

# Fata Morgana – A Presentation System for Product Design

Gudrun Klinker, Allen H. Dutoit, Martin Bauer,  
Institut für Informatik, Technische Universität München  
80290 München, Germany  
{klinker,dutoit,bauerma}@in.tum.de

Johannes Bayer, Vinko Novak, Dietmar Matzke  
BMW, 80788 München, Germany  
{Johannes.Bayer,Vinko.Novak,Dietmar.Matzke}@bmw.de

## Abstract

*Mobile Augmented Reality applications promise substantial savings in time and costs for product designers, in particular, for large products requiring scale models and expensive clay mockups (e.g., cars). Such applications are novel and introduce interesting challenges when attempting to describe them to potential users and stakeholders. For example, it is difficult, a priori, to assess the nonfunctional requirements of such applications and anticipate the usability issues that the product designers are likely to raise. In this paper, we describe our efforts to develop a proof-of-concept AR system for car designers. Over the course of a year, we developed two prototypes, one within a university context, the other at a car manufacturer. The lessons learned from both efforts illustrate the technical and human challenges encountered when closely collaborating with the end user in the design of a novel application.*

## 1 Introduction

One of the very promising application areas of Augmented Reality (AR) is the design of new products, such as cars or buildings[6]. Historically this has been the realm of Virtual Reality (VR). In VR, digital models are presented with utmost realism in expensive viewing arrangements, such as CAVEs or large projection walls. Yet, designers and architects have not yet committed wholeheartedly to the VR-approach. One of the reasons may be that special viewing arrangements such as projection walls do not permit people to view the digital models within a real environment. Moreover, it is difficult for designers to compare a new digital model with existing physical mockups – in contrast to their daily life. In car design, a typical evaluation scenario involves the comparison of a previous generation

car (e.g., the original Mini) with the mockups of new candidates (e.g., the new Mini) placed on turn tables in a large show room.

AR can help alleviate these problems by placing the virtual objects side-by-side with real objects. For example, one of the turn tables in a show room could be reserved for a virtual car. Designers can inspect it, walk around it, and compare it with other models just like they are used to looking at real cars.

The goal of the Fata Morgana project is to investigate the usability and technical challenges presented by such an application in the context of car design. We envisioned a mobile AR application, in which the car designer carries a wearable computer displaying a virtual car in a head mounted display (HMD). In the envisioned system, the head of the designer is tracked by a variety of sensors, such as a camera recognizing markers placed on the turn tables and a gyroscope. Based on the head position, a remote high-performance graphics server renders a model of the virtual car under evaluation. The image is then transmitted to the wearable for display in the HMD. The main issues we anticipated were usability issues (e.g., do the HMD and the head mounted camera interfere with the designer's work?) and technical (e.g., can the head tracking of the designer and the car rendering be done in real time?), hence, the importance of close collaboration with a real client, in this project, BMW.

We took a two step approach to develop this application. During the first iteration (4 months, 25 students and instructors), we elicited requirements from car designers, explored several competing visionary concepts, designed an architecture, and demonstrated a proof of concept prototype for review by BMW. During the next iteration (6 months, 1 student, 1 BMW staff, 1 BMW manager), we applied the lessons learned during the first iteration and built a second prototype out of pre-existing components, this time, for

review by the car designers. The focus of each iteration (exploratory vs. consolidation) and the context in which the prototypes were built (university course vs. industry project) were different, therefore resulting in prototypes that also differed sharply.

In this paper, we report on the flow and change of issues that arose during this two-iteration process and discuss several approaches towards generating suitable demonstrations, and later, operational systems. Section 2 describes the results of the first iteration. Section 3 describes the results of the second iteration. Section 4 reflects on both iterations and contrasts the two resulting prototypes and approaches.

## 2 Phase 1: Exploring the application domain

We conduct an AR project course every year, involving about 25-30 students who work on an actual system [5]. The goals of the project course are twofold: First, we expose students to a real situation with real constraints. In addition to teaching them algorithms and basic architectures, we enable them to experience first hand the constraints and limitations of each approach, hence, teaching them how to make engineering choices when building an AR system. Second, by working with novices, we have the opportunity to start from a blank page and generate many different visionary concepts for an AR application.

