Projection-Based Augmented Reality

Distributed Systems Seminar FS2013

Alexander Cebulla

acebulla@student.ethz.ch

ABSTRACT

In this seminar report a branch of augmented reality (AR), namely, projection-based augmented reality (projected AR) is discussed. To do so four different projected AR systems are presented: Virtual Showcase, iLamp, RoomProjector and SLAMProjector.

By a comparison between projected AR and hand-held see-through displays, which have become common through the success of tablets and smart phones, it becomes apparent that these technologies well complement each other.

Motivated by the question of what is needed to make a projector mobile, the presentation order of the devices is chosen with respect to their level of mobility. In this way, it is possible to illustrate how a device needs to fulfil one or more requirement to be able to work at a certain level of mobility. Thereby, the main requirements are:

- self-containment
- geometry-awareness
- spatial-awareness

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

General terms: Design, Human Factors

Keywords: Projection-based augmented reality, spatial displays, mobile projectors, seminar report

1. INTRODUCTION

Because of the technological progress, which allows for information and communication technology to become increasingly cheaper and smaller, the vision of creating intelligent environments becomes more and more reality. In such a setting the technology should disappear "as it becomes embedded into physical objects and the spaces in which we live and work." [16].

Naturally, the question arises of how to interact with technology, which is to a great extent invisible for the user. The answer to this, which, from my point of view, lies in the creation of a seamless mix of virtual information and reality, is the concern of AR. A branch of it, namely, projected AR, will be discussed throughout this report. In order to do so, first an intuition for AR is given. Then different types of AR displays are discussed, identifying advantages and disadvantages of each one. By comparing hand-held and projected AR displays, it becomes apparent that both technologies complement each other. This insight motivates the question of what are the requirements for creating a mobile projected AR device. To answer this, the presentation order of the to-be-presented projected AR systems was chosen according to their level of mobility. In this way, it is possible to go from spatial over easily transportable to fully mobile devices, while highlighting the requirements they need to fulfill in order to work in a certain domain.

2. RELATED TALKS

Intelligent Environments: In his talk [4] Alexander Grest provides the "Office of the Future" as an example for an intelligent environment and discusses various aspects, like telepresence, of it.

Handheld augmented reality: Reto Lindegger talks about different applications for hand-held augmented reality [11]. My list of advantages and disadvantages of handheld displays is an extension of his.

Input for Intelligent Environments: While this report will explain how a user can provide input to the different discussed devices, it is not its main concern. For a more thorough discussion of this aspect, I refer to the following talks [8, 9, 10].

3. AUGMENTED REALITY

In the following subsections an intuition for AR is given. Furthermore, a classification of the different AR displays, including advantages and disadvantages, is provided. A comparison of hand-held and projected AR displays should illustrate that both technologies well complement each other.

3.1 AR – an Intuition

As with any other complex topic, there are various definitions for it and AR is no exception. For example, one which is often used is given by [14]. Here AR is defined "as systems that have the following three characteristics:

1) Combines real and virtual

2) Interactive in real time

3) Registered in 3-D"

However, this excludes virtual information, which consists of sound or 2D images. Because some of the applications, which will be presented, explicitly use 2D images, this definition would deny them their status as an example of AR. I regard myself by no means as an expert on this topic and, therefore, will only present the intuition I gained of what AR is.

To identify an AR system as such it must fulfill the following two conditions:

1) It enhances reality with virtual information, where this information usually consists of, but is not limited to, 3D images.
2) The displayed virtual information depends on the context created by the reality, in which it is projected.

3.2 Classification

The following classification is based on [1], from which I also took figure 1.

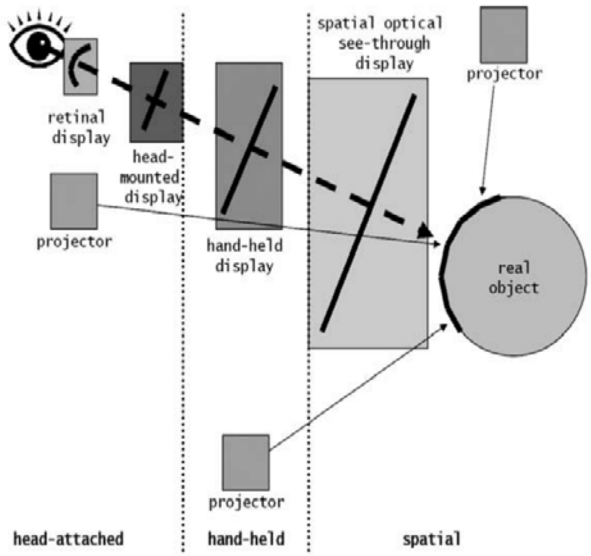

Figure 1: Image generation of different AR displays.

