PapAR: Paper Prototyping for Augmented Reality

Felix Lauber[1], Claudius Böttcher[2], Andreas Butz[1]
University of Munich (LMU)
Amalienstraße 17
80333 Munich, Germany
[1]<firstname.lastname>@ifi.lmu.de, [2]claudius.boettcher@gmail.com

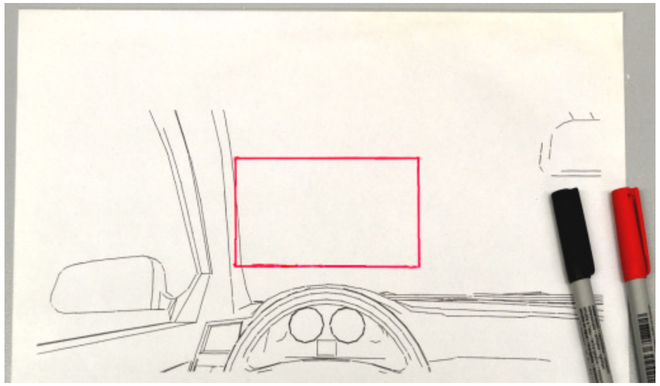

Figure 1: PapAR uses an additional layer of transparent foil to indicate the position and size of an HMD's field of view.

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Abstract
Paper prototyping is a well-established technique in traditional user interface design as it supports design teams in early development phases to communicate and discuss their ideas. Unfortunately, there is no equivalent technique for the development of augmented reality (AR) applications. We developed PapAR, a prototyping technique with the same simplicity as using pen and paper but taking into account important specifics of AR applications. By drawing on two layers instead of one, with PapAR it is possible to represent the dynamic behavior of different content stabilization techniques as well as the interplay of virtual content and the underlying real world (Fig. 1). We used PapAR in the early design phase of a user interface, which is specifically designed to be displayed in a head-mounted display (HMD) in the car. In this paper we first present the PapAR technique itself and then discuss our first experiences of using it.

Author Keywords
Paper prototyping, head-mounted displays, augmented reality, mixed reality, in-vehicle user interfaces.

ACM Classification Keywords
H.5.2 [INFORMATION INTERFACES AND PRESENTATION]: User Interfaces – Prototyping

PAPER PROTOTYPING FOR NOVEL UI PARADIGMS

Paper prototyping is well established in the traditional development cycle of user interface design. Especially in very early stages, it is an important technique for communicating ideas to team members and for discussing different concept variations [1]. Paper prototyping allows the design team to acquire early user feedback. It allows them to work with different ideas/concepts in parallel and encourages team members in communication and creativity [4]. This explains why paper prototyping or equivalent early stage prototyping techniques are not only used in the development process of graphical user interfaces. New user interface paradigms have arisen and developers as well as designers have tried to elaborate paper prototyping to be used in 'their' domain of user interface development. Wiethoff et al. have successfully developed and evaluated a paper prototyping toolkit for tangible user interfaces (TUI) [6]. Broy et al. have found a way to extend paper prototyping into the third dimension and have developed an equivalent technique for prototyping user interfaces for stereoscopic 3D displays [3]. Augmented Reality also represents such a novel user interface paradigm, making it difficult to apply traditional prototyping methods.

PAPER PROTOTYPING FOR AR

With the increasing maturity and decreasing price of HMDs, tracking and other basic technologies for AR, it has become technically feasible and even economically desirable to use AR interfaces in a much wider variety of use cases. This means that AR applications move from research into the economic reality, where a systematic approach to development and prototyping is a clear requirement. While it is common practice in traditional UI development to use paper prototyping in early design phases, this can be very challenging for mixed-reality (MR) applications. First, these applications are strongly connected to the underlying real world and often do not even make sense without it. Second, if developed for HMDs, content can be stabilized in different coordinate systems, leading to behavior, which is hard to reproduce in a traditional paper prototype.

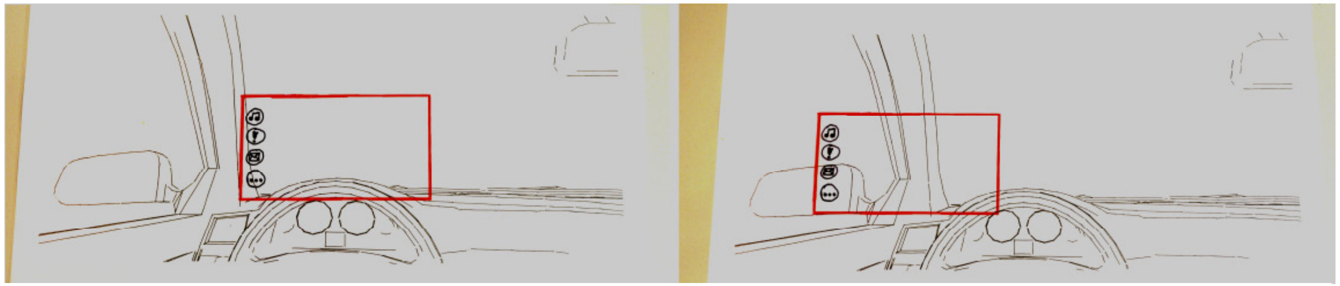

Figure 2: By using an additional layer of transparent foil, with PapAR it is possible to represent the dynamic characteristics of the display area of a head-mounted display. Head-stabilized content is drawn on the foil and can be moved in relation to the real world scenario.