The project course is preceded by a brief problem definition phase during which we define with the client the scope and parameters of the problem space. In the Fata Morgana project, we interviewed a car designer, attached a video camera to his head, and recorded several sequences during a simulated design evaluation session. During the first month of the project course, we organized students into teams of 5-6 to initially further develop the requirements of the system and propose several competing concepts (one per team), phrased in terms of visionary scenarios. During a requirements review, we selected ideas from each concept, based on their originality and technical feasibility, leading to a single concept that was then realized by the whole project (see Section 2.1). From that point on, the teams collaborated by building complementing subsystems. Individual teams focused on tracking the head of the user, on producing a high-quality rendering on a remote server, and on transmitting the rendered image back to the wearable of the car design (see Section 2.2). The final prototype was demonstrated at the end of the semester to the client. During the subsequent consolidation phase, a student from the project course worked at the client site to produce a robust demonstration prototype, based on the lessons learned during the exploratory phase (see Section 3).

We now examine in more detail the requirements elicited during the exploratory phase.

## 2.1 Requirements

Currently, car designers draw sketches of a new car on paper. A modeler then converts the 2D sketches into a 3D CAS (Computer Aided Styling) model with the collaboration of the designer. The CAS model is used to mill a clay mockup that is then covered with foil to increase the realism of the model. The clay models, affixed on top of a chassis with actual car wheels are almost indistinguishable from a real car. The designer then evaluates the design and goes back to the sketches or the CAS model to correct and improve the details. Eventually, after several iterations, the clay model is presented to the members of the board that decide whether they want to build that car or not.



Figure 1. The process of modeling cars

Each iteration in this process involves many people and can take several months. The required material and the equipment is expensive and restricts the number of designs that can be evaluated. We decided to replace this tedious process by an AR system that enables designers to visualize the virtual car as soon as the CAS model is available. In Fata Morgana, the designer is looking at an empty turn table, augmented with a life-size virtual car – potentially next to a clay mockup on a second turntable. While it is not possible to completely eliminate the use of clay models from the car design process, we anticipate that the availability of Fata Morgana will enable designers to go through many more iterations in a shorter time, only using clay models for the final presentation to the board members.



Figure 2. Envisioned view of a virtual car and a real mockup – which one is more realistic?

After the idea of an augmented reality visualization system for car prototypes was brought to attention, we used several sessions with designers, modelers, and computer scientists at BMW to discuss the overall requirements of the system. We discussed acceptance issues as well as potential options for simplifying the overall problem space.

### 2.1.1 Overall setup

At BMW, the show room is approximately 25 by 40 meters. The show room includes five turn tables, each large enough for a car or a clay mockup. One of the walls of the show room is a bay window that provides natural lighting for the car model. Ceiling lights complement the natural light with configurable lightening schemes, enabling designers to evaluate the mockups under different conditions.



Figure 3. Show room at BMW

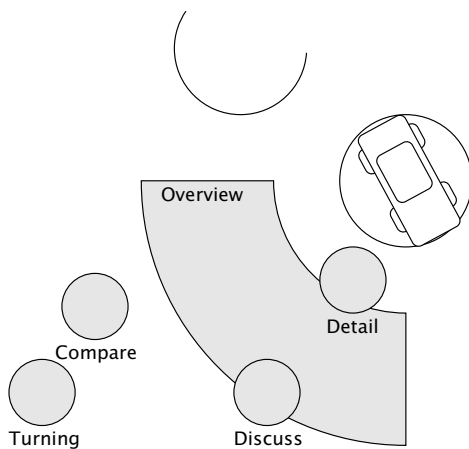


Figure 4. Setup in the show room at BMW

### 2.1.2 Basic scenarios

After discussion with the designers and inspecting the show room, we identified five different scenarios that exemplify how a car designer would use the Fata Morgana system:

- *Turning.* The car designer remains in a fixed location and looks at the car rotating on a turn table.
- *Overview.* The car designer performs an overview evaluation of the car, by walking around and turning his head to change the lighting conditions.
- *Detail.* The car designer focuses on a specific detail of the car, such as a character line on the side of the car or the shape of the front spoiler.
- *Discuss.* The car designer discusses the car under evaluation with a colleague.
- *Compare.* The car designer compares two cars, for example, an existing car and a new design.

