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LONG PAPER

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Augmented reality navigation systems

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Abstract The augmented reality (AR) research community has been developing a manifold of ideas and concepts to improve the depiction of virtual objects in a real scene. In contrast, current AR applications require the use of unwieldy equipment which discourages their use. In order to essentially ease the perception of digital information and to naturally interact with the pervasive computing landscape, the required AR equipment has to be seamlessly integrated into the user's natural environment. Considering this basic principle, this paper proposes the car as an AR apparatus and presents an innovative visualization paradigm for navigation systems that is anticipated to enhance user interaction.

Keywords Augmented reality · Navigation systems · Visualization paradigms · User interaction

1 Introduction

A major strength of augmented reality (AR) systems is their intuitive depiction of information, where the user perceives virtual and real objects as coexisting in the same space [1]. At a glance, the user naturally recognizes the content of the information (i.e., an object's location, size, shape, color and maybe its movement) without needing to understand abstract metaphors that cumbersomely paraphrase the same information content in conventional textual, graphical or even virtual reality systems.

The AR paradigm opens innovative interaction facilities to users: human natural familiarity with the physical environment and physical objects defines the basic principles for exchanging data between the virtual and the real world, thus allowing gestures, body language, movement, gaze and physical awareness to trigger events in the AR space [10, 14, 15].

Hence, there are two major concepts that characterize AR systems: (1) the clear and intuitive depiction and perception of information and (2) the natural interaction interface for users. Both concepts are supposed to facilitate computer-supported tasks where humans are not confronted with abstract visualizations and synthetic manipulation procedures [5].

Although beyond doubt this goal is creditable and many research systems demonstrate the applicability of the concepts, hardly any AR application has matured beyond a lab-based prototype [2, 6].

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2 Limiting factors for augmented reality

In 1997, Azuma [1] published a survey of six classes of potential AR applications: medical, maintenance and repair, annotation, robot path planning, entertainment and military aircraft navigation and targeting. Such a survey disclosed the registration problem, the inaccuracy of tracking and sensing, technical restrictions (like the marginal resolution of displays and their weak contrast) and several other problems as limiting factors for building AR applications. Since then, much effort has been spent on addressing these technological problems by integrating complex tracking methods into hybrid positioning systems [11, 12, 14, 17–19, 23] (using picture recognition and/or alternate tracking techniques) and by introducing new head-mounted displays.

However, solving the registration problem or improving the resolution of head-mounted displays does not necessarily increase the areas of application for AR systems [2]. As long as users still have to be equipped with a strange-looking and unhandy head-mounted display, a head tracker and a backpack containing the CPU, the GPS receiver and the batteries (see Fig. 1), they will feel restricted in their freedom of movement and dismiss the appliance.

Figure 1 was taken from the ISMAR 2003 conference proceedings [29]. While we assume that the respective paper describes valuable work, it also reflects the state of the art for handling AR equipment. Pictures like these can be found throughout the latest scientific contributions concerning AR.

Even if the head-mounted display shrinks in the near future and is integrated with the head tracker into stylish glasses that wirelessly communicate with a miniaturized pocket PC, users are still supposed to carry additional equipment which they might not want.

Beyond that, the paradigm of natural user interaction seems to be just theory. In order to make a system react to a person's gesture, the person either has to be equipped with additional sensory gadgets or the surrounding environment must recognize such a data input (e.g., via cameras). Both variants pose major drawbacks regarding the user's freedom on the one hand, and the range of applicability on the other, depending on the coverage by cameras.

Consequently, beyond technological restrictions, there seems to be two more major obstacles that limit the wider use of AR [2]: social acceptance issues and user interaction limitations.

3 Social issues and user interaction

Persuading a user to wear a system means addressing, among other things, fashion issues. Will users wear a system if they feel it detracts from their appearance [2]? The perspective adopted in this paper is that AR applications can only evolve when users are not any longer constrained in their fashion, but also in their normal movement. Hence, the following are proposed:

- using at most one small device for perceiving AR information, or, better,
- using no additional device at all. The user does not carry any electronic device for viewing AR information; the hardware must be integrated in the user's natural environment such that anyone can use it without adapting regular behavior.