In order to provide a classification first the term see-through display must be explained. The basic idea behind this is to have a display, which can overlay virtual information over a real environment. Therefore, if the display does not show information at a certain location, one can see through it. There are two basic approaches to realize such a display:

1) Video-mixing: Here the real environment is filmed by a camera, then combined with virtual information and finally displayed.
2) Optical: Here an optical combiner (e.g.: a half-silvered mirror or a transparent monitor) is used, such that one can observe the real environment, while it is overlaid with virtual information.

Figure 1 shows three domains, each of which will now be discussed:

Head-attached displays: As implied by the name the user has to wear the display on his or her head. Two of the depicted displays are:

1) Retinal displays, which use a low-powered laser to project an image directly onto the retina of the user.
2) Head-mounted displays (HUDs) were traditionally the displays of choice. Despite that, they were replaced in recent years by hand-held displays. Similar to them they are also see-through displays.

Please note that for the rest of this report head-attached displays are ignored and I refer to [1] for an analysis of these displays.

Hand-held displays: Almost all hand-held displays come nowadays in the form of tablets or smart phones, which can be classified as video see-through displays.

The following list of advantages and disadvantages of smart phones is based upon [11]:

Advantages:

- Relatively cheap
- Common and available
- Have a range of sensors already built in: GPS, accelerometer …
- Unlimited field of view through moving the smart phone around

Disadvantages:

- Small display, therefore, if one does not want to move the phone all the time, the field of view is limited.
- User might need to hold / move the device over an extended period of time
- The resolution, in which the reality is displayed, is limited by the resolution of the camera and/or the display screen. This is a general problem of the video mixing technique. However, it must be noted that the resolution of the camera and screen of smart phones has drastically increased over the recent years.

Spatial displays: The main difference between spatial and body-attached displays is that the former free the user from all or most of the needed technology and instead directly integrate it into the environment. They, therefore, allow for larger displays and a better control over environmental factors, while sacrificing mobility.

Projected AR displays: As one can see from figure 1 it is possible to make use of projectors in every domain. In addition, the following advantages become apparent:

- Projectors can directly project onto the object; therefore, the projector and its image must not necessarily be located in the same domain.
- The eye of the observer does not need to switch focus between the image plane and the real environment, thus, projected AR allows for an easy eye accommodation.
- The image plane of projectors does not need to be a rectangular plane. It can have various shapes and might be non-planar.
- A projector can be much smaller than the image it projects.

Two disadvantages of projectors are:

- Low light-intensity. While this is normally not a problem for stationary projectors, it can be a major challenge for mobile projectors. Depending on the application a trade-off between battery life, light intensity and projector size must be found.
- The image is always projected into the scene. While this is normally seen as an advantage, it might be a problem if one wants to display information in mid-air.

3.3 Comparison of Projected AR Displays and Hand-held See-through Displays

By comparing mobile projected AR device with a hand-held see-through display (see table 1), it becomes apparent that both technologies complement each other.

	Hand-held see-through displays	**Mobile projected AR displays**
Outdoor usage	Standard application of smart phones	Problem of low light intensity
Displaying objects in mid-air	Possible	Only by using a mobile plane
Computing ergonomics	User must be active; needs to move/hold the display	Lazy; user can let his/her hand hang on his/ her side
Display size	Limited by the device size	Theoretically unlimited
Image plane	Planar; separated from the real objects	Can be non-planar; is near the real objects, allows for an easy eye accommodation

Table 1: Comparison of projected AR and hand-held see-through displays (advantages highlighted in grey)