In order to get quantitative information on system requirements, we asked a car designer to act out each of these scenarios while recording his visual impressions with a head-mounted camera. To this end, he inspected a real car on a turn table as if it was a new design. In the Fata Morgana system, the designer would be looking at an empty turn table, augmented with a life-size virtual car – potentially next to a physical mockup or real car.

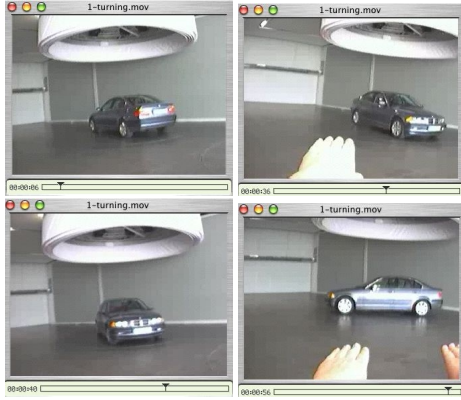
The recorded videos provided us with specific information on the amount and the kind of motions a designer is likely to produce when looking at new car designs. Next, we look at each scenario in detail.

#### 2.1.3 The 'Turning' scenario

In this scenario, the car rotates on a turn table in front of the designer. The designer stands at a considerable distance (10–11 m) in order to see the entire car. Typically, the designer rapidly moves forward and backward (1 m) in order to get a better impression of the interplay between car shape and illumination from the light reflections he sees. He doesn't turn his head much – the entire car stays within the field of view for the entire time. He often puts his hands into his field of view, using them as a reference frame.

#### 2.1.4 The 'Overview' scenario

In this scenario, the car does not turn. Instead, the designer moves freely within the scene to get an overview of the car from several viewing angles (e.g. a side view and a front view). Due to the walking motion and head rotations, the camera image sways a lot. Furthermore, the background changes significantly, ranging across several large walls.



measurements	Turning
distance to object	10–11 m
positional area	1 m <sup>2</sup>
positional speed	standing
view angle	±20 deg
rotational speed	10 deg/sec

**Figure 5. Snapshots and measurements from the 'Turning' scenario**

The floor and the ceiling are occasionally – but not consistently – within the field of view.

### 2.1.5 The 'Detail' scenario

In this scenario, the designer inspects a certain aspect of the car in great detail. Neither the car nor the designer move much, except for head motions. The design is much closer to the car than before (within 0.5–2m). Occasionally, the designer places his hand next to the feature he is observing.

### 2.1.6 The 'Discuss' scenario

In this scenario, the designer discusses a new car model with a colleague. Both stand at an intermediate distance from the car (2–3 m) such that most of the car is in their field of view. Characteristic for this scenario are fast head rotations from the car to the colleague and back to the car, followed by longer periods during which the designers are each looking at the car.

### 2.1.7 The 'Compare' scenario

In this scenario, the designer compares two cars. The designer stands at a suitable distance from both cars (4–8 m) such that he can easily look back and forth. Typically he stares at one car for a while and then rapidly turns his head to the other one for comparison. Figure 9 illustrates such



measurements	Overview
distance to object	2–8 m
positional area	30 m <sup>2</sup>
positional speed	walking (1–2 m/sec)
view angle	±80 deg
rotational speed	45 deg/sec

**Figure 6. Snapshots and measurements from the 'Overview' scenario**

head rotations between an empty turn table (meant to exhibit an AR-display of a virtual car) and a second turn table with a real car.