A car's windshield can render the metaphor of the AR paradigm and be used to superimpose virtual information in front of the real world outside the car. A camera detects the driver's eye position [30] and consequently enables the system to appropriately display the augmentation relative to the driver's height and location on the seat. All the (hybrid) tracking equipment (GPS, wheel sensors, odometer, etc.) is included in the car's navigation technology, making the car a big accessible and movable see-through display. The user just has to enter it as usual, and is immediately able to perceive AR information through the windshield and interact with the system without carrying additional electronic devices or changing habits. Such a car serves as an example of an AR apparatus that is pervasively integrated into the user's natural environment and directly available there.

4 A new visualization paradigm

The idea of perceiving graphical information via the windshield is not new. With the technology for color head-up displays emerging, car manufacturers are embracing the idea to display speed, fuel level and even fragments of conventional navigation information on the front shield (see Fig. 2).

Fig. 1 Inconvenient handling

Fig. 2 Current head-up displays

However, the potential of the windshield as a see-through instrument for AR applications is much higher. For example, considering the driver's perspective, navigation information could be presented by virtually painting the designated route in a translucent color (see Fig. 3).

The underlying concept is simple and should immediately be understandable by anybody. Conventional navigation systems always present abstractions of navigation data. They either show a flat arrow indicating a turn or pointing in the desired direction, or they present an overcrowded bird's eye view showing a geographical map and the driver's current position and orientation on it. Regardless of which method is used, the information presented is not clear and demands the ability to abstract [8, 9, 22].

By virtually painting the road in a semi-transparent color, the new paradigm eliminates the ambiguity that might arise, e.g., when conventional navigation systems require the driver to turn left with two junctions back-to-back (see Fig. 3).

Junctions that are hidden from the driver in the real world (e.g., because other vehicles or rises in the landscape restrict the driver's view) can be made visible via AR (see Fig. 4).

Conventional navigation systems require users to count exits, which is tricky and may again be ambiguous when the driver is not sure whether to additionally count a small auxiliary exit. AR navigation systems relieve the driver from this burden and clearly color the designated exit (see Fig. 5).

Finally, since the driver is no longer impeded by a constrained view of the current traffic and driving situation while diverting his eyes from the street and looking at the navigation display of conventional navigation systems, she or he always surveys the road ahead and is capable of recognizing hazards without any delay (see Fig. 6).

Fig. 4 Hidden exit

In the context of this paper, this paradigm is considered to be a self-explanatory and easy to understand visualization method. Furthermore, it is a working example of an AR application where users need not carry bothersome equipment, maintain their unrestricted freedom and interact naturally with the system by simply following the colored route.

5 Conceptual design

The concepts beyond the examples discussed in the previous section have been submitted for patenting and implemented in prototypical applications within a research cooperation between the Siemens AG Corporate Technology in Munich, Germany, the Johannes Kepler University of Linz located in Upper Austria and the Ars Electronica Futurelab, also in Linz.

Fig. 3 Innovative AR navigation information

Fig. 5 Roundabout

Fig. 6 Safety aspects

5.1 Framework

The AR navigation system is built upon a core framework where state-of-the-art positioning systems (primarily GPS) are used for keeping track of the car [21]. Image recognition algorithms for tracking are not included in the framework, which economizes calculating power and enables applications to be executed on devices with lower CPU power.

Like many other modern AR architectures, the framework also enables software developers to easily construct virtual geometric models of the digital annotations, and to rotate, shift and translate them relative to the observer's eye position.

Finally, for drawing the AR scene on any display, the framework provides state-of-the-art rendering techniques [20], encapsulating the underlying operating systems and standard graphics rendering techniques.

5.2 Computation procedure

The 3D depiction of the street in AR navigation systems is calculated using the data coming from a conventional navigation system—the current GPS position and orientation, the maps, the topography information and the calculated route (see Fig. 7).

