"Studierstube" – An Environment For Collaboration in Augmented Reality

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Introduction. We propose an architecture for multi-user augmented reality, with applications in visualization, presentation, and education. In many situations, augmented reality is preferable over fully immersive virtual environments, because the visual quality of the real world is not compromised, and many users may consider such a system less inhibitive. Our aim is to create a system capable of both displaying virtual objects and augmenting physical objects with geometrically aligned information.

Three-dimensional stereoscopic graphics are presented to a group of users, each wearing a light-weight see-through head mounted display, allowing to see real and virtual objects simultaneously. Each user is head-tracked and can thus independently choose his or her viewpoint. As everybody sees the same model, and at the same time users see each other, working together is very effective. It is therefore easily possible for a work group to discuss the viewed object. Consequently, groupware support can be kept simple and mostly left over to social protocols. Besides, it is possible for individuals to customize the data set that is presented to them, according to their interests and needs.

The main features of this setup are:

- **Virtuality**: Objects that do not exist in the real world can be viewed and examined.
- **Augmentation**: Real objects can be augmented with geometry aligned information.
- **Cooperation**: Multiple users can see each other and cooperate in a normal way without being constrained by the virtual reality system's limitations.
- **Independence**: Each user has the option to move freely and independently of the other users. In particular, each user may freely choose a viewpoint.
- **Individuality**: The displayed data set can be different for each viewer, as required by the application's needs and the individual's choice.

Software structure. As a simple, yet instructive prototype, we decided to create the 3-D equivalent of a slide-show presentation. A series of 3-D models is presented to the group, and one person (the presenter) can switch back and forth models. Each model can consist of multiple layers of information (e.g. surface, structure, annotations), which can be individually turned on and off by one participant without affecting the others' display.

Layers. To allow customization of the display, we introduce layers similar in concept to the ones found in technical illustration programs or CAD packages: Data is separated into disjoint sets according to semantic considerations (e.g. floor plan with walls only - furniture - measurements). Display can be turned on and off for every layer individually. Users may see the same model and at the same time not see the same model, as everyone sees a different set of aspects of the same thing. This is useful if professional people (e.g. an architect) talk to inexperienced people (e.g. customer), or if people with different interest (e.g. designer and engineer) collaborate.

Annotations. While it is often true that illustrations and graphics make difficult concepts clearer than textual explanations can, for complicated models a legend that explains important parts and gives names is just as important. The system will provide a possibility to link text to specific 3D points of a model. The text is then displayed “in place”, but in 2D overlaid onto the 3D image similar to [Reki95]. As the user moves his viewpoint, the text stays screen-aligned so that it is always clearly readable. The system takes care that multiple text elements do not overlap and occlude each other. By means of the layer mechanism, individual annotation sets can be switched on and off. The annotation concept will be especially useful if physical props (e.g. demonstration objects or mock-ups for education) are used, but it will also improve the quality of purely virtual presentations.

If information on the geometry of static and mobile objects is available, occlusion can be handled by rendering the virtual counterparts of physical objects in background color. In many cases coarse approximations of the physical objects (e.g. ellipsoids for participants’ heads) work sufficiently well.

Related work. Previous work on augmented reality applications concentrates on sophisticated presentation tools [Fein93], but does not examine multi-user capabilities. A few multi-user visualization systems were proposed in the last years. The CAVE-System [Cruz92] and the responsive workbench [Krüg95] are the most prominent examples. The CAVE uses LCD-shutter glasses to view stereoscopic 3-D scenes. In the CAVE users are surrounded by large projection walls, and one user is head-tracked, so that the images on all walls correspond to that viewer’s position. The viewers have the impression to be surrounded by 3-D virtual scene. The responsive workbench [Krüg95] uses one display area, which is built in a table top. Like in the CAVE viewers wearing LCD shutter glasses having the impression to see objects floating above the table. Both provide correct stereoscopy for only one viewer; for all other viewers there are noticeable visual artifacts. Furthermore, a relatively step viewing angle is necessary to achieve a good 3D impression, i.e. the viewers have to stay close to the table and side by side.

Discussion. Our architecture has several advantages over projection screen/shutter glasses based systems: With shutter glasses, correct perspective stereoscopic perception is only possible for one user – the one wearing the head tracker. Furthermore, unlike with the Responsive Workbench, the users’ choice of viewpoint is limited as they have to stay close to the display. Unlike projection screen based systems, our system allows users to customize the selection of data they see individually. Augmentation of real world objects is only possible with see-through HMDs, because screens are opaque and cannot overlay information onto physical objects. However, our setup also has some drawbacks: HMDs still have low resolution compared to large projection screens, and even the most advanced registration procedures [Azum94] often fail to produce sufficiently accurate alignment of real and virtual objects.

Implementation. Our current test system for two users consists of two Indy workstations connected over a TCP/IP network. Rendering is done on Virtual I/O I-Glasses using Open Inventor [Stra92], tracking with a Polhemus Fastrack system. With this setup, we have created a number of environments, such as an architectural model and a visualization of a dynamic system, in which simple interactions like positioning and scaling are possible. First experiments with unskilled users have proven our concept to be easily integrated into an informal working environment. The remarkable low acceptance threshold promises a successful integration with a broad range of applications. Experience shows that the precise registration of tracked objects among multiple users is of higher significance than between augmentation and reality.

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