing a more equalized visual realism in combined virtual-real images, artistic stylization methods can be applied to the real background image as well as the graphical models. The name s*tylized augmented reality* has been proposed for this approach, which generates a similar visual style for the entire output image [8]. Fig. 2 illustrates the basic principle of stylized augmented reality.

It has to be noted that the application of artistic or illustrative stylization methods to mixed reality images not only leads to an equalized realism. Due to the artistic depiction, the representation of the scene is altered, and in many artistic styles, some visual detail is removed. This may not be acceptable in certain applications, e.g., in security-related scenarios, critical medical applications or car navigation. In other application scenarios like entertainment, education, and museum exhibits, however, the stylized representation is acceptable and may even genuinely enrich the user's experience.

3.1 Technical Challenges

The artistic stylization of combined real and virtual images is technically somewhat different from previously described methods for non-photorealistic rendering. Unlike in other contexts, a stylized augmented reality system has to process both a 2D video stream and 3D graphical models simultaneously. For both types of input data, a visually equivalent (or at least very similar) graphical output has to be generated. Each input channel has its own properties and challenges. For the 2D video images, image noise and motion blur are particular problems, as is the preservation of temporal coherence in the processed output. The 3D models in the mixed environment provide additional information like face normals and textures, and rendering complex models can be computationally expensive.

An additional challenge when stylizing mixed reality scenes is the extremely short processing time available for this task. In a mixed reality system, the actual image generation is embedded in a complex pipeline comprising video acquisition and camera tracking algorithms. Therefore, any stylization method must be completed within milliseconds in order to ensure overall real-time frame rates. Finally, in a mixed reality system no user interaction can be provided for the actual stylization process because specialized mobile display setups like head-mounted displays are often used. Moreover, since the application scenarios themselves often require interaction, requiring a manual intervention for the stylization process would disrupt the user experience. These three challenges, the fusion of 2D and 3D data, very short processing times, and the necessity of fully automatic algorithms, are a unique combination of constraints. Therefore, existing non-photorealistic rendering techniques have to be modified, or new approaches must be developed for the requirements of stylized augmented reality.

3.2 Basic Rendering Pipeline

There are two basic approaches to generating a stylized augmented reality video stream. One possibility is to perform the stylization of video and 3D model data separately. In this method, a specialized image stylization filter processes the camera image, while a non-photorealistic rendering algorithm displays the virtual models (see Fig. 3). The design and rendering parameters of these two stylization components have to be tuned so that a visually equivalent output is generated. In more complex cases, the image stylization filter and artistic renderer can also share additional stylization information, e.g., a 2D grid of brush stroke positions. The second basic approach consists of generating a conventional augmented reality image and applying an image stylization filter afterwards (see Fig. 4). Since a readback of the composited augmented reality image from graphics hardware would be prohibitively expensive, this approach can effectively only be realized by executing the image post-processing filter on the programmable graphics processing unit (GPU). In practice, variations and refinements of these two basic approaches are often used. The following sections describe some stylization types in more detail.

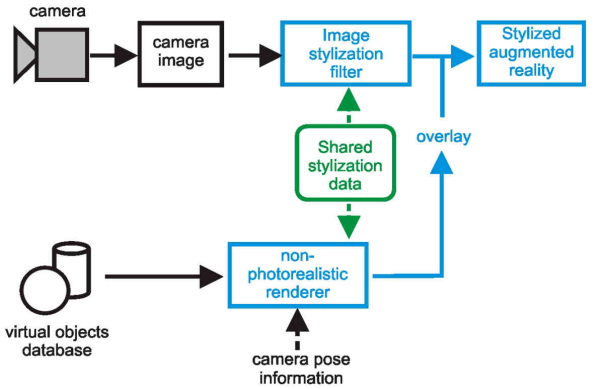

Fig. 3. Generating stylized augmented reality images using two processing branches.