6 System architecture

The framework architecture provides a variety of input interfaces for receiving the required data from the navigation system (see Fig. 8). Most car navigation systems are equipped with a GPS receiver for locating the current position of the car. Additionally, they keep track of the car using wheel sensors (when GPS is not constantly available, e.g., within city areas or tunnels), and they utilize alternative orientation trackers (compasses, gyros, etc.) for improving the orientation information from the GPS signal. In case of alternatively offered tracking

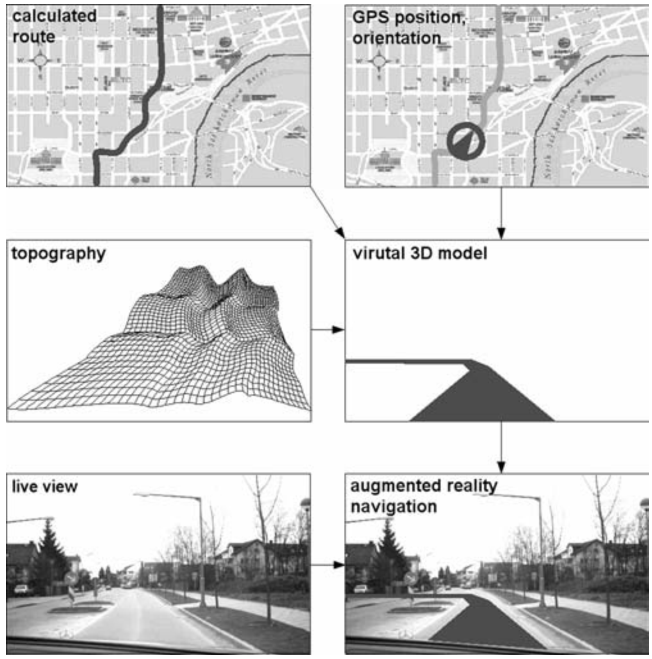

Fig. 7 Calculation of AR path

technologies, e.g., in underground garages, the framework is also prepared for indoor tracking systems and other wireless positioning approaches.

Static model data (i.e., 2D and 3D maps typically stored on a compact disc), dynamic model data (i.e., ongoing road construction and accidents) and the route-planning algorithm enable the system to compute the virtual 3D road image.

Unfortunately, current head-up displays for cars [7] are not yet able to cover the full area of the windshield, which would be required in order to support the proposed paradigm. Instead, the annotation of the route is superimposed on a live-stream video (coming from a camera behind the rear-view mirror) showing the road

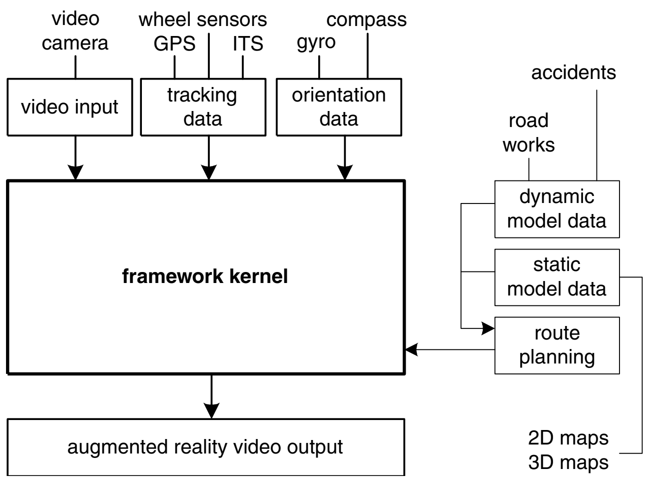

Fig. 8 The system as a black box

ahead on the navigation display. Therefore, an additional video interface for transferring the live stream from a camera completes the list of interface components.

This technique of showing a live-stream video of the scene in front of the car makes the navigation display a quasi transparent instrument, with the advantage that the alignment of the virtual objects need not be calibrated for every individual user's eye position. There is only one constant observer—the camera position at the back of the rear-view mirror—enabling one AR view that can be perceived by multiple users simultaneously from the same perspective.

6.1 Generic tracking

Figure 8 just outlines the system. Naturally, the algorithms must handle a challenging and complex problem. Just consider the different types of tracking techniques currently available on the market. Two types of location and orientation sensitivity systems can be distinguished: active and passive.