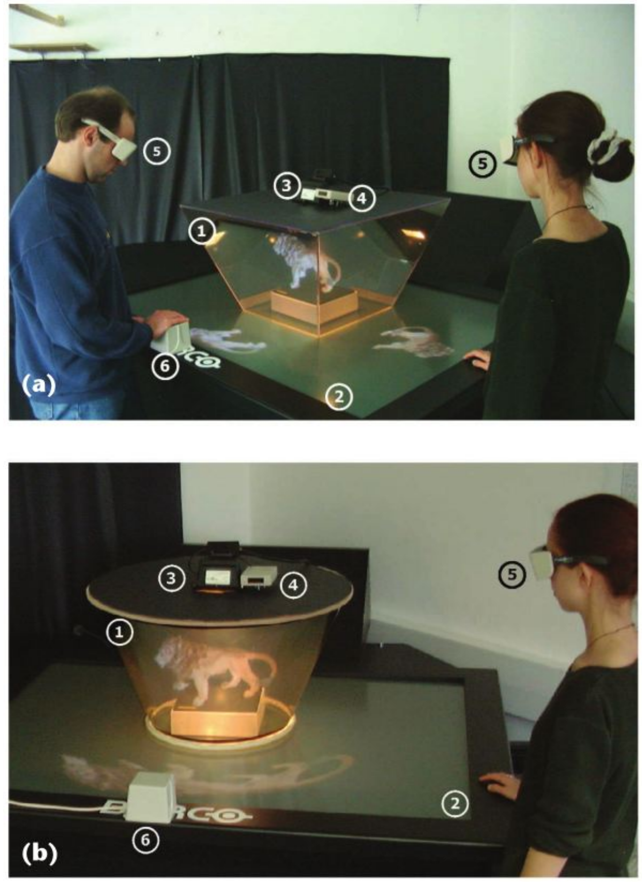

Figure 2: General build of the Virtual Showcase

4. SPATIAL DISPLAYS

Through the combination of a beam splitter and a projector or monitor, it is relatively simple to create a spatial optical see-through display.

4.1 Virtual Showcase

The Virtual Showcase can be seen as the standard example for a spatial projection-based AR display and was first discussed in [3]. Later a case study was conducted, which is described by [2].

Build: There are different variations of the Virtual Showcase introduced in [2, 3]. However, these variations share a general build, illustrated by Figure 2 [3]:

1)
    a) Convex assembly of four half-silvered mirror beam splitters
    b) Single mirror beam splitter
2) Projection screen
3) Controllable light projectors
4) Infrared emitters
5) Shutter glasses
6) Electromagnetic tracking device

The projection screen for these two builds was realized with a single CRT projector. Notice that version a) can support up to four users, while version b) can only support one user.

Function: The object, which one wants to augment, is placed inside of the beam splitters. Then, depending on the position of the user, the virtual information is predistorted and projected onto the projection screen. It is reflected by the beam splitter and, thereby, overlaid over the real object behind the beam splitter. Through the use of the controllable light projectors, it is possible to illuminate the real object on a per-pixel basis. It is, therefore, possible to generate realistic occlusions effects and even to only display the virtual information, by completely fading out the real object (i.e. not illuminating it at all).

Application and Case Study: The proposed application, which was used to conduct the case study, "was to use the Virtual Showcase for presenting the state-of-the-art scientific findings of a leading paleontologist to a novice audience in an exciting and effective way" [2]. The idea was to augment the skull of a dinosaur with muscles and missing bones. Additionally, the execution of a so-called power bite should be visualized in the form of an animation. For this the real skull was faded out completely as described above.

An interesting result of the user study was that many users thought a Virtual Showcase is suitable for a Museum exhibit. However, the case study also revealed that the Virtual Showcase was too expensive. This encouraged the authors to create another version of the Virtual Showcase, where they replaced the CRT projector with four CRT monitors, thereby, increasing the resolution of the display and decreasing its cost.

4.2 Discussion

In my opinion the combination of beam splitters with projectors or monitors is an elegant way of creating spatial optical see-through displays. Because such displays are stationary, they allow for a great degree of control over environmental factors. This was illustrated by the Virtual Showcase through the use of the light projectors, with which a pixel-wise illumination is possible. It is, therefore, feasible to create high quality AR applications, which perfectly fit into the context of an exhibition. However, with respect to the classification of AR displays, this paper highlights more the advantages and disadvantages of spatial displays in general and not so much of projected AR displays.

5. TRANSPORTABLE PROJECTORS

To create projected AR displays, which can be easily transported, one obviously needs more than just a projector. In [15] the following three requirements were identified:

A projected AR display should be:

- Self-contained: There should be little to no dependence on the infrastructure.
- Geometric-aware: It must have an understanding of the geometry of the display surface, as well as the orientation of the projector.
- Self-configuring: The ad-hoc integration into a cluster of projectors should be possible.

in order to be easily transportable.

5.1 iLamp: Creation of an Self-Contained Projector

A device, which fulfills the above conditions, is the iLamp. It was presented in [15].

Build: To make a projector geometric-aware a tilt sensor and a camera were added. Moreover, the projector was enhanced with computing abilities, a user-interface and wireless communication to allow it to be self-configuring. All parts were combined into a single self-contained unit (see Fig. 3 [15]).

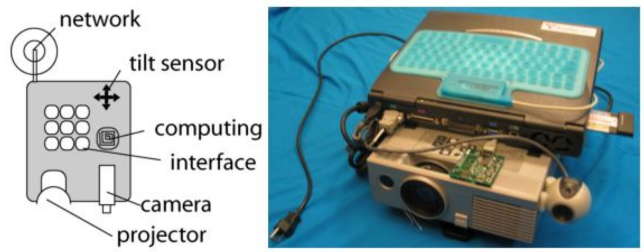

Figure 3: Overview of the iLamp

Projection onto a non-planar surface: As it was already mentioned, projectors have the advantage of directly projecting onto objects, which can be of arbitrary shapes. An easily transportable projector should be able to, for example, use surfaces like room corners or columns. The goal, thereby, is to minimize the distortion of the projected image, regardless of the observer's viewpoint (see Fig. 4 [15]). A method for achieving this was presented in [15], where the distortion was measured by conformality:

1) Use the camera of the unit to capture images of projected structured light.
2) Generate a 3D mesh.
3) Compute a conformal mapping between the to-be-projected image and the 3D mesh, which is then used as a texture map.

