

Augmented Reality: Application to In-Vehicle Navigation

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Even with today's technically advanced navigation systems, user experience situations where announcements are difficult to understand and misleading. Augmented reality – the integration of computer generated content into the vehicle surrounding – can provide an intuitive and unambiguous way to communicate navigation information; it can even serve as a novel user interface that allows interaction with the surrounding. In this paper, challenges, constraints, and possible solutions for AR in-vehicle applications are discussed. Details of the technical and design decisions of the “first in-vehicle augmented video system” are explained, as well as features and possible future upgrades.

Keywords: Augmented Reality, Navigation, Sensor Fusion, In-Vehicle Infotainment Systems, Head-up displays, Glasses, Virtual-Reality

1. Introduction

In-vehicle navigation systems, smartphones and mobile navigation systems have reached a high quality regarding precision and availability at reasonable prices. Traffic information has evolved from spatial resolutions of kilometers, manual collection and hourly distribution via radio announcements to fully automated live acquisition and online distribution. Vehicle-to-vehicle communication will further complete the technical information model around the car with real time warnings and notifications. Even for the most slowly changing part of private transport – the road transport infrastructure – live map data will be collected in real time.

Still, even with all these information technology improvements, users experience situations where they receive technically correct navigation announcements, which are hard to understand and process. Drivers still take wrong exits, end up in re-routing loops and search building entrances, house numbers, shops and parking lots at their final destination. The appropriate communication of the relevant information to the driver still poses a key challenge.

Augmented reality (AR) – the integration of computer generated content into the vehicle surrounding – can help to bridge the gap between the technical information model and the driver. Whenever a state-of-the-art navigation system requests to “take the next exit”, the driver himself has to decide whether the next exit is meant or if this is just an un-mapped wide doorway the navigation system silently ignores. In contrast to this, an augmented reality navigation system can highlight the exact position where to turn – and highlight exactly the side street to enter. Therefore it provides an intuitive way for the communication of information. In this paper, core functions, challenges, constraints, and design decisions of the “first in-vehicle augmented video system” (Harman 2018) are explained as well as options for possible future extensions.

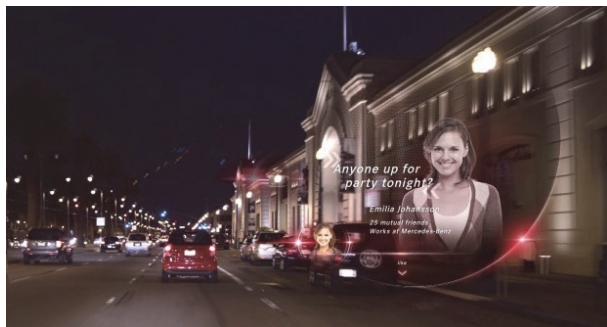


Fig. 1 A text message displayed in a huge head-up display which is not registered in three dimensions (left). Augmented video navigation display with guidance arrows registered at a fixed world position (right). Images courtesy of Daimler AG.

Within this paper, we stick to a usage of the term augmentation inspired by early standard publications on augmented reality (Milgram et al. 1995; Azuma 1997). Systems are considered to be AR systems

- which combine real and virtual objects (e.g. surrounding and computer generated content),
- allow interaction in real time (e.g. driving a real car through a surrounding with added artificial objects),
- where objects are registered in three dimensions (e.g. guidance arrows stick on the street at a fixed position).

This standard definition is strict in so far, as following this definition, showing a text message on a head-up display is not considered as augmented reality because the objects are not registered in three dimensions (Fig. 1).

2. Challenges for Augmented Reality Applications

Application of augmented reality poses challenges to three main fields of technology and information design:

- Conceptual, application class and augmented reality user interface design: to achieve comprehensibility, clarity and legibility of information. Preparation of the most relevant information requires situation dependent processing of information to prepare the relevant information the driver needs before the driver knows what to search for.
- Display technology: Field-of-view, legibility, and latency have to be sufficient to serve as immersive real-time information display.
- Real-time image and sensor data processing: required for object registration. It is needed to determine placement, size and realistic movement of the virtual objects. In vehicle applications, positioning of objects has to take the high angular velocity of vehicles and vehicle body movement into account, which is mainly controlled by varying forces (steering) and from barely predictable forces (road surface and potholes).

Throughout the next three sections of this paper we will look in detail into these three main challenges as well as current and possible future solutions for them.