Active sensitivity systems determine their current position and/or orientation independently. For example, a GPS receiver connected to the navigation computer of a car enables the computer itself to detect its current position.

Passive sensitivity systems are not (directly) aware of their current position and/or orientation. A central reference station (a tracking server) holds the tracking data of all objects (tracking receivers) moving within its area of influence. Many indoor navigation systems are passive sensitivity systems, as a central server first collects the data of the floating receivers within a network of static antennas and then provides the receiver's location to any associated process via a certain interface (see Fig. 9). Usually, this process is executed on a CPU which is physically connected to the tracking receiver.

In order to accomplish a generic design that combines all input technologies penetrating the current market, the framework architecture inserts an additional component between the indoor tracking server and the requesting CPU (betokened generic tracker in Fig. 10).

This tracker requests location and/or orientation data from the indoor tracking server, converts potential relative indoor tracking coordinates into an internal format and wirelessly transmits them via a slim protocol (e.g., UDP packages) to the framework kernel (the requesting process). Due to the diversity of location systems, the generic tracker must obviously have a customer-dependent front end (represented by the shaded area at the left of the generic tracker in Fig. 10), but its back end implements a common protocol for submitting tracking data to the framework kernel.

The generic tracker may also be executed on the tracked object itself, receiving position data via a different customer-specific interface (e.g., from a directly connected GPS module; see Fig. 11).

Thus, no matter which type of location sensitivity is used for tracking an object, the framework kernel remains unaffected.

6.2 AR path calculation

Once the current position and orientation are known, the system is ready to calculate the virtual path representing the designated route. The route from the navigation system is provided by sequence of geographical points in the 3D space (see left part of Fig. 12). A distinction is drawn between shape points tagging the route in front of the car and maneuver points indicating upcoming navigation maneuvers.