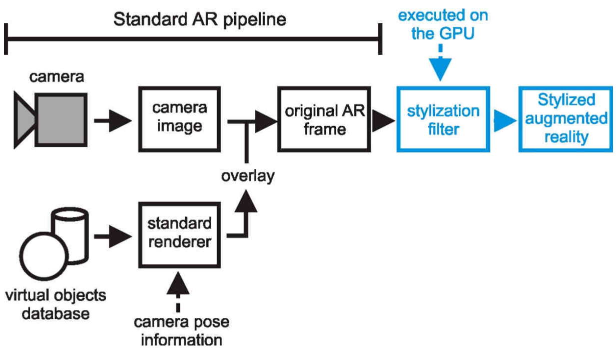

Fig. 4. Generating stylized augmented reality images using a postprocessing pipeline.

3.3 Artistic Stylization for Mixed Reality

The principle of stylized augmented reality has been implemented using several artistic and illustrative rendering styles. Here, we will discuss some basic aspects of generating an artistic depiction of mixed reality scenes. A method for the real-time cartoon-like stylization of mixed reality video streams was described in [6][7]. This stylization type has been designed as an image post-processing approach. At first, conventional mixed reality images are composited by rendering virtual models over the camera image. Then, the cartoon-like image filter is executed on the GPU.

The cartoon-like filter consists of two main steps, which are inspired by the properties of real cartoons. Generally speaking, cartoons consist of uniformly colored patches enclosed by black silhouette lines. Therefore, as the first step of the cartoon-like stylization filter, a color simplification is performed. This color simplification uses a specialized, adapted non-linear filter based on bilateral image filtering. It generates images in which similarly colored regions are averaged, while high contrast image features are preserved. Several iterations of the filter are required in order to achieve a satisfying color simplification.

The second step of the cartoon-like image filter is silhouette detection, which is described in more detail the next section. Fig. 5 shows two examples of images generated with the cartoon-like stylized augmented reality system. On current graphics hardware, the system achieves real-time frame rates.

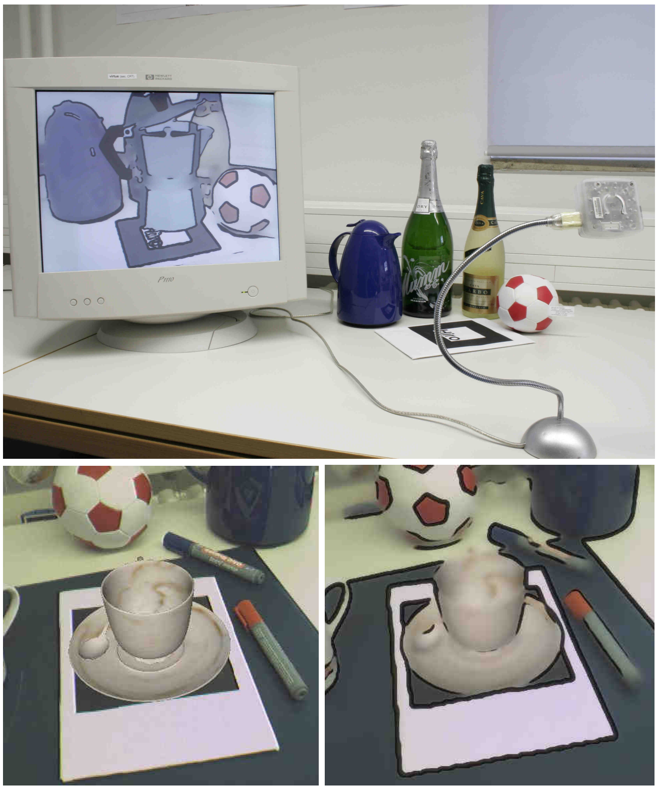

Fig. 5. Cartoon-like stylized augmented reality. Top: The webcam seen at the right captures a real scene, while the computer screen shows the scene augmented with a virtual coffee maker in the cartoon-like style. Bottom: A virtual tea cup in conventional (left) and cartoon-like stylized augmented reality (right).

