Augmented Reality

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I. Introduction

A. Brief Definition

"Augmentare" is the Latin word for "enlarge, enhance, enrich". In that sense, the term "Augmented Reality" (AR) describes a technology, which is used to provide a user with information which enriches his/her perception of the real world in such a way, that this information is perceived to be a part of the spatial environment of the user.

B. Historical Development

The idea to such a technology was already born in the 1960s, when first head-mounted displays (HMD) were built by the visionary Ivan Sutherland [1]. The original application of such displays was tele-presence – the display would show imagery, captured by remote servo-controlled IR cameras, which were moved according to the user's head motion. This allowed the user to change his viewing direction very naturally and provided an immersive feeling, In 1966, the live camera images were replaced by computer-synthesized images – and the technology of "Virtual Reality" (VR) was born. During the following decades, a lot of technical development was done in this area of VR, which provided means of complete immersion in a virtual environment, generated by increasingly powerful computers with more and more advanced graphics capabilities. Implementations of such immersive VR technology could be found in simulation (aircraft and cars), training, design and prototyping, and entertainment (for examples 3D shows in Las Vegas). Applications which were mixing the real world perception with information in the sense of Augmented Reality, were mostly implemented in military applications, where helmet mounted displays provided overlay graphics for target selection and night vision. For use in other domains, these applications were too cumbersome, requiring heavy head-worn displays and precise tracking systems.

Progress in many enabling research areas related to VR has brought an increased focus on AR in the past 10 years, when it was realized that AR could have benefits in much broader areas than the narrow applications of VR technology. With the increased capabilities of VR systems, the concept of placing these synthesized renditions into the perception of the real world became intriguing. This was much more challenging than a purely immersive visualization, because the registration precision for AR has to be much higher – the user would immediately notice misalignment of virtual objects when he also sees the real world. The benefits of this approach to "augment" the reality in many areas are obvious: information can be presented to the user, as if it is part of the real world. Therefore, he/she can intuitively understand the information in the current context. Applications which can utilize this immediate intuitive visualization concept are for example navigation in an unknown city, where names of streets or landmarks can be shown directly on the relevant objects, and where directions can be given directly into the user's view. Architects can see prototypes of their buildings right on the scene where they are to be built, plumbers can see the installations behind closed walls ("virtual X-Ray vision"), and physicians can overlay medical imaging data directly onto the patients body. Maintenance and manufacturing are other important applications of AR technology, which allow instructions to be overlaid directly onto the parts of the objects. The first time that such an AR system was tested in larger scale in a realistic manufacturing environment was in the 1990s in a Boeing airplane factory for assembling wire bundles [2]. Many inherent hurdles such as wearability and precise information alignment (=registration) still have to be overcome in order to help AR applications to a break-through success.

AR research evolved from the areas of virtual reality, wearable and ubiquitous computing, and human-computer interface. One of the most relevant technical issues in developing AR applications is solving the registration problem: registration means aligning the virtual information with the real world so that it appears to be a part of the real environment. This registration must occur in real time, otherwise the user will