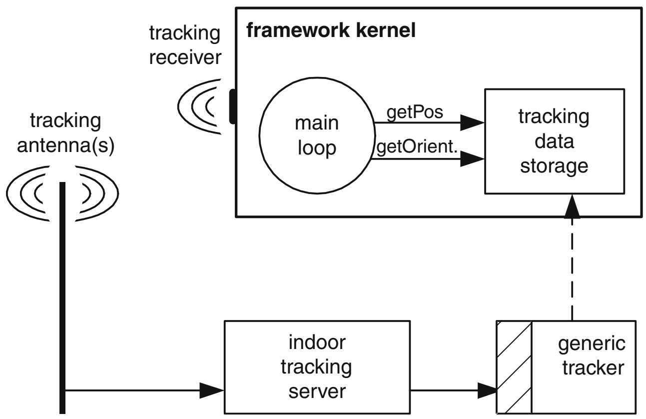

Fig. 10 Indirect position acquisition

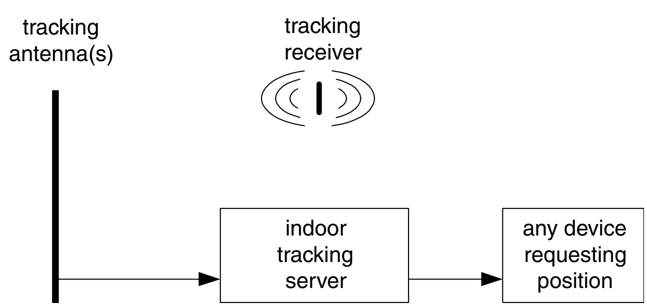

Fig. 9 Passive sensitivity system

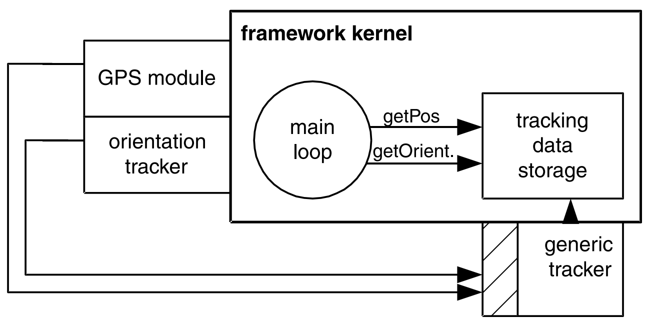

Fig. 11 Direct position acquisition

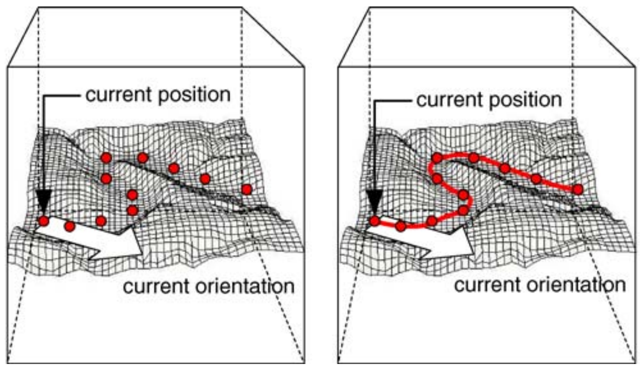

Fig. 12 Three-dimensional shape points tag the route

The concatenation of these points (e.g., through a cubic spline or by nurbs) results in the desired virtual path (see right part of Fig. 12). Accordingly, the static topography information for calculating a virtual 3D route (as depicted in Fig. 7) is not retrieved directly from the 3D maps of the navigation computer, but comes indirectly through the shape and maneuver points.

The system calculates a virtual 3D model of the spline relative to a fictive origin within a virtual space. Corresponding graphical matrix transformations rotate, shift and zoom this 3D model relative to the current position and orientation of the car (and respectively several other parameters such as the current speed, wheel sensor data, etc.), so that the spline finally resembles a colored part of the street viewed from the driver's perspective (see Fig. 13).

The calculation procedure is fast. All the shape points of a route are transmitted to the framework just once—as soon as the navigation computer has calculated them, implicating a singular spline or nurbs calculation during an initialization phase.

The 3D transformation of the path has to be done continuously within a selected time cycle as the observer position changes permanently. However, the complexity of the geometric objects to be transformed is low. The path consists of a sequence of triangles (a so called tristrip; see Fig. 14) which is characterized by only a few

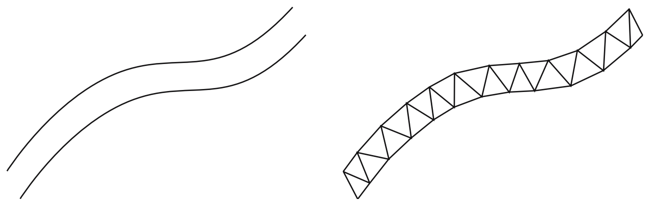

Fig. 14 The path is a tristrip

points that can be transformed quickly by the algorithms of the graphic renderers. Besides, not the whole path is considered but only a short, predefined length of it beginning at the current position.

Furthermore, the augmentation does not necessarily need graphical embellishments like shadowing or texture mapping. It abstains from time-consuming operations and focuses on a few, simple matrix calculations concerning the vertices of the tristrip [27].

6.3 Generic rendering

The AR navigation framework stores the calculated 3D path in an appropriate data structure, a scene graph, which is used by many popular 3D renderers [13]. The scene graph is detached from any graphical library or operating system needed to illustrate the routing information.

A traversal of the graphical objects and transformation nodes stored in the scene graph initiates the AR drawing process.

The generic scene graph data structure can be processed by several different graphic renderers (expressed by the shaded area below the AR renderer in Fig. 15), which allows the output to be displayed on various customer-dependent navigation displays.