## 2.2 Design issues and possible technical solutions

In the project course, we identified the following system design issues as the most critical:

- Mobility:** Designers need to be able to roam freely within the show room. Consequently, they need to wear a portable system showing them the virtual car model on the designated turn table in real time.
- High fidelity:** Designers are used to high-end graphics systems and will not accept poor graphical quality. Consequently, the system needs to include a high-end graphics server. Moreover, because of the mobility requirement above, the wearable computer needs to communicate with the graphics server through a wireless network. The use of such a network, however, raises the issue of handling network failures and slow downs during design evaluations.
- Robust user tracking in a large environment:** In the recorded scenarios the designer demonstrated significant head motions, resulting in tremendous changes in the surrounding scenery. The distances and



measurements	Detail
distance to object	0.5–2 m
positional area	1 $m^2$
positional speed	standing
view angle	$\pm 60$ deg
rotational speed	60 deg/sec

**Figure 7. Snapshots and measurements from the 'Detail' scenario**

the speed of the motions involved would defeat any existing tracking solution. This raises the issue of finding a hybrid solution that is robust enough to deal with all the scenarios we identified.

Next, we look at the issues of mobility and high-end rendering in Section 2.2.1. We examine the issue of robust tracking in Section 2.2.2.

### 2.2.1 Distributed rendering

The need for a remote high-end graphics server in the Fata Morgana system is obvious: today's wearable systems cannot yet produce the photo-realistic renderings of digital car models that designers are accustomed to. Thus, Fata Morgana needs to be able to request such high-end services via a wireless network.

Yet, such network services might not be readily available at all times. First, the network might be congested. Second, if more than one designer are working in the show room, parallel requests from each of them may overload the remote graphics server. Third, the user could be moving so fast that rendered images are already outdated by the time they are received by the wearable. At this point, it might be advantageous to just show a 'quick-and-dirty' wire-frame or low resolution rendering of the car according to the most recent user position rather than a beautiful rendering for a long-gone user position. Furthermore, concepts of *speculative computing* could be employed to build systems with



measurements	Discuss
distance to object	2–3 m
positional area	2 $m^2$
positional speed	standing
view angle	$\pm 90$ deg
rotational speed	180 deg/sec

**Figure 8. Snapshots and measurements from the 'Discuss' scenario**

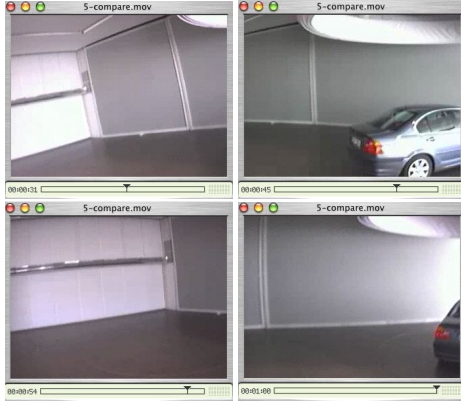
several high-end graphics servers which each generates a detailed rendering from a slightly different user position – as predicted with a known amount of variance from a user motion model.

To this end, it is advantageous for the Fata Morgana system architecture to include a concept which allows for the inclusion of one or more local or remote graphics servers of different quality levels – all feeding into a mixing module on the wearable system which decides at run-time which rendering should be displayed, based on the current user position and the positions that were used to compute the rendering.

### 2.2.2 User tracking

User tracking in a large show room is not trivial. Due to the large size of the show room, it is not easily possible to transfer tracking concepts that have proven to be robust and reliable in the corner of a laboratory to the Fata Morgana scenarios:

- *Marker cluttering.* Car designers cover a wide area while moving about the show room. In particular, head rotations result in tremendous, very fast, changes in the background scenery. Any inside-out system [8] that requires the known placement of several markers in the scene background is doomed to fail. Too many markers would have to be installed on the show room walls for the system to work reliably and robustly. More-



measurements	Compare
distance to object	4–8 m
positional area	2 m <sup>2</sup>
positional speed	standing
view angle	±90 deg
rotational speed	180 deg/sec

**Figure 9. Snapshots and measurements from the 'Compare' scenario**

over, it is unclear whether designers will appreciate the presence of unfashionable markers throughout the show room.

- *Changing environment.* The show room at BMW is used by different groups to present cars to a broad range of audiences. Consequently, the lightening, decorations, furniture, and background colors often change as a function of the event. Such changing conditions introduce difficult challenges when developing a robust optical marker recognition system.
- *Distance.* As an alternative to optical markers, we considered using infrared LEDs. These have the advantage to be invisible to the user. However, small battery powered LEDs do not project light across large enough distances to be useful in our case.