3. Conceptual, Application Class and User Interface Design

As discussed in the introduction, of course navigation poses the most obvious and relevant application class for augmented reality.

3.1. Navigation

As a first step, standard turn-by-turn navigation in combination with audio announcements can be replaced with three-dimensional arrows pointing to the destination street (Fig. 1, right). This straight forward concept – with arrows positioned on street level – requires positioning and registration with relative accuracy of meters. More advanced navigation concepts with lane level guidance require positioning on lane basis and even within the lane (Rabe et. al. 2016). Such lane-level and in-lane positioning is needed if instead of arrow guidance, the route needs to be shown as line or ‘magic navigation carpet’ to follow. Although such concepts have been shown widely in presentations, videos and mockups, no ready to use implementation is available to the knowledge of the author.

To achieve comprehensibility and legibility of information, the AR object design has to be chosen to clearly distinguish from existing natural objects in the surrounding, e.g. by choosing a clearly visible color. Blue has proven to be a good choice, it is used only for traffic signs, e.g. the German autobahn, but barely appears in another context on the road (compare Fig. 3 as well). Light blue can be recognized in various lighting conditions easily and still does not glow too bright at night.

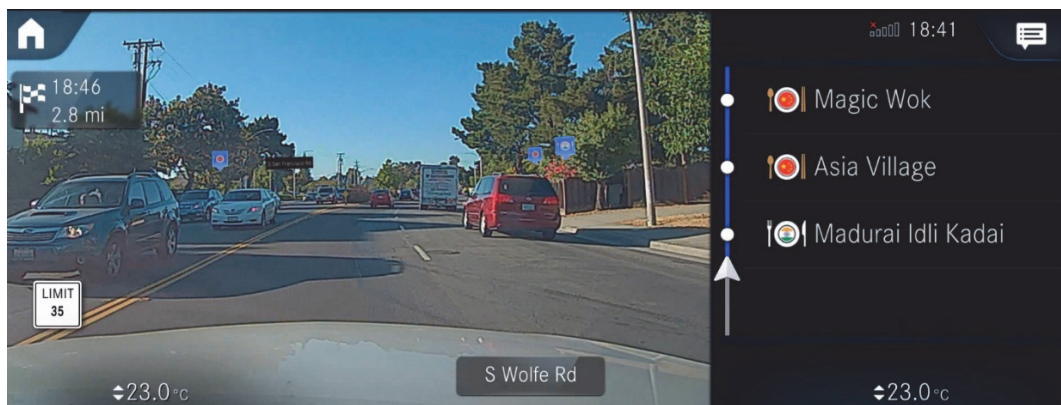


Fig 2. Point-of-interest display sample within augmented reality system. By clicking on the respective icons users can access context data like webpages, telephone numbers or – for more distant objects – start a route guidance. Image courtesy of Daimler AG.

Additional to turn-by-turn navigation, other navigation information can also be intuitively shown to the user. House numbers – which are often barely visible, written in small letters and are often difficult to find – can help drivers to stop losing time on the last meters of their navigation. Of course, the destination house number or as map quality is good enough now in some countries, even the entrance of larger buildings can be highlighted. The same applies for road names, street names and intersection names (a key feature for orientation in Japan).

3.2. Points-of-Interest

For the driver, in addition to plain guidance objects, also parking information and public transport timetables can be helpful points-of-interest that may help reaching the destination more easily. In some situations also highlighting other objects of interest, like restaurants, shops, restrooms and cash machines will help. It can even serve as a novel user interface that allows a totally new interaction between driver, passengers and their surrounding.

For rear seat applications – where the driver cannot be distracted – even location-based social media and extended point-of-interest content such as travel guides and location-based news can be shown as entertainment during long and potentially boring trips.

3.3. Driver Assistance Systems

With the advent of automated driving functions such as predictive cruise control and automatic steering functions, users which are not used to such functionality need to build up confidence. Augmented reality can visualize the objects automatic systems recognize and use in their environment analysis (e.g. the lead vehicle ahead, objects on parallel lanes, ...). These objects can be shown to driver and passengers to build up confidence in novel automated driving functions.

4. Display Technology

From first propeller shaft driven dials, to stepper motor driven ones in combination with segment displays, today huge and further growing displays have become the state-of-art in infotainment systems. Even compact cars such as the 2018 Mercedes-Benz A-class can be ordered with two 10 inch infotainment displays spanning the dashboard. In addition to video displays, head-up displays (HUDs) have become widely available for the projection of information in the primary field of view of the driver. At first glance, head-ups seem to be the primary place where the AR information should be presented.