3.4 Silhouette Rendering for Artistic Mixed Reality

Silhouettes are essential in many artistic rendering methods because they provide more detail about the shape of both real and virtual objects in the scene (see Fig. 5 and Fig. 6). There are several ways to implement silhouette edge detection; some work in image space and some work in object space. The cartoon-like image post-processing filter described in [7] uses an image space edge detection method executed on the GPU. This edge detector is a modified Sobel filter, which responds to strong local contrasts in the image. The determined edge detection responses are then used for drawing black silhouette lines over the simplified color image.

A more complex image space approach was chosen to generate silhouettes in [13]. Here, an object silhouette is drawn based on particles that are generated around the edge. The corresponding particle positions are calculated from a reference image that is used as a template for both the positions and a “force” mask that shows where the particles are supposed to move to. The particles serve as starting and ending points for brush strokes placed accordingly to generate the silhouette, which is drawn using the method described in [24]. The reference image is calculated with a Sobel filter that is applied to the depth buffer of the virtual (augmented) 3D geometry and the real world image. The images shown in Fig. 6 were rendered using this silhouette generation algorithm.

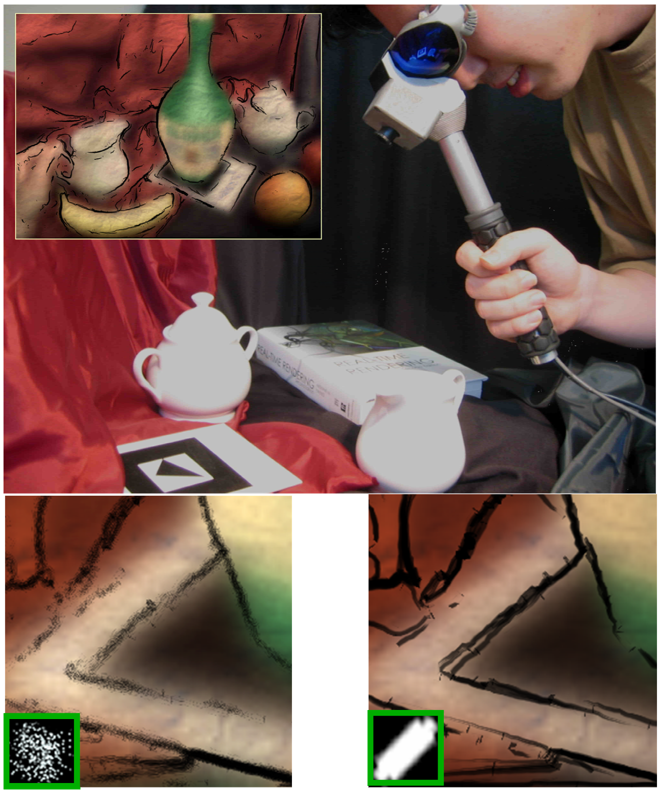

Fig. 6. Artistic stylization in mixed reality with advanced silhouette generation. Users can enjoy the whole scene in a non-photorealistic style by using a HMD mounted on a stick. The two images show a close-up of the artistic silhouettes using different textures.

3.5 Pointillism Stylization

In the preceding sections, the artistic depiction of mixed reality scenes using rendering styles based on color simplification and edge emphasis was discussed. In addition to these approaches to stylized augmented reality, several other types of stylization have been implemented. One example is a brush stroke style similar to the painting technique of pointillism. This artistic rendering method for augmented video streams uses a large number of small brush strokes to compose the output image [9]. The input camera image is sampled at certain locations to provide the colors for brush strokes covering the image. Afterwards, the virtual models in the scene are displayed with a specialized particle renderer, which places brush strokes at the same locations as the camera image filter. The approach has been implemented using image processing on the CPU and standard real-time graphics methods, allowing for interactive frame rates. Fig. 7 shows an example image rendered in the brush stroke style.

Besides these types of artistic depiction for mixed reality, a number of illustrative styles have also been explored. These illustrative stylization approaches will be discussed in the context of their respective application scenarios in Section V.

Fig. 7. Brush stroke stylization for mixed reality scenes. The tea cup shown at the center of the image is a virtual object. The camera image depicting the user's hand and several highlighters in the background are displayed using small brush strokes, as is the virtual tea cup.