Within the project course, students suggested using a hybrid tracking approach: a camera (e.g., an Omnicam [7]) centered on or above the turn table could track designers moving in the vicinity of the virtual car. To this end, designers would wear special markers by which they can be identified. Anybody in view of this central camera is a candidate for seeing the augmented car on the turn table. People outside this scope are ignored. Subsequently, the wearable systems of candidate viewers are contacted and informed of their newest approximated position within the scene. The wearable system then is free to accept the positional infor-

mation or to use its own local tools to determine a more accurate position.

## 2.3 Prototypical demonstration system

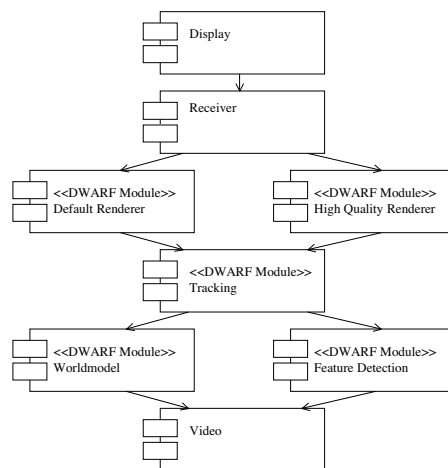
### 2.3.1 Base system

For the base layer of the *Fata Morgana* system we used DWARF[1]. DWARF is a framework for the communication infrastructure of a not necessarily wearable augmented reality system and provides additionally several reusable components and blueprints for a wide range of applications.

DWARF uses a two-stage communication protocol where the first stage is responsible to set up communication channels (in our case, CORBA events) and in the second stage, the whole communication runs only using these channels without the overhead of an additional communication layer. Therefore we were able to have the tracking running on one machine while the graphic rendering was done on a second, but still get acceptable performance over the network.

Additionally, in our special case the modular and dynamic architecture of the DWARF framework enabled us to have several teams of students work on different components of the overall system without having them to worry much about the communication between the components. Also, we were able to reuse some existing components for the final system as well as for communication stubs.

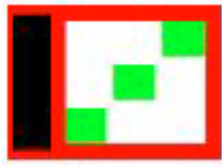
### 2.3.2 Fata Morgana I components



**Figure 10. Fata Morgana I architecture**

The Fata Morgana I system was composed of the following components:

- **Video** This component acquires individual frames from the head mounted camera and forwards them to



**Figure 11. Tracking pattern**

the other subsystems.

- **World model.** This component maintains the central data structure of the system. For example, it stores the coordinates of the markers, the cars, and the users, as well as references to the geometrical models representing the cars.
- **Feature detection.** This component is responsible for detecting new markers in the video frames and then forwards the image coordinates of the newly discovered marker to the tracking component. The students decided to use marker patterns similar to the one shown in figure 11.
- **Tracking.** The tracking component is responsible for computing the position of the current user based on the positions of the detected marker in the video frame and the actual position of the markers in the world. This component uses the Tsai algorithm [9] to incrementally compute the current user location, using the previous position for calibration initialization.
- **Low-quality renderer** The low-quality renderer produces a fast rendering of the car based on the current position of the user. It usually runs on the local wearable computer. With the use of DWARF, however, the different renderers can be configured to run anywhere on the network. The rendered graphics along with the user position that was used to produce it is forwarded to the receiver component.
- **High-quality renderer** The high-quality renderer is functionally equivalent to the low-quality renderer, except that it runs on a different machine than the rest of the system. It uses more sophisticated algorithms to generate the car graphics, and hence, can take more time to do so.
- **Receiver.** The receiver component selects the best graphics based on the current user position and the position used by each renderer to produce the most recent graphics.

For the first Fata Morgana prototype, we made several simplifying assumptions, due to cost and time pressure. We

used many large A4 optical markers for tracking that were distributed on the turntable and on the walls of the show room. The markers were tracked from a head mounted camera, with the feature detection and tracking subsystems running on a local machine. The gyroscope sensor was not included in the first prototype. A remote graphics server was simulated by using a second machine on the network. However, the local and remote rendering components were not functionally different.