4.1. State-of-the Art versus Augmented Reality Head-up Displays

State-of the art head-ups with their special projection pipeline generate virtual images which appear to fly at a certain display distance in front of the driver. The position in the field of view makes it easier for people to keep track of displayed information and the surrounding at the same time. The virtual display distance disburdens the driver from having to accommodate from far (street surrounding) to the very close instrument cluster.

For augmented reality head-ups, the display distance needs to be further enlarged to be able to accommodate the eyes at the very same time to the street surrounding and the augmented information. The immersion of augmented content to the surrounding only works, if both surrounding and the virtual content can be perceived at the *same* time. Hence, including a transparent screen inside the windshield is not an option for augmented reality display, although it is proposed sometimes (Nowak 2017). Like having a post-it on the windscreen, you can either accommodate to it (windscreen distance) or the surrounding. One or the other is out of focus and the different distances never blend together. Head-ups need a complex optical pipeline to project the virtual image at the desired display distance.



Fig. 3 Continental Augmented Reality Head-up Prototype: Augmented guidance and AR head-up display area (above) in combination with conventional head-up (below). In both cases the display area is visible as enlightened background in this image. Screenshot from (Continental/SAE 2018); 0:42 min. Image courtesy of Continental AG.

With the huge virtual display distance, the needed optical complexity and the installation space of AR head-ups further increase. Additionally, the required field of view of an AR head-up is tremendously larger than the field of view of state-of-the-art solutions for icons and text (Fig. 3). Head-up developer Continental for example showcases an AR head-up with a virtual image area of 1.3 by 0.6 meters (@7.5m display distance) (Continental 2017). Unfortunately, the potential installation space in a vehicle includes the mechanical steering column and lies in an area which is highly relevant in the event of a car crash. Therefore, a wide application of AR head-ups is still limited to a small number of luxury vehicles with enough place for the head-up itself and place for enough pillars and material to achieve a high structural stability of the vehicle crash box.

4.2. Using Alternative Display Technology

Using AR on a traditional non-transparent video display can be an interesting alternative to using head-ups. First of all, the view angle and direction of the video background image of the augmentation can be easily adapted to the desired application class. It can even be adapted on the fly if needed. With huge view angles than head-ups, augmentation can be used also to mark objects which are not directly connected to the street. Examples are house entrances, distant points-of-interests up to objects far away like hilltops and their names.

Other than with AR head-ups – where artificial objects may occlude important information in the primary field of view within the windscreen area – AR video can never occlude objects in the driver's primary field of view. Also, with AR video, the image is delayed a bit by recording, transmission and replay on a screen. This gives us just enough time to read in sensor data (from gyros, accelerometers and global positioning systems), process it and have the result ready when the image is displayed to the user (see also Section 4).

Furthermore, augmented video display can provide safety benefits over traditional navigation map and driving recommendation display. Today, the driver peeks at the navigation map and schematic announcements, analyses and interprets them while his gaze is completely averted from the street. As objects are already registered at real world positions, identifying positions does not require complex interpretation, like transforming the two dimensional map to the real world. With AR the information is already where it belongs. And even while peering at the AR video screen, the events in front of the vehicle are indirectly in the driver's field of view. Therefore, at least theoretically, AR video can provide safety benefits and reduce distraction of the driver over traditional navigation. Practical assessments of our first prototype implementation have at least shown that it does not lead to more driving errors.

5. In-Vehicle Augmented Reality System: Challenges and Solutions

In order to augment virtual objects and register them in a way that they appear to be real, the virtual camera for the computer generated content has to be in line with the real one (augmented video) or the observer (augmentation in a head-up). Registration of objects requires us to know camera pose (position, orientation and dynamic movement) in the same coordinate systems as the object.

Various methods have been proposed for determining the camera pose, depending on the application class. Camera position can be determined using sensors: local or global positioning systems, accelerometers (e.g. Thomas et. al. (1998)), gyroscopes or magnetometers can be used. Alternatively, the camera pose can be determined from the camera image itself. Tracking the camera pose using markers, image features and applying Simultaneous Localization and Mapping (SLAM) algorithms have been examined e.g. by Williams et. al. (2007) until recently (Gao et.al. 2017). Also combinations of such methods have been researched by You et. al. (1999) and developed to market ready products like the Metaio toolkit (Sterlin 2011). Apples ARKit is an improved version of Metaio's SLAM (Tabatabaie 2018).