IV. Visualizing Motion in Mixed Reality Scenes with Non-Photorealistic Techniques

As an alternative to the artistic stylization of complete mixed reality images, specific non-photorealistic methods can be applied to certain parts of a mixed reality scene only. In this section, we will discuss how to visualize the motion of graphical objects in mixed reality using styles inspired by comic books. In his book "Understanding Comics", McCloud analyzed the abstract illustration of motion for still images [22]. McCloud proposed motion lines and multiple images as the most important properties for still images. He, we discuss how to render dynamic and interactive mixed reality images using stylized rendering techniques. Our approach is based on these three methods to stylize motion:

- **Squash-And-Stretch:** When an object is moved, it is scaled along its movement direction [20].
- **Multiple Images:** Snapshots of the moving object are taken at a certain time interval, which can be adapted [21].
- **Motion Lines:** Motion lines have been used for quite a long time to convey the sense of motion. Depending on the medium, the culture, and of course on the personal style of the artists, a number of different types of motion lines have emerged [21].

4.1 Squash-And-Stretch

One of the most interesting principles in animation is the squash-and-stretch technique, which scales the moving object based on the velocity and/or acceleration of its motion [4][20]. In our squash-and-stretch system, a speed-dependent scaling factor, s_v, is determined. The value of s_v is computed so that it reaches a user-definable maximal scaling of s_{vmax} if the object speed is at or above a user-defined maximal speed of v_{max}. If the object is not moving, s_v has a value of 1, meaning that there is no speed-dependent scaling.

In order to also consider the acceleration of the object, a second scaling factor, s_a, is computed. If the speed increases (positive acceleration a), the object is stretched. The closer a gets to a_{max}, the closer s_a gets to s_{amax}. Again, both a_{max} and s_{amax} are user-defined parameters. If the acceleration a is negative (i.e., the object is slowed down), the object is getting squashed. The closer the absolute value of a gets to a_{min}, the closer s_a gets to s_{amin}. Finally, we calculate the resulting stretching factor $s_{result} = s_v \cdot s_a$, which is used to scale the object along its motion vector. Moreover, we also make sure that the overall area of the object is preserved.

4.2 Multiple Images

Snapshots of the moving object are taken at a constant time interval that can be configured. The easiest form of multiple images is to draw the whole object several times, but a number of different other styles for multiple images exist. One possible style is to only draw the contours of the object in each iteration. Assuming that a scene is rendered for instance with 60 fps and the replication rate is 20 fps, the contour replication is generated every third frame. A texture containing all contour replications is drawn in the background. When a new contour replication is generated, the object is rendered to the texture. A common style of multiple images is to use a decreasing opacity in the contour replications. Another very common method is to stylize multiple images by drawing the contour replications only partly or streaked.

4.3 Motion Lines (Speedlines)

This technique is a frequently used method in comics and cartoons. It can express a high degree of movement and focuses on the dynamics of the illustration. Fig. 8 depicts typical still images with motion lines, which represent an abstraction of the dynamic behavior. In technical illustrations, for example, motion is often portrayed using abstract arrows (see top left image in Fig. 8). In this example, the user knows immediately how to open the printer in order to change the ink cartridge. Likewise, in mixed reality scenarios, the motion path can be enhanced by using motion lines. Masuch describes in [21] a possibility to find adequate starting points for the motion lines in image space.