### 2.3.3 Client acceptance test

The goals given to us by the client where to explore as many options and concepts as possible. The focus was on generating many visionary ideas and not necessarily ideas that could be realized quickly.

The final presentation to the client included four different paper concepts that were presented to the client, including a car configurator that enabled the designer to change wheel rims and body colors using speech recognition. To make the concept presentation more concrete, we demonstrated the Fata Morgana I system on a 1:24 scale wood model of the show room, using a laptop and a firewire camera as a simulated wearable and a desktop machine as remote graphics server. A rate of about 1 frame per second was achieved with few optimizations and low cost hardware. The prototype was then used to explain the technical trade-offs that were identified during this phase. The demonstration, which was beyond the client's expectation, triggered the decision to hire one of the students of the project course to build a simpler but better performing prototype for the purpose of demonstration to the end user. This is the topic of the next section.

## 3 Phase 2: Consolidating the lessons learned during the exploratory phase

The second phase of the project was started with the goal of building a demonstration system, Fata Morgana II, on BMW's premises such that designers would be exposed to the new technology more directly.

### 3.1 Changing requirements

In Phase 2, the goals shifted from exploring general, visionary concepts of building an idealized AR-system for model design towards starting an engineering effort to build a small, working system that is well integrated with already existing software at BMW. Priorities needed to be adjusted accordingly and trade-offs had to be made:

- **High fidelity at any cost.** The work with designers showed that they will not tolerate low-quality presentations of their models because this is counterproductive



**Figure 12. Augmented desktop of a car modeler**

to their task of evaluating high-quality designs. Thus, there is no use for a low-quality local renderer.

Accordingly, Fata Morgana II is not split into a local and a remote renderer. Rather, the entire AR-system is designed to view high-quality renderings of a powerful – yet stationary – graphic server as fast as possible.

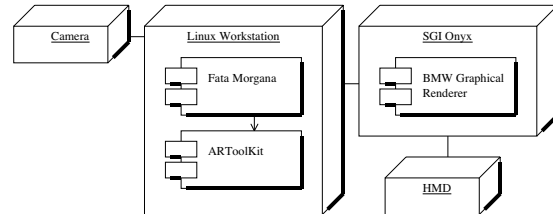
- **System failures cannot be tolerated.** The high-end graphics server is a multi-user system and central to the productive work of the entire modelling group. Experimental use of the system to develop research prototypes is only acceptable if it doesn't interfere with other work. In particular, it is unacceptable to install system software that is still brittle and could cause the server to crash.

For such reasons, it was currently not yet possible to use the DWARF middleware. Instead Fata Morgana II was integrated directly with the already existing graphics system.

- **User mobility is not absolutely necessary.** Attaching the system this closely to services of the high-end rendering system meant that user mobility had to be sacrificed. In Fata Morgana II, the HMD is attached directly to the graphic server to support maximal quality and throughput. Thus, the user cannot roam the show room in this prototype.
- **Robust user tracking – not necessarily in the show room itself.** Consequently, user tracking could also be confined to a small area – thereby opening the way to use already existing tracking systems, such as the ARToolKit [2].

According to the newly defined requirements, the demonstration system was planned to present cars on a designer's desk, using the *Magic Book* approach [3]. Designers can look through a book of different car models. Whenever they open a new page, a new, special symbol on the page indicates to the Fata Morgana II system which car model should be presented – and it pops up from the page.

## 3.2 System architecture



**Figure 13. Fata Morgana II architecture**

### 3.2.1 Fata Morgana II components

Fata Morgana II consists of three major components, the main component, a tracking component, and a rendering component which is set up as a client-server arrangement.