Marker based methods and feature based methods are especially suitable for indoor applications, where constant lighting conditions are available and external positioning systems are not. In such applications, markers have to be placed, visibly or invisible in the surrounding and features have to be mapped and stored in feature databases.

5.1. Conditions for Augmented Reality Automotive Applications

For automotive applications, typical map data bases do not provide means to collect and store features. Markers are barely available along the road and objects such as points-of-interest or road geometry are geo-referenced only. Therefore camera pose information for augmented reality application is required as absolute world position – in three dimensions with elevation, to correctly display objects along slopes and overpasses. To determine correct elevation of vehicle in relation to objects, an extended elevation model is added to the map.

Furthermore, vehicle movement can happen at high speeds and high turn rates, e.g. considering the high yaw rate while crossing a roundabout. Lateral and longitudinal accelerations are tremendously larger than those AR smartphone applications have to deal with. Also, augmented reality has to function under diverse light situations such as night (with dazzling lights passing) and flickering brightness (e.g. from alley trees). Hence, AR in vehicle

applications needs very stable sensor based global positioning, at least as a fallback solution – whenever image processing fails.

5.2. Object Registration for Automotive Applications: Pose Estimation

Our approach for AR positioning therefore is based primarily on a sensor fusion approach using state-of-the-art hardware available in today's navigation systems. In automotive applications additional sensors and hardware are to be avoided as costs are high, taking the specific temperature and working environment conditions into account. Also, computational efficiency is still an issue today, even with high performant embedded systems, as a large number of applications need to run simultaneously on a single in-vehicle infotainment system. Fig. 4 gives a short overview on the components and mechanisms exploited for positioning.

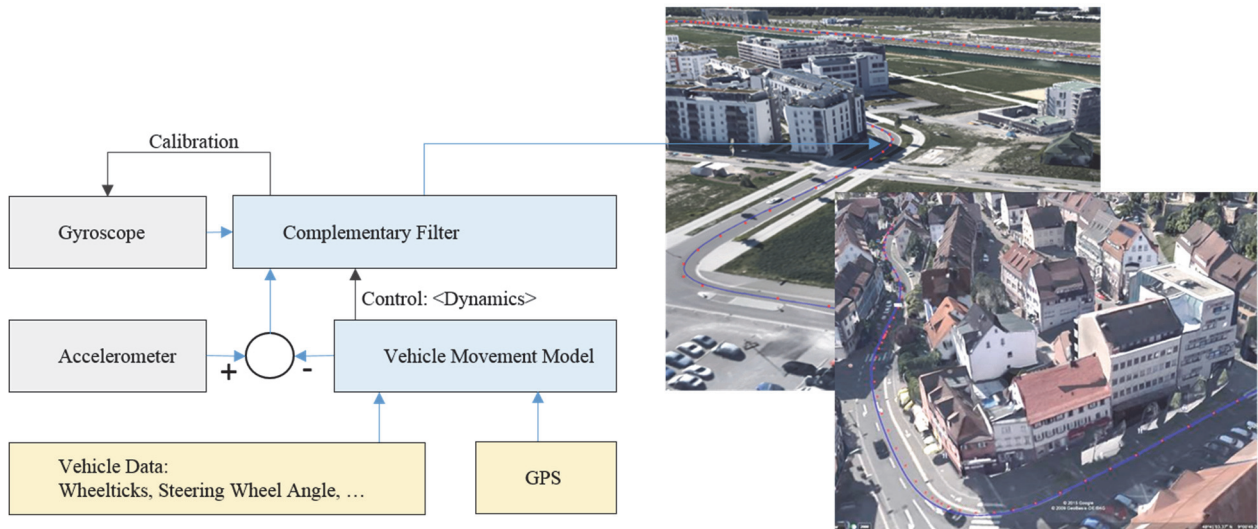


Fig. 4 Sensor fusion data flow for in-vehicle pose estimation (left). Visualization of pose data (blue line) and raw GPS data (red dots) are in Google Earth (right).

Based on vehicle data and GPS information, the lowest layer of the algorithm determines forces expected from the vehicle movement. Real forces, which affect the vehicle body, are measured using an accelerometer. This accelerometer is part of a standard in-vehicle state of the art MEMS combined inertial sensor, capable of detecting acceleration and angular rates in three perpendicular axes ($a\text{-xyz}$, $\Omega\text{-xyz}$).