In this paper we present PapAR, a paper prototyping technique for mixed and augmented reality systems. We will introduce the technique itself and then review its benefits by using it in an application design process.

REQUIREMENTS OF A PROTOTYPING TECHNIQUE FOR AR

We believe that traditional paper prototyping techniques do not apply very well to Augmented Reality systems. When developing AR or MR applications for HMDs, there are two specifics of such systems, which should be already taken into account in very early design phases.

Content Stabilization

When using an HMD as an output device, virtual content can be displayed within different frames of reference. Typically one differentiates between head-, body- and world-stabilized content [2]. While it appears fairly simple to prototype world-stabilized content (sketching a real-world scenario as well as the virtual augmentations on paper), head-stabilized content moves with the user's head and thus may interfere with real world objects in certain situations (Fig. 2).

Coexistence of virtual and real content

The second specific of such applications, which is important to consider already in early design phases, is the coexistence of virtual and real content. MR and especially AR visualizations always are strongly connected to the portion of the real world, they intend to augment.

Current see-through HMD systems usually have a diagonal field of view of 10 to 40 degrees. In contrast, human vision is capable of covering a horizontal FOV of approximately 180 degrees [5]. As a consequence, users might look at an augmented real world object without seeing the intended augmentation because the object is positioned *within their* FOV but *outside the HMD's* FOV (Fig. 3).

But also when developing head-stabilized content, it is important to have a realistic idea of how the virtual and the real content will coexist in the final application. As head-stabilized content keeps its position within the HMD's display area, it might be within the user's primary field of view and obstruct important real world information. In a car for example, it might be possible

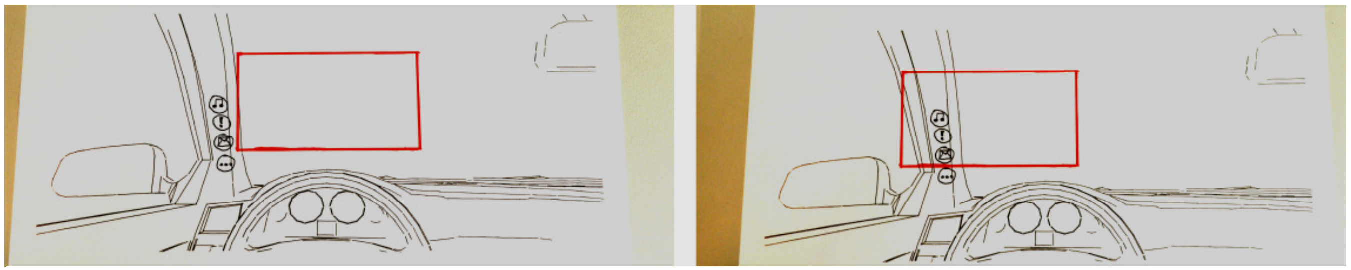

Figure 3: World-stabilized content is drawn directly on the picture of the real world scenario. In the later application, augmentations can only be seen, when the HMD's display area superimposes the augmented objects.

to find an ideal position for virtual content in one driving situation (e.g., when looking straight ahead); this position, however, might obstruct other traffic participants when the driver is turning his head in a different driving situation (e.g., glancing into the rear view mirror/over one's shoulder).

PAPAR: A PROTOTYPING TECHNIQUE WITH PAPER AND FOIL

PapAR is a prototyping technique for AR and MR systems, which is almost as simple as traditional paper prototyping but can overcome the problems mentioned above.

The main idea of the technique is to draw on two different layers, instead of using just one sheet of paper. While the first layer simply is a sheet of paper, the second layer is made from transparent foil (e.g., an overhead transparency). The real-world scenario now can be printed or drawn on the first layer in order to provide the basic framework for the application. The HMD's field of view is represented by a rectangular box on the second layer with the correct aspect ratio and FOV (in relation to the scene on the first layer). Concept developers now can draw 'virtual' content either directly on the sheet of paper (world-stabilized content) or on the transparent slide within the representation of the HMD's FOV (head stabilized content). Subsequently both layers can be moved relatively to each other, to give others an idea how the content will be superimposed to the real world scenario depending on the user's head movements.