An explanation of structured light is given in [13].

Figure 4: Distortion correction for an image projected onto a non-planar surface.

5.2 Clusters of Projectors

A problem of transportable projectors might be a low light intensity. To counter this problem one might dim the room or reduce the distance between the projector and the real object on which it projects. Depending on the application these solutions might not be acceptable, especially since the later one will reduce size of the projected image.

A possible solution is to combine different projectors into a cluster. This is possible, because the iLamp is self-configuring. The concrete procedure an iLamp must execute in order to join a cluster is described in [15] and can be summarized as follows:

1) During the first step it is checked, if the new projector belongs to the cluster of other projectors, i.e. if their projected images overlap. To check this, the new projector sends a 'Ready to join' message and projects a light pattern. If this pattern is seen by any other camera, then the second step is executed.

2) This step is called quick calibration. One after another each projector projects a structured pattern (i.e., a checkerboard), while all the other projectors have their cameras activated. From the recorded information each unit computes the largest inscribed rectangle of all the projected patterns and then checks how its own projection fits into this rectangle. After that it can project the corresponding image part. The result is a uniform projection (see Fig. 5 [15]).

Figure 5: A cluster of projectors forming a seamless display

5.3 Beamatron: A Steerable Displays

Another possibility to increase the field of view of an AR device was already discussed for hand-held displays, namely, the movement of the display. To successfully apply this idea to a projector, it must solve the following problems:

- The projection should stable during the movement of the device.
- It must be able to project images 'correctly' on arbitrary surface.

To solve these problems geometric-awareness is required.

An example for a projector, which solves these problems, is the Beamatron. It was presented in [17].

Build: To allow for a steerable display, a video projector was mounted on a light platform. Furthermore, a Kinect sensor was attached to it.

Figure 6: The Beamatron

Stabilizing Projected Graphics During Movement: When a moveable projector is moved, while it projects an image, this movement must be taken into account in order to stabilize the projection. For example, if a real object is augmented, the virtual information should remain attached to this object, even when the projector is moving. To solve this problem the authors of [17] built a circuit board, which directly connects to the built-in pan and tilt sensors of the platform. They were, therefore, able to accommodate for any movement of the projector.

Understanding the Geometry of the Display Surface: Through the use of the Kinect sensor, in combination with Kinect Fusion [5], the unit is able to obtain smoothed depth images of its environment (see Fig. 7 [17]). These depth images can then be used to project images 'correctly' onto arbitrary surfaces as described in the next section.

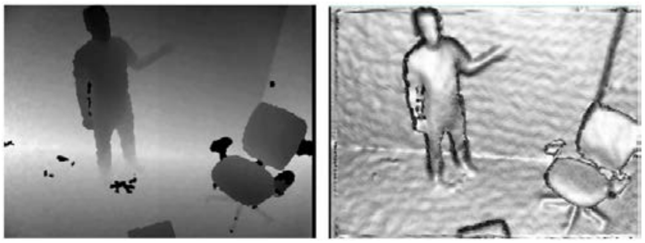

Figure 7: Multiple depth images are combined into one smooth estimate of the room geometry.

Projecting Images 'Correctly' onto Arbitrary Surfaces: It was already discussed how an image can be projected onto a real object, such that its distortion is minimized for a number of observers with different viewpoints. For the Beamatron the authors wanted that the projection creates the illusion of a real 3D object for a single observer (see Fig. 8 [17]). To achieve this two rendering passes are required:

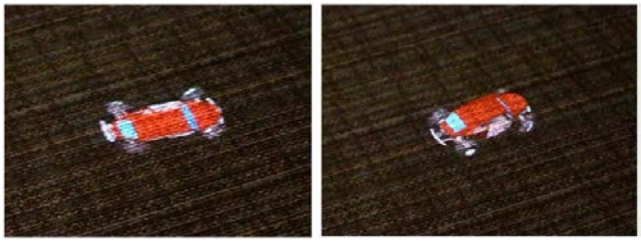

Figure 8: Rendering of a toy car. Left: Without projective texturing; Right: With projective texturing

1) Render the real objects along with the virtual objects from the point of view of the user.
2) Use the result as a texture map while rendering the real geometry.