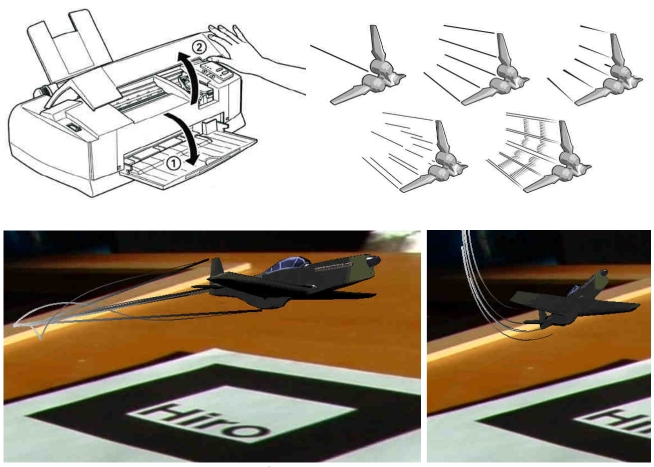

Fig. 8. Technical illustrations often use arrows to visualize the motion. Motion lines (also known as speedlines) can also enhance the visualization of motion in a mixed reality scenario. Top left: technical illustration example. Top right: motion lines and multiple images in a cartoon-style drawing. Bottom: motion lines in mixed reality.

V. Case Studies

The preceding sections have introduced basic concepts for applying stylized depiction to mixed reality. In this section, we describe application cases for non-photorealistic and stylized rendering in mixed reality systems.

5.1 Technical Illustration in Mixed Reality

As an application of the equivalent stylization of real and virtual objects in mixed reality, we have explored the display of technical illustrations. This system combines an illustration-like camera image filter with a special illustrative rendering algorithm for virtual objects [6][10]. The resulting output images mostly consist of black-and-white hatching which represents the shading of objects, as well as black silhouette lines. Additionally, the inner structures of graphical models are automatically extracted and visualized as colored elements (red and blue are used in the examples shown here). Fig. 9 shows the CAD model of a mini submarine visualized in the illustrative style. The technical illustration style is well suited for this type of application.

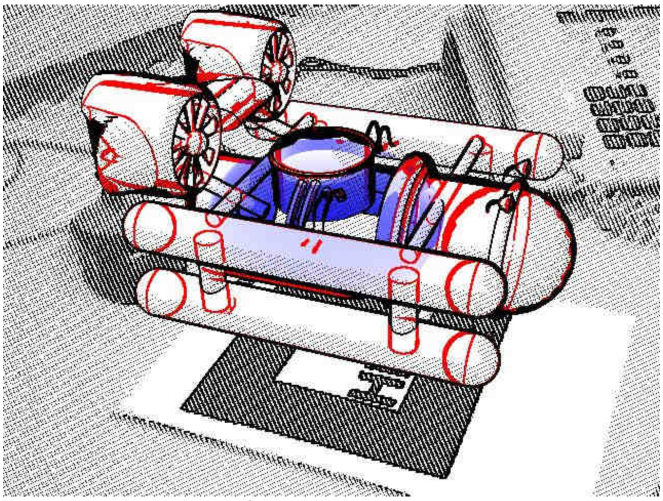

Fig. 9. Illustrative display of a mixed reality scene. The virtual object at the center is the model of a mini submarine. For the submarine, some inner structures are shown as blue and red elements. In the entire image, shape is conveyed using black-and-white hatching and silhouettes.

5.2 Focus and Context Visualization

Kalkofen et al. presented a mixed reality visualization system which combines illustrative rendering of graphical models with a stylized representation of the camera image [15]. They describe tools for selecting important information in the mixed reality environment. These important parts of displayed models are then highlighted, while surrounding elements are also still emphasized to provide the graphical context. As one functionality of their system, the silhouette edges of virtual models can be extracted, and at the same time, silhouettes are computed for the surrounding camera image. This way, an adapted visual realism for real and virtual scene elements is achieved. Fig. 10 shows an example image generated by their system.

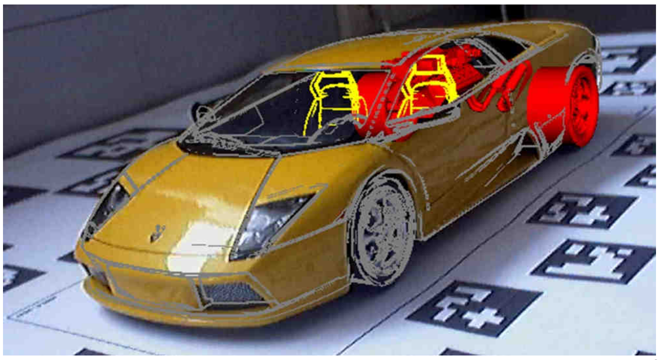

Fig. 10. Focus and context visualization in mixed reality. (Image courtesy of Denis Kalkofen, Graz University of Technology.)