USING PAPAR AS A PROTOTYPING TOOL

We successfully used PapAR to develop an infotainment system for car drivers. During the concept phase, two stabilization techniques were discussed: The infotainment menu structure either should be head-stabilized or cockpit-stabilized (content appears at a fixed place within the car's reference frame).

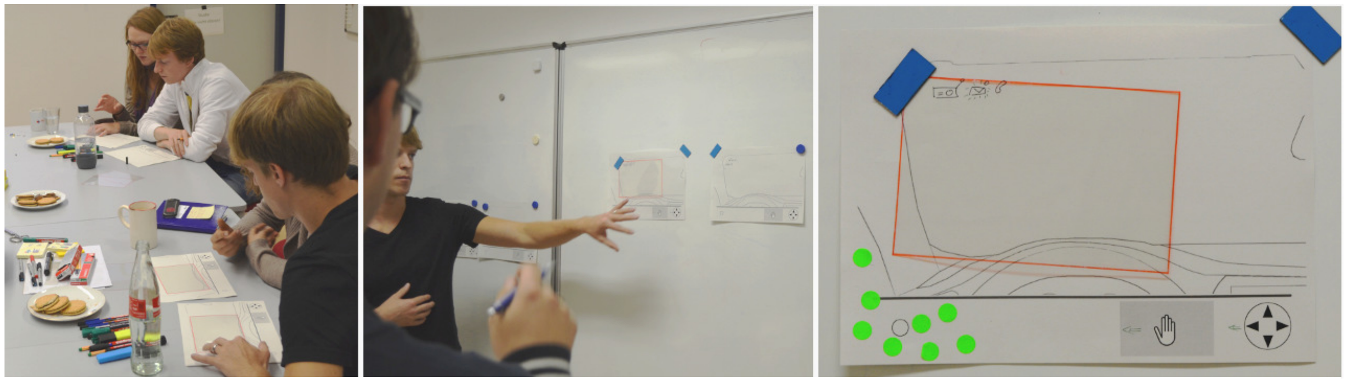

Figure 4: PapAR supports concept developers in their creative process such as working on new concepts in small groups, discussing the results and presenting them to others.

Calculation of the FOV Representation in Case of a Photograph

Assuming that

f := the focal length used for taking the picture

$Size_{Sensor}$:= the size of the camera's sensor

The FOV of the resulting picture can be calculated as follows:

$$FOV_{Photo} = 2 \times \tan^{-1}\left(\frac{Size_{Sensor}}{2f}\right)$$

In this case, one of the most important aspects during the first design phase was to pay attention to the interplay of the visualization and the car cockpit. In a first step we printed a 3D rendering of a car cockpit onto the sheet of paper (first layer). The settings of the virtual camera (position and angle of aperture) in the 3D engine were chosen to resemble typical driver's perspective. In a second step, we printed the representation of the HMD's display area on the transparent foil (second layer). Its size was calculated using the settings of the virtual camera and the FOV of the HMD we would use for later prototyping stages. The main prerequisite for concept developers was to build an interaction concept, in which the visualization neither obstructs important parts of the cockpit (e.g., the rear view mirror, instrument panel) nor forces the driver to turn his head in order to get it into vision.

One of the first concept ideas, which came up during the workshop (Fig. 4), was to place the menu items vertically along the left a-pillar. By using PapAR, concept designers very quickly realized that this location mostly was outside the HMD's display area and therefore would require the driver to turn his head each time to be able to see the virtual menu items (Fig. 3). This, however, was considered to be very distracting and therefore unacceptable, which is why this approach was dismissed after the first couple of sketches.

CONCLUSION AND FUTURE WORK

In this paper we proposed a simple, low-cost and effective paper prototyping technique, specifically designed for the requirements of MR and AR applications. In comparison to traditionally used software prototyping, concept mockups can be developed very quickly and the outcome can be seen by all concept developers simultaneously. We successfully used the technique in the early design phase for an HMD driven interface within the automotive context.

Our technique works very well with static backgrounds as the number of background images, which have to be printed, is very limited. This is why we believe, that it is especially suitable for prototyping mixed reality applications for car drivers. The typical driver's perspective as well as the necessary stabilization techniques can be realistically represented and give concept designers a first impression of the concept's potential challenges and benefits.

We used a 3D-scene to control the camera's FOV and adapted the HMD's FOV representation accordingly. However, we think that this technique could also be used with photographs. The camera's FOV can be calculated (see side bar) to maintain the relationship between the HMD's FOV and the picture of the real scenario.

In future work we will further examine our technique in the design process for AR and MR applications and extend it to using it with different output technologies (e.g., handhelds) and stabilization techniques (e.g., body-stabilized content). We further will try to provide tools which support concept developers in calculating and obtaining the correctly sized images for the background scene and the representation of the HMD's FOV.

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