- **ARToolKit** The ARToolKit is currently used as the tracking system. It is integrated into the overall system via a suitable wrapper. Due to this wrapper, we are providing a more abstract interface between the tracker and the remaining Fata Morgana system – in the expectation that we will be able to exchange the toolkit for other tracking modalities when necessary.
- **BMW Graphical Renderer** The renderer is based on a pre-existing high performance graphics server of the designer group at BMW. The server is capable of rendering high-quality designs in real-time in VR-oriented projection environments. Accordingly, it is well suited to satisfy similar requirements for Fata Morgana II.
- **Fata Morgana Application** The third component initializes the system and maintains the overall control of the system, reacting to user interaction via a GUI and forwarding information to the rendering and tracking components.

The system is deployed on two machines, an SGI Onyx and a Linux Workstation. For system safety and efficiency reasons, only the high end graphics server runs on the SGI machine. All experimental software related to the Fata Morgana prototype resides on the Linux workstation.



The Linux Workstation reads the video stream from a firewire camera. The ARToolKit-based tracking component gets the position and ID of the marker that is shown on the current page of the magic book and sends it across the network to the SGI ONYX graphics server.

The SGI machine renders the image by placing the virtual camera at the position determined by the AR-ToolKit. The optical see-through head-mounted display (Sony Glasstron) is attached directly to one of the output channels of the SGI, thereby minimizing the display lag.

### 3.3 Feedback from Designers evaluating the system

Fata Morgana II is currently being presented to a number of designers and other BMW staff. So far, most designers preferred commenting informally on the system rather than filling out a questionnaire.

Everybody indicated high interest in the use of AR for car design applications. Presentation speed and resolution were considered to be the most critical issues, followed by the ability to provide geometrically correct perspective projection – an issue commonly encountered on projection walls that can provide the correct projection only for a single person. The HMD size was considered acceptable.

Users also commented repeatedly covered the following issues:

- AR is a chance for becoming mobile, i.e.: the need for large projection walls is reduced.
- The field of view of current HMDs is far from acceptable.
- As a matter of principle, AR applications have to be untethered.
- Due to low image resolution, the current system exhibited a significant amount of jittering which was considered unacceptable.
- The current image proportions on the HMD were not geometrically correct.

## 4 Discussion and Conclusion

Before working on Fata Morgana, the AR authors of this paper and the BMW authors had limited ideas about each other's work domains. This collaboration first resulted in the identification of many practical issues, usually not encountered in the laboratory, that need to be solved for mobile augmented reality applications. However, this collaboration also resulted in reflecting on the process of close collaboration with clients and end-users, discovering the challenges common to eliciting requirements for a novel application that is difficult to describe.

Collaborating with end users from the start enabled us to uncover several usability issues that would not have been identified otherwise. Consider the following examples:

- *'Walking around interface.'* During the project course, we had many discussions about which types of controls should be provided to the designer. Since the model under evaluation is virtual, it seemed reasonable to provide a mouse or a wand that allowed the designer to rotate the car quickly, thus minimizing the amount of walking necessary to view the car. However, from our discussions and from the videos we shot from the designer, we decided against such controls. The point of view of the car designers is that Fata Morgana would best support their work if it were transparent, that is, if they forgot that they were looking at a virtual car. Consequently, the most important input to the application would be the user position, resulting in the ultimate direct manipulation interface, where the user naturally moves around to control his view.
- *Reflections.* By observing a car designer looking at the car, we noticed large strides followed by small back and forth head motions. When asked to verbalize what he was doing, the designer explained that the rapid strides simulate the street motion of the car ("cars are designed to move, after all"). The small head motions modified the reflections from the window frames on the car surface, which enabled the designer to evaluate small details, such as the curvature of the hood or the spoiler. This discussion led to a new technical challenge for us, as this meant that an operational Fata Morgana prototype would need to render such reflections on the virtual model in real-time.
- *Designer walking vs. car turning* Initially, we did not distinguish between the case where the car designer walks around the car and the case where the designer stands and the car rotates on the turntable. Geometrically speaking, when we only consider markers on the turntable, these two situations are equivalent. The designer videos clearly indicated that this is not the case since user motion induces much more background variation, as well as a swaying element that have to be accommodated by the tracking system.
- *Self perception.* Car designers attribute much importance to appearance and visual attributes of objects. Wearing a black HMD and a helmet with a camera screwed on top of it is not a feasible option for the end users in the operational version of Fata Morgana [4].