5.3 Mobile Mixed Reality

During the past years, the use of mobile devices for implementing mixed reality techniques has become a very important area of research. Mobile devices like personal digital assistants (PDAs) and mobile phones have become very widespread, and many of them are equipped with digital cameras and sufficient computing power. One central challenge when working with mobile devices is their small display size. In order to present information to the user in an easily understandable way, special visualization methods have to be designed.

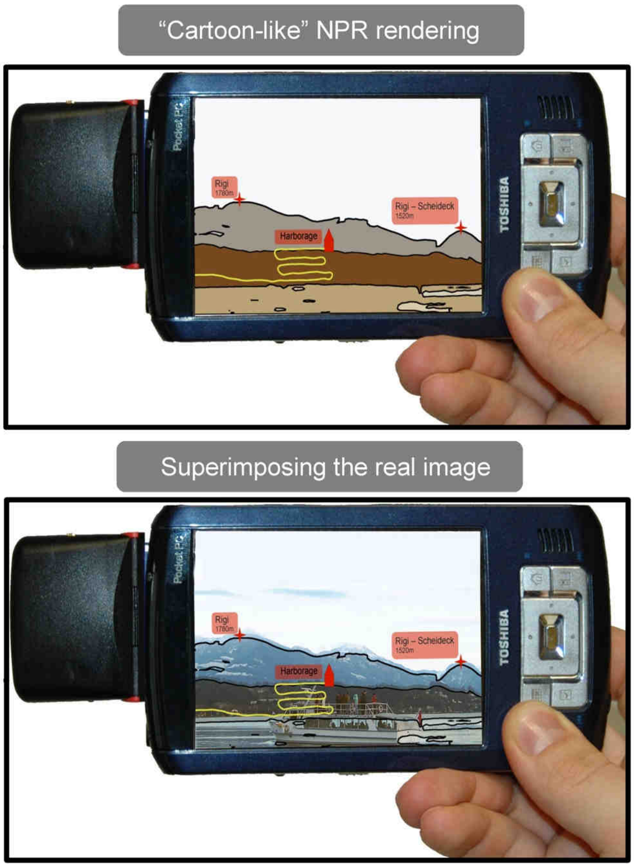

Fig. 11. Cartoon-like non-photorealistic visualization of an augmented landscape on a mobile device. (Image courtesy of Sebastian Knödel, University of Bordeaux, France [18].)

Knödel et al. developed methods for the efficient rendering of mixed reality environments on mobile devices [18]. One of their approaches uses a cartoon-like style in order to generate a clearer representation of an annotated landscape for small displays (see Fig. 11). The authors use a predefined model of the landscape, which is rendered in the non-photorealistic style and blended over the camera image. Unlike in the systems previously prescribed here, no image processing of the actual camera image takes place. Still, the motivation of Knödel et al.'s approach is the same as for the other mixed reality stylization methods discussed in this article. Since a conventionally rendered overlay of graphical models is not well suited for presenting information on a mobile device, they chose to generate images which effectively are stylized versions of the augmented scene.

5.4 Selective Stylization for Tangible Interaction

In tangible user interfaces, real physical objects (so-called props) are used for direct, immediate input. As an example for the use of stylization in a tangible mixed reality system, an urban planning application was developed [12]. In this urban planning simulation, cardboard props representing buildings can be freely positioned in the tangible interaction zone, which represents a city map.

One drawback of the previously discussed stylized augmented reality principle for many applications is that the entire output image is altered. While this may be acceptable for certain scenarios like games or education settings, it is not desirable in other applications. In an augmented tangible interaction system, it is preferable to have unmodified visual feedback for the user's hand and arm, and also for background regions not belonging to the actual application environment.