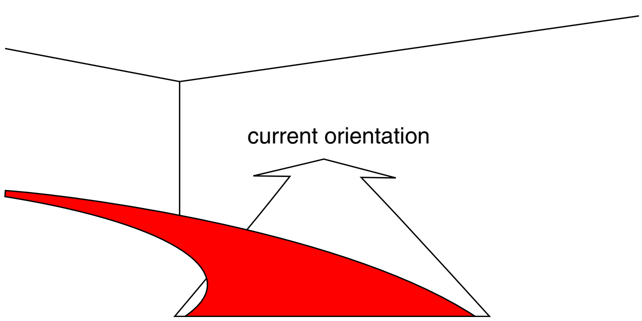

Fig. 13 The route from the driver's perspective

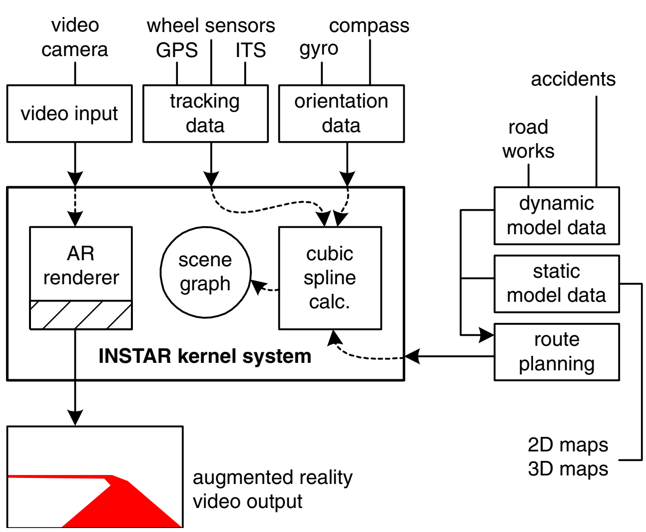

Fig. 15 Generic AR data calculation and storage

7 Results

The framework was developed using a self-made simulation environment. All the navigation data coming from a commercially available car navigation system were recorded synchronously together with a video stream from a digital camera mounted inside a test car. These data repetitively served as the simulation input for the initial AR navigation system running on a personal computer. Initially, the framework software was written in C++ and applied for the operating systems Windows 2000 and XP. At the back end, OpenGL was used to combine the computed 3D route and the video stream to an AR navigation view.

Figure 16 shows an OpenGL window in front of the simulation environment with a semi-transparent yellow path guiding the way. The various colors of the path borders serve different purposes, e.g., red indicates a left turn and green indicates a right turn. The shape points representing the path already traveled are easy to recognize in the lower window.

7.1 AR car navigation system

The implemented simulation environment was ported to a test car. Initially, the system was still executed on a laptop computer connected to the built-in Siemens VDO navigation system via a serial port. A digital firewire camera mounted behind the rear-view mirror provided the live stream of the scene in front of the car. Thus, the new visualization concept could be experienced in a real testing environment (see Fig. 17).

Although the prototypical implementation was restricted to use the navigation display for the augmentation instead of the windshield—the results are still valuable. The developed AR car navigation system is successful in providing to users natural interaction. Safety issues are also addressed: the driver is always aware of the road ahead, even while looking at the navigation display, because the live-stream video simultaneously shows the current driving situation in real time.

7.2 AR pedestrian navigation system

As the framework architecture allows exchanging navigation devices, and the graphical depiction of the routing information is rather primitive and therefore fast, the proposed visualization paradigm can also be employed for pedestrians, by upholding the strict principles for social issues and user interaction. The augmentation of the real world must be achieved by superimposing the digital path on a live-stream video of the environment shown on the display of a small handheld device (see Fig. 18).

Users maintain their freedom of movement, and they need not carry additional equipment beyond their mobile phones (which can be considered as omnipresent gadgets).

As a first step toward facilitating the mobility aspect of navigation systems, the kernel of the framework was