Collaborating with end users and clients for extended periods of time also results in their involvement in technical

decisions. The prototype then is the result of many requirements – not all of which are based on merely technical considerations of optimal trade-offs. Consider the following examples:

- *Local vs. remote rendering* In the university prototype, we anticipated that the graphics server would not be responsive enough to enable real time rendering during fast movements. This led us to include the possibility of a local low-quality rendering server and a mixing module. In the industry prototype, this feature was removed, as designers were shocked at the idea of seeing anything else than a high quality rendering.

Looking back, we think that the ability of having multiple local and remote rendering servers of cascaded quality may have to be reconsidered since designer feedback indicated that untethered user mobility is critical to their use of AR. Furthermore, user studies indicating the limitations of human perception during fast motion, as well as dangers of motion sickness due to rendering lag need to be taken into account.

- *Priorities of different organizations* The university prototype focused on technical issues and started brainstorming on topics such as robust tracking and tracking markers over relatively large distances. The industry prototype, however, focused on producing a simple and reliable demo that could be shown and experienced by end users. Each prototype basically resulted from the priorities of its producing organization.

When viewed in this perspective, the above technical conflict disappears, as both partners are optimizing different criteria. It is important to keep these differences in mind: Reaching the goals of only one of the partners will not be sufficient to keep the project alive.

Car designers are artists; they love reflections, shadows, and the subtle details of their car designs. Therefore it is still unknown, whether car designers will accept augmented reality at all at the end of the day; the main issues remain image quality and response time: display technologies need to be much more advanced to bring the vision of a real car, with real reflections, real shadows, and real details to the car designer, whether he runs around the room or simply shakes his head.

## References

- [1] M. Bauer, B. Bruegge, G. Klinker, A. MacWilliams, T. Reicher, S. Riss, C. Sandor, and M. Wagner. Design of a componentbased augmented reality framework. In *IEEE and ACM International Symposium on Augmented Reality*, Oct. 2001.
- [2] M. Billinghurst, H. Kato, and I. Poupyrev. Ar-toolkit: A computer vision based augmented reality toolkit. In *IEEE VR2000*, New Jersey, 2000. see also <http://www.hitl.washington.edu/share/frames.html>.
- [3] M. Billinghurst, H. Kato, and I. Poupyrev. The magicbook - moving seamlessly between reality and virtuality. *IEEE Computer Graphics and Applications*, 21(3):6–8, 2001. see also <http://www.hitl.washington.edu/magicbook/index.html>.
- [4] D. Curtis, D. Mizell, P. Gruenbaum, and A. Janin. Several devils in the details: Making an ar app work in the airplane factory. In *Proc. IEEE and ACM IWAR'98 (1. International Workshop on Augmented Reality)*, pages 47–60, San Francisco, November 1998. AK Peters.
- [5] G. Klinker, O. Creighton, A. H. Dutoit, R. Kobylinski, and C. Vilsmeier. Augmented maintenance of powerplants: A prototyping case study of a mobile ar system. In *IEEE and ACM International Symposium on Augmented Reality*, Oct. 2001.
- [6] G. Klinker, D. Stricker, and D. Reiners. Augmented reality for exterior construction applications. In W. Barfield and T. Caudell, editors, *Fundamentals of Wearable Computers and Augmented Reality*. Lawrence Erlbaum Press, 2001.
- [7] S. K. Nayar. Omnidirectional vision. In *Proc. of Eighth International Symposium on Robotics Research (ISRR)*, Shonan, Japan, October 1997. see also <http://www.cs.columbia.edu/CAVE/omnicam/>.
- [8] J. Rolland, L. Davis, and Y. Baillet. A survey of tracking technology for virtual environments. In W. Barfield and T. Caudell, editors, *Fundamentals of Wearable Computers and Augmented Reality (chap. 3)*, pages 67–112. Lawrence Erlbaum Press, 2001.
- [9] R. Tsai. An efficient and accurate camera calibration technique for 3D machine vision. In *Proc. CVPR*, pages 364–374. IEEE, 1986. see also <http://www.cs.cmu.edu/rgw/TsaiCode.html>.