Keeping Track of the User Position: Often the sensing capability of an easily transportable projector is limited by the condition of being self-contained. For example, the Beamatron as described so far can only sense activities, which happen in the field of view of the Kinect sensor. To overcome this problem the authors decided to extend the sensing abilities of the Beamatron by adding infrastructure in the form of three Kinect sensors. These sensors were mounted – two horizontally and one vertically - in the corners of the room. By using their array microphone it was possible to localize the user while he or she speaks (see Fig. 9 [17]). Furthermore, he or she could give commands, which were recognized by the Beamatron.

Application: An application given by the authors is the Beamabuggy. A user controls a toy car with a steering wheel. Because of the geometric-awareness of the Beamatron, the virtual car is rendered correctly from the viewpoint of the user, where this viewpoint was determined through the sound localization described above. Furthermore, the car realistically reacts to the real environment, e.g. it is possible to jump over a ramp (see Fig. 10 [17]).

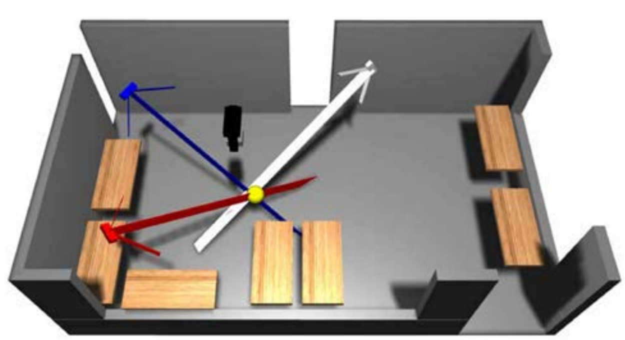

Figure 9: Illustration of how the array microphones are used to localize a user.

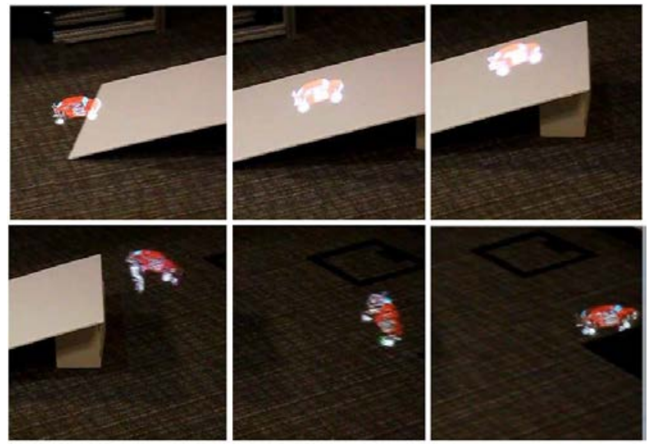

Figure 10: Because of geometric-awareness a virtual object can react realistically to the real environment.

5.4 Discussion

Because projectors can create large displays, without being large themselves, they are well-suited for creating AR devices, which can be transported easily and still retain some of the advantages of a fully stationary display.

Three important requirements were identified in [15], which must be considered in order to create such an easy-to-transport device. From my point of view, the most important one is the geometric-awareness. Through it important problems, like:

- Projecting an image, such that it appears 'wall-papered' onto a real object or to be 3D.
- stabilizing the projection during movement

could be solved.

To tackle the problems of low light-intensity and a limited field of view, two solutions were presented:

- Creating a cluster of projectors
- Making a single projector steerable.

Through the latter solution it became apparent that there exists a trade-off between how self-contained or independent a unit can be and how much it can sense.

In the next section, I want to discuss further requirements needed to go from a projector, which can be oriented in different ways, but remains fixed in space, to a fully mobile projector.

6. MOBILE PROJECTORS

There is an important difference between a mobile and easily transportable projector. While the latter one might need to be aware of its orientation or the shape of the projection surface, the former one, additionally, must be able to determine its position relative to the scene. This ability is substantial for mobile projectors and requires spatial-awareness.

Therefore, the following requirements can be identified as requirements for a mobile projector:

- Self-contained: There should be little to no dependence on the infrastructure.
- Restriction on size and weight: Obviously the size and weight of the unit are limited, depending on how the mobility of the device is realized (e.g. is it carried by a human or mounted on a movable rack).
- Spatial-awareness: The system infers the location and the orientation of the device in the 3D space of the real environment.
- Geometry-awareness: The system constructs the 3D structure of the world (User, Furniture, Walls …) around it.

The definitions of spatial- and geometry-awareness were given in [12].

In order to show possible methods for achieving spatial-awareness, three mobile projectors will be presented:

1. An iLamp, which can determine its position relative to some markers attached to the scene.
2. The RoomProjector, which utilizes four Kinect sensors mounted on the ceiling at the mid-point of each room wall
3. The SLAMProjector, which uses the Simultaneous Localization and Mapping (SLAM) system described in [6]

The RoomProjector and the SLAMProjector were introduced in [12].