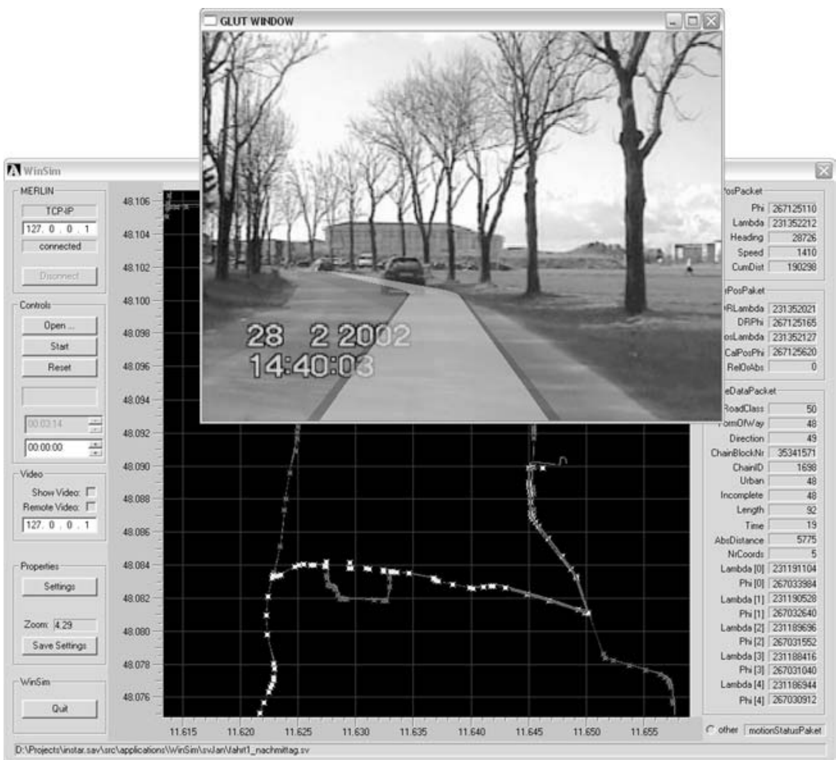

Fig. 16 Simulation environment

Fig. 17 AR car navigation prototype

Fig. 18 Mobile phone as AR display

moved onto a handheld using PocketGL as a graphic renderer. In the same way as in the laptop version, the handheld was directly connected to the car navigation computer and additionally plugged into a video jacket in order to receive the video signals from the camera (see Fig. 19). This step simultaneously proved the exchangeability aspect of the navigation displays.

Pedestrian navigation systems differ from car navigation systems in one important aspect: whereas the camera in the car constantly captures the scene ahead, the mobile device can arbitrarily be moved in any direction. This demands the supplementary use of an orientation tracker, not only indicating the user's alignment to the compass, but also the device's orientation in the 3D space.

Fig. 19 AR system running on a PDA

For the first prototypical implementation, a PDA was used. The functions of the route-planning algorithms were moved to an external server, with communication taking place via WLAN (for a commercial application, detailed pedestrian maps of an entire country cannot and should not be stored locally on a small device). All the remaining gadgets needed for an AR system (a GPS receiver, the orientation tracker, a camera and a WLAN network card) were plugged onto the PDA.

In order to satisfy the rigorous requirements set for practically utilizable AR products, the framework was finally ported to a mobile phone using GPRS for transmitting navigation data. Initial test applications using Smart Phones (extended by GPS and orientation sensors inside the devices) and AR on the display have confirmed the applicability of the framework for small devices (see Fig. 20).

7.3 Experiences

Due to the restriction that the AR navigation system has been undisclosed during the development phase, and because it is now available only in one test car and on

Fig. 20 AR system on a smart phone

one test cell phone, no empirical research could be done so far to formally evaluate the acceptance of the new human/machine interaction method. However, the developer crew has acknowledged the intuitive and easily understandable presentation of the navigation information in several test runs in the cities of Munich and Linz.

One of the next tasks will be to systematically study the acceptance of this concept by end users, in order to confirm the objectives and advantages of the new visualization paradigm outside the developer team, and to potentially improve the developed system. As an example, we argue that the driver is always aware of the current driving situation. Strictly speaking, the AR view has a different level of detail for the driver, and thus can create various problems, e.g., the augmentation might distract the driver from paying attention to the real scene outside the car.

Another example concerns the degree to which pedestrians would like to have their normal view superimposed by AR or would they find it intrusive and disturbing. Maybe the average user would prefer to remember a short route on an abstract 2D map instead of constantly holding a cell phone to see the augmented route ahead.

Nevertheless, the authors regard the AR navigation paradigm as a potentially very powerful contribution to improving user interaction, but also refer to unexplored problems like the two examples above, which can only be investigated by systematic usability evaluations, where not only user acceptance but also security and liability aspects in case of an accident have to be considered.