Expected accelerations can be subtracted from measured latitudinal and longitudinal accelerations to determine the longitudinal and transverse inclination of the vehicle body and the camera integrated into it. Still, of course as the vehicle data is discretized in time and distributed on vehicle networks with sensor acquisition, processing and routing delays, already this calculation requires complex filtering operations and special handling of particular cases such as standstill and reversing.

Even with all optimizations of numerical calculations, this first orientation angle estimation can still be affected and lead to instable inclination (or ground force vector) determination in very dynamic situations. To overcome such situations, the second layer of the algorithm stabilizes the inclination determination using the inertial sensor's gyroscope. The gyroscope is calibrated in less dynamic situations using the results from the lower layer and stores, tracks and stabilizes the inclination determination in very dynamic situations using a complementary filter. Tests of the pose estimation during the research and later also the development phase have shown that registration of objects is stable enough to keep objects in a stable position even during highly dynamic driving scenarios such as passing roundabout like structures at high speeds, situations with slight drift or steep curves. Real time system performance and signal processing (jitter, enlarged latency, ...) has proven as one of the most critical issues regarding pose stability.

6. Summary and Outlook

This paper presented the chances and challenges for a first augmented reality application in vehicle infotainment systems. On one hand, it was highlighted that integrating the turn-by-turn directions with augmented reality transports the navigation user interface into a new era regarding the ease of use and intuitivity. On the other, AR application may complement automated driving functions with a user interface that will help people to get confidence into them. Advantages and disadvantages of different display solutions were discussed, and it was highlighted that augmented video offers advantages regarding opening angle, possible occlusions of objects, latency and availability over head-up displays. Then, our approach for the core technical challenge of augmented reality

applications, the registration, was discussed, highlighting that real time sensor fusion of state-of-the-art hardware available in today's navigations systems plus vehicle data provides a registration of objects, stable enough even for highly dynamic driving situations such as roundabouts or steep curves. Having established AR as a novel means for interaction with the surrounding, now it can be extended with additional application classes, such as automated driving visualizations, as well as integration of location-based news and social media. With the availability of 3D sensing technology like stereo-camera (Schmid and Fritsch 2016) or LIDAR in more and more vehicles, depth dependent occlusion can be added and the system can move from adding 'overlays' to a full three dimensional integration of objects to the surrounding (Fig. 5).

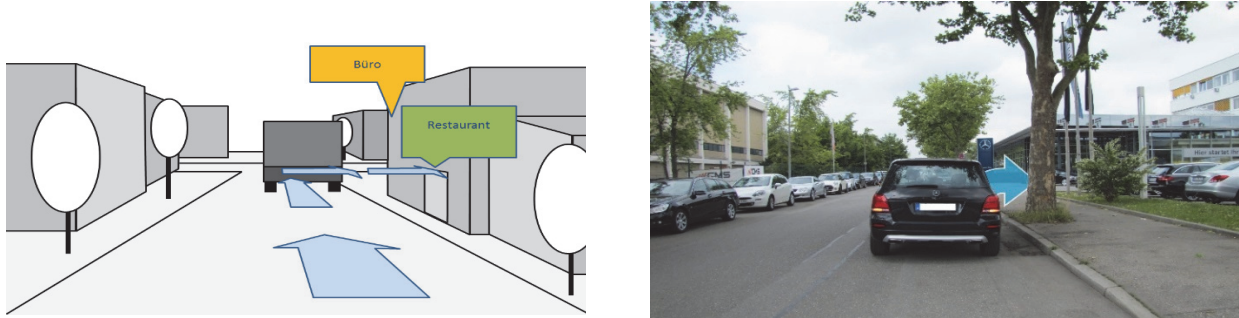


Fig. 5 Available augmented reality systems typically superimpose the augmentation to the image, without considering the distance. The inconsistent depth information can be misleading (left, augmentation colored). Three dimensional fusion is possible with depth data and leads to an even more consistent augmentation (right).

Also, the system can serve as a basis for augmented reality head-ups, integration of glasses or projection systems for side windows. Recent advances in adding waveguide nanostructure optics into glass material have led to AR capable head-ups for motorcycle helmets with virtual display distances of several meters in front of the eye (Digilens 2018). If similar waveguide optics could be integrated into windscreens or head-up combiner mirrors, a wide application of augmented head-ups would be technically possible.

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