6.1 Infrastructure-based and Infrastructure-less Approaches

Clearly, the iLamp and the RoomProjector are dependent on some form of infrastructure. This, however, is in accordance with the provided definition for being self-contained. Furthermore, as discussed for the Beamatron, the sensing capabilities of a completely self-contained device might be limited. Therefore, to overcome this, a device might have some dependence on the infrastructure.

6.2 Making an iLamp Mobile: Spatial-awareness Through Markers

The build of an iLamp was already explained in section 5.1. Notice that this build already fulfills the requirements for an easily transportable system. Therefore, it is self-contained and geometric aware. In order to also make it spatially aware, a simple, infrastructure-based method is discussed in [15]. Because the requirement for geometry-awareness is realized through a camera, an iLamp is able to identify markers attached to the real environment. Since the size and position of the markers are known, the device can calculate its position relative to a marker. In addition, these markers can encode a unique identity (i.e. through color combinations), which allows the device to identify individual objects. It can therefore project specific information onto them.

This method is relatively simple. However, it has two disadvantages:

- A marker must be in the field of view of the device's sensor (i.e. its camera).
- The device might need to be configured for each marker individually.

6.3 RoomProjector: Spatial- and Geometry-awareness Using Four Kinect Sensors

The RoomProjector uses infrastructure-based sensing to create spatial- and geometric-awareness. Consequently, its position is tracked with the help of four Kinect sensors, mounted on the ceiling at the mid-point of each room wall. Furthermore, these sensors are used to create a model of the environment and, thereby, also provide geometry-awareness.

Build: The RoomProjector (see Fig. 11 [12]) itself consists of:

- An inertial measurement unit (IMU), which determines the orientation of the device.
- A laser projector
- An IR camera and diffuse IR illumination. The camera and the projector are coaxial. A hot mirror, which is in front of the projector, reflects IR light from the scene into the camera.

In the room, four Kinect sensors are installed on the ceiling at the mid-point of each wall. Each sensor is angled down by 45°.

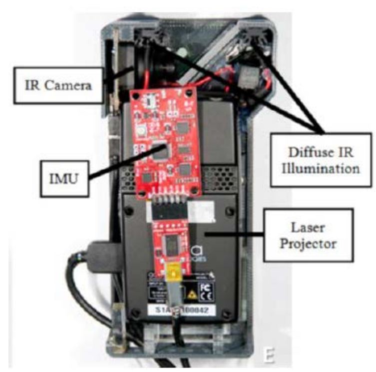

Figure 11: The RoomProjector

Registration of the Environment: To construct a model of the room and, thereby, provide geometry-awareness, an average of a number of depth map samples is computed for each of the four Kinect sensors. From these averages a single fused point cloud is generated. This is then used to construct a background mesh.

Since the whole procedure is executed while the room is empty, the background mesh can then be used to segment out the user via background subtraction.

Tracking the Projector Position: In order to use the Kinect sensors for inferring the position of the RoomProjector, the sensors must be able to identify it in a fast and reliable way. To achieve this, the projector is covered with retro-reflective tape. As a consequence, it appears much brighter in the 2D Kinect IR image, since the IR light pattern of the sensors will reflect off the projector.

The position of the projector is then triangulated as follows: First, for every sensor, the 3D positions of all pixels, which belong to the largest connected component that is brighter than some threshold, are extracted from the sensor's depth map. It is then possible to shoot rays from the center of the Kinect IR camera through each of these 3D positions. The intersections of the rays, from the different sensors, form a point cloud, of which the center of mass is the estimated projector position.

Applications: Because the onboard IR camera and the projector are coaxial, it is possible to detect the hand of the user in front of the projector. The user can therefore use his or her hand to interact with the projector. Notice that during such an interaction a shadow is casted onto the scene. Different applications are now possible. For example, menu items can be displayed at the fingertips of the user. To select an item the user bends his or her finger and the selected item will be displayed in the palm of the user (see Fig. 12 C [12]).

Another application creates for each pixel of the hand a static rigid body, which then can be used for a 2D physics simulation (see Fig. 12 A and B).

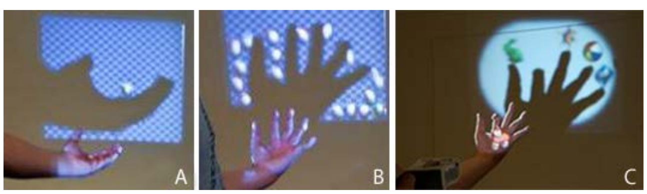

Figure 12: A) and B) Interaction between the user's hand and virtual spheres. C) Menu items are displayed around the user's hand.

These interactions happen in the coordinate space of the camera. Further interactions are possible if the data from the onboard camera are combined with those from the environment. For example, since the position of the projector relative to the environment is known and the fingertips of the user are sensed by the IR camera, it possible to shoot a ray from the projector through the fingertip and to calculate where it intersects the background mesh. This can be used to "draw" onto the mesh. It also illustrates how data (i.e. virtual ink) can be associated with a certain location in the room. The projector can then be used to "reveal" this data, thus implementing a flashlight-like metaphor (see Fig. 13 A and B [12]).