8 The future

The prototypical implementations have shown the feasibility of the concepts presented in the introductory sections of this paper, and their practical transformation is imminent.

For future applications, design studies are being carried out on the augmentation of digital information. One promising modification could arise by considering that the easiest way to find a destination is to follow somebody who knows the way. This idea leads to an alternative augmentation variant showing a virtual car in front of one's own car, blinking, braking and accelerating (see Fig. 21), making the navigation aspect in cars as natural as possible.

As soon as the technology of head-up displays enables the coverage of larger parts of the windshield [28], the augmentation of the route will be directly displayed on the front shield (e.g., by pressing a button on the steering wheel; see Fig. 22). This would signify a major step toward fully implementing the proposed paradigm.

Beyond that, pervasive and ubiquitous computing techniques might extend the features of AR navigation systems, e.g., by adding context-sensitive services. In coordination with external sensors or smart devices [3], these services can call attention to points of interest along the route. Figure 23 depicts this idea: the system considers the fuel gauge of a car and, when necessary,

Fig. 21 Virtual follow-me car

Fig. 22 Fulfilled vision

Fig. 23 Context-sensitive AR information

displays the location of the nearest gas station along the route and maybe further information, e.g., the price, if available, within a pervasive computing environment.

9 Related work

Work at the University of Nottingham focuses on human factors design issues in general and also on human factors of in-car technology [7–9]. The researchers present established work as well as innovative and creative design issues concerning the perception of navigation information. However, they do not consider AR as an alternative visual presentation of information.

The research community for AR proposes ideas for easily comprehensible, innovative AR user interfaces for location-based services. As an example, the Mobile Augmented Reality System project [15, 16] presents an approach where AR is used for path finding and orientation. Equipped with a huge backpack including a GPS receiver for position determination and a head-mounted display, users are guided within a delimited area by textual location-based instructions and a graphical route displayed as a pipe system. However, this system narrows the user's freedom of movement significantly; in the perspective adopted in this paper, a head-mounted display is not considered to be a natural interaction instrument.

The Studierstube Augmented Reality project [25] also considers similar navigation information by using an AR pipe system to indicate a route, but again, unwieldy equipment discourages practical use.

The University of Graz in Austria presents a hybrid positioning technique for an AR outdoor tracking system using wearable apparatus [24, 26]. However, the methods for locating and identifying points and objects in the real world by coordinating dissimilar positioning techniques represents the main focus of their research, with less attention to the AR view.

One application related very closely to the one presented in this paper was developed by the United States Coast Guard. Their prototype Virtual Aids to Navigation (vATON) [31] provides mariners with navigation information and virtual representations via see-through AR eyewear. vATON allows lane marking, ship identification and virtual placement of markers and map symbols that would be difficult or impossible to maintain in any cost-effective manner. Unfortunately, no publications are available to provide deeper insight into their approach.

Several other research projects in this area deal with human interaction factors, AR views and the growing range of divergent positioning techniques [1, 4, 8, 20]. Nevertheless, none of the approaches developed so far enhances the navigation information by simply coloring the route to the destination, and thereby decreasing the level of abstraction at the user interface to a minimum, and consequently making navigation intuitive and natural.

10 Conclusion

Augmented reality applications provide fascinating views onto annotated worlds, enabling its users to easily grasp computer-generated digital information. As this information is primarily presented via virtual geometric objects seamlessly placed in the real world, likewise the offered interaction possibilities appear to be exciting, where users can trigger actions by simply pointing at virtual objects with their fingers.

However, inconvenient and distracting wearable AR apparatus restricting the users' freedom of movement are limiting factors for building usable AR applications.

Considering the visualization and interaction possibilities of AR on the one hand, and social issues on the other, an innovative visualization paradigm has been created for navigation systems, where users intuitively perceive navigation information through the windshield of a car and maintain their unrestricted freedom of movement as the AR apparatus is integrated into the users' environment. User interaction can be carried out naturally because users are not locked up in a cage and chained to wearable equipment.

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