Therefore, the concept of *selective stylization* has been proposed [12]. In a selectively stylized mixed reality environment, both real and virtual objects are displayed in a non-photorealistic style within the interaction zone. Outside regions, and also the user's hand and arm, are shown without modifications. A straightforward color-based segmentation method detects the hand and arm of the user. (We assume that the arm or sleeve is approximately skin-colored.) We denote those areas of the combined real-virtual image which are to be stylized as the *stylization domain*. The stylization domain is computed in real-time for each video frame.

Fig. 12 shows an example screenshot from the selectively stylized tangible interaction system. The top image depicts the stylization domain computed for one frame. In the bottom image, the urban planning simulation is shown. A real building prop, virtual buildings, and the city map are rendered in a black-and-white technical illustration style. Moreover, the simulated flow of wind is visualized with red line segments, and shadows cast between buildings are simulated.

Using the concept of selective stylization, a seamless visual integration of real and virtual elements is achieved. Regions which are not an immediate part of the application, however, are shown without modifications. This way, a direct connection of the user with the observed scene is maintained.

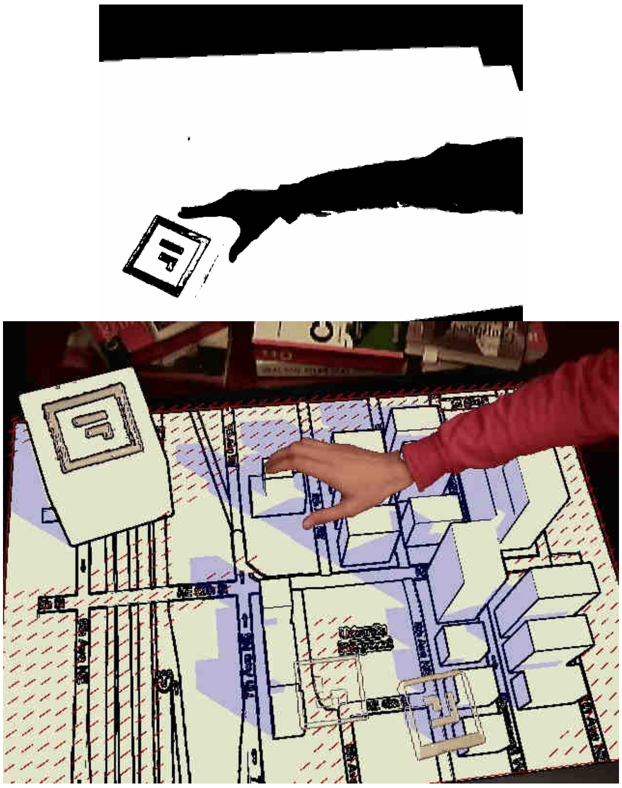

Fig. 12. Selective stylization for tangible user interfaces. Top: Stylization domain for one example frame. White pixels will be stylized; black pixels will remain unaltered. Bottom: Screenshot of the final, selectively stylized, tangible urban planning simulation. (Images courtesy of Daniel Flohr, Universität Tübingen.)

5.5 Psychophysical Experiments

Psychophysical experiments are an interesting application area for stylized augmented reality. An initial study found that in a controlled experiment, it was more difficult for participants to distinguish virtual models from real objects in stylized images and videos than in conventional representations [11].

Currently, a more complex psychophysical study is being prepared at the Georgia Institute of Technology. This experiment is based on the well-known "pit room" setup described by Slater et al. [25]. In the pit room scenario, participants are exposed to a situation in which they look down a seemingly deep virtual pit. The strength with which the participants react to this virtual pit has been used to quantify the degree of immersion in a virtual environment. In the newly designed experiment, participants will look at the scenario in a mixed reality system – they can see the virtual pit, but also their own body (e.g., hands and feet). In order to reduce the difference in visual realism, a cartoon-like stylization is applied to both the virtual pit and the user's body. This way, a visually very similar output is generated for the entire augmented video stream. The purpose of this study will be to evaluate whether the equivalent stylization of real and virtual scene elements has an impact on the effectiveness of the pit stimulus. Currently, a mock-up of the stylized pit room experiment has been created in a stylized AR interface to the popular SecondLife multiplayer online world [19] (see Fig. 13).

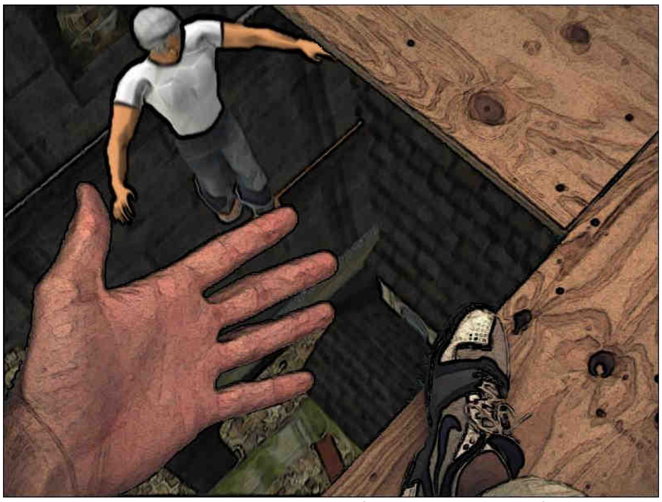

Fig. 13. Stylized augmented reality interface to the SecondLife multiplayer online world [19]. This stylized AR SecondLife client has been used to create a mock-up for the pit room experiment. In this image, a hand and foot of the user are shown, together with the virtual pit and an additional virtual avatar. All elements in the scene are displayed in a similar cartoon-like style, reducing the visual differences between them. (Image courtesy of Blair MacIntyre, Augmented Environments Lab, Georgia Institute of Technology.)

VI. Conclusion

6.1 Lessons Learned

Einstein once said "Keep it as simple as possible but not simpler". It is useful to reduce visual clutter - especially in mixed reality, where we enhance the real world with additional information. Consequently, it is more important to reduce the added content to its minimum and to present it in a better way so that users immediately benefit from its presentation. One way to enhance the graphical content is to outline shapes of an object. As described before, there are several techniques which help to generate silhouettes in real-time. The goal is to detect the shape contours and remove parts that should be suppressed. On the other hand, we have to enhance important features. However, it is still not a trivial task to automatically find which parts of a shape are important and which are not. Relevant details may be lost during the simplification process. This is a general problem of NPR and noticed by a variety of researchers.

Highlighting of digital shapes is one of the key issues in mixed reality, where users have to complete a certain task. As also proposed by Mark Bolas, greater abstraction in a virtual world engages the users' senses and creates a greater sense of being "in" the digital world. Rendering in NPR allows a more efficient visualization since the user can focus on the information to be conveyed. Finally, the world can also be more legible.

6.2 Discussion

In this article, we have discussed various approaches to using stylized rendering methods in mixed reality. There are different motivations for applying non-photorealistic or other stylized display techniques in mixed reality systems. One main objective is to create an environment in which real and virtual objects become less distinguishable, or not distinguishable at all (stylized augmented reality). For some applications, it may simply be desirable to provide an alternative visual style in order to provide a different user experience. This is often the case for games, entertainment scenarios, or education applications.

A second frequent motivation is to create a more easily understandable visualization, which emphasizes important structures, de-emphasizes irrelevant visual context, and possibly adds helpful elements. Such techniques are often inspired by methods used in technical or scientific illustrations, and we have described the transfer of some of these approaches into mixed reality (for instance the motion lines and technical illustration systems). Finally, some mixed reality scenarios pose specific problems for the presentation of graphical information, e.g., due to small displays in mobile mixed reality or low contrast in outdoor systems. In some of these cases, the use of non-photorealistic stylization has also been explored.

This article has given a survey of existing work in the area of stylized rendering for mixed reality systems. The described application cases demonstrate that illustrative and artistic stylization methods are steadily being adopted for a range of mixed reality scenarios. We are confident that this research direction will produce further interesting and useful developments in the future.

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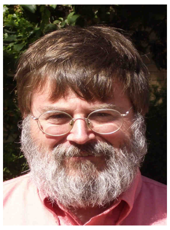

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