It is also possible to use the infrastructure for estimating the position of the user's hand in 3D. Thus, the user can draw directly into the room. The projector will then cast the virtual ink's virtual shadow onto the real environment (see Fig. 13 C).

This shows one possible solution to a problem mentioned during the classification. That is, how to display objects in mid-air. Besides casting virtual shadows, the authors also suggested the use of a mobile plane as a viewport into the virtual world.

Figure 13: A) and B) Flashlight-like metaphor: Virtual drawings or images are associated with a certain location. C) The user "draws" in 3D, while virtual shadows are projected.

Advantages and Problems: In my opinion, the great advantage of the RoomProjector lies in its sensing capability. As already discussed, mobile projectors often have limited sensing capabilities. However, because the RoomProjector uses its infrastructure not only to achieve spatial, but also geometry-awareness, it could, theoretically, detect any new object introduced in the room after the background mesh was calculated. For example, a user could interact with the system via body gestures.

Nevertheless, the sensing is limited by its coarseness. That is to say, only prominent objects can be recovered from the scene.

Figure 14: The SLAMProjector

Furthermore, the hybrid tracking of the projector via IMU and Kinect sensors can be noisy and error prone. The user's body might lead to an occlusion of the projector. In addition, ferrous objects in the room might interfere with the IMU, which measures the yaw of the projector through its magnetometer.

Another issue is that at the moment it is not possible to track multiple units. That is, how to differentiate between them during triangulation.

6.4 SLAMProjector: Simultaneous Localization of the Projector and Mapping of the Environment

To overcome the coarseness problem of the RoomProjector the authors created another system, the SLAMProjector. It uses a Kinect sensor directly mounted on the projector in conjunction with the SLAM system presented in [6] (see Fig. 14 [12]).

The SLAM system: KinectFusion uses the depth data from the Kinect sensor to build a model of the environment in real-time. Furthermore, it uses this model to recover the position and orientation of the projector. It, thereby, provides spatial- as well as geometry-awareness to the device.

Applications: With the SLAMProjector applications similar to those of the RoomProjector are possible. However, one can now move the Kinect sensor to the object of interest. For this reason, it is feasible to interact with less prominent objects and the coarseness problem of the RoomProjector is overcome. For example, while it is possible to “draw” onto walls with the RoomProjector, the SLAMProjector also allows for drawing onto small objects, like books.

Furthermore, interaction with objects, which are, for example, under a table or inside of a drawer is possible. Such objects would not be detected by the infrastructure of the RoomProjector.

Another interesting application, which uses the ability of the SLAM system to create a high quality virtual model of a real object, allows the segmentation of objects through touching them. It is then possible to place a virtual copy of a real object at any desired location.

Advantages and Problems: The great advantages of the SLAMProjector are its independence from the infrastructure and its high 3D sensing fidelity. As described, the SLAM system tracks the location of the projector with the help of a model of the environment, it builds over time. This however can lead to the accumulation of errors, which cause drift. Another problem arises, if the user uses his or her hand to interact with the SLAMProjector, similar to the interaction described for the RoomProjector. Since the user

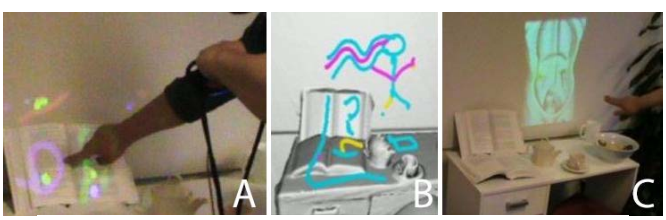

Figure 15: A) and B) The SLAMProjector allows for interaction with less prominent objects. C) A virtual copy of a real object can be created.

hides a large part of the scene from the Kinect sensor, this can degrade the tracking quality of the system.

6.5 Discussion

Three different mobile projectors were presented. A short comparison of them can be found in table 2, which is based on table 1 from [12].

	Spatial-aware	Geometry-aware	User Input
iLamp (infrastructure-based)	Markers + tilt sensor	Discrete number of planar objects	Physical button Device motion
RoomProjector (infrastructure-based)	4 Kinect sensors + IMU	Background subtraction Coarseness problem	Hand and body gestures
SLAMProjector (infrastructure-less)	SLAM system: Kinect sensor + KinectFusion	High quality model of environment	Hand gestures at arm’s length

Table 2: Overview over the mobile projectors.

Clearly, using markers is the simplest of the introduced methods for achieving spatial-awareness. Nevertheless, it allows adding spatial-awareness to any system, which fulfills the requirements of an easily transportable projector and is able to detect markers (i.e. their size and position). The most advanced method, in my opinion, is used by the SLAMProjector. It is completely mobile and still allows for applications similar to those of the RoomProjector. In addition, it creates a high quality model of the environment and, thereby, overcomes the coarseness problem of the RoomProjector. However, it has some tracking issues, especially since with the SLAM system errors can accumulate over time, which leads to drift.
The RoomProjector, on the other hand, does not have this problem, but there might be issues if the user occludes the projector from more than one Kinect sensor.

The great strength of the RoomProjector lies in its ability to sense, on a coarse level, the complete room.

7. CONCLUSION AND FUTURE PROSPECTS

In this seminar report four different projected AR systems, with varying levels of mobility, were discussed. By comparing projected AR with hand-held see-through displays, it became apparent that the advantages of one technology can compensate the disadvantages of the other technology and vice versa. Therefore, the question of how to create a mobile projected AR device aroused. I tried to answer this question by pointing out how a device needs to fulfill certain requirements in order to work at various levels of mobility.

Hopefully, it became evident through this report that there are lots of future prospects for projected AR devices. For example, spatial optical see-through displays provide a non-intrusive way of displaying information. They can increase the safety of car driving by displaying information on the windscreen. In this way, the driver can keep his or her eyes always on the street. A navigation system, which already does this, is the Cyber Navi from Pioneer.

Moving on, less serious applications might arise from the ability of projectors to project directly into the scene. In fact, entertainment systems, which can completely or partially augment a room, have already been studied [7].

Finally, speaking about fully mobile application, various companies already presented combinations between smart phones and projectors (e.g. Samsung GALAXY Beam I8530). However, to the best of my knowledge, so far none of those devices uses its projector for projected AR.

REFERENCES

1. Bimber, O. and Raskar, R. *Spatial Augmented Reality: Merging Real and Virtual Worlds*, AK Peters (2005).
2. Bimber, O., Encarnação, L.M., and Schmalstieg, D. The Virtual Showcase as a new Platform for Augmented Reality Digital Storytelling. In *Proceedings of the workshop on Virtual environments.* 2003. 39. 87–95.
3. Bimber, O., Fröhlich, B., Schmalstieg, D., Encarnação, L.M. The virtual showcase. *IEEE Computer Graphics and Applications*, 21(6):48–55, 2001.
4. Grest, Alexander. Multi-user Systems. Distributed Systems Seminar 2013, ETHZ.
5. Izadi, S., Kim, D., Hilliges, O., Molyneaux, D., et al. KinectFusion: Realtime 3D Reconstruction and Interaction Using a Moving Depth Camera. In *Proc. UIST 2011*. ACM 2011. 559-568.
6. Izadi, S., Kim, D., Hilliges, O., Molyneaux, D., et al., KinectFusion: RealTime Interactions with Dynamic 3D Surface Reconstructions, In *Proc. UIST 2011*. ACM 2011.
7. Jones, B.R., Benko, H., Ofek, E. and Wilson, A.D. IllumiRoom: Peripheral Projected Illusions for Interactive Experiences. SIGGRAPH. 2013
8. Kaufmann, Antonie. Capturing Full Body Motion. Distributed Systems Seminar 2013, ETHZ.
9. Kilcher, Sara. Touch Technologies. Distributed Systems Seminar 2013, ETHZ.
10. Kundig, Adrian. Capturing Gestures. Distributed Systems Seminar 2013, ETHZ.
11. Lindegger, Reto. Handheld Augmented Reality. Distributed Systems Seminar 2013, ETHZ.
12. Molyneaux, D., Izadi, S., Kim, D., Hilliges, O. et al. Interactive Environment-Aware Handheld Projectors for Pervasive Computing Spaces. *Pervasive 2012.* Springer. 2012.
13. Proesmans, M. Van Gool, L., and Defoort, F. Reading Between the Lines - A Method for Extracting Dynamic 3D with Texture. *Proc. ICCV 1998*
14. R. T. Azuma, A survey of Augmented Reality, *Teleoperators and Virtual Environments*, vol. 6, no. 4, pp. 355-385, Aug. 1997.
15. Raskar, R., Van Baar, J., Beardsley, P., Willwacher, T., Rao, S., Forlines, C. iLamps: Geometrically Aware and Self-Configuring Projectors. In *SIGGRAPH '05: ACM/SIGGRAPH. 2005*. Courses, 5.
16. Steventon, A., Wright, S., Eds. *Intelligent Spaces: The Application of Pervasive ICT.* Springer. 2006.
17. Wilson, A. D., Benko, H., Izadi, S., Hilliges, O. Steerable Augmented Reality with the Beamatron, In *Proc. UIST 2012.* ACM 2012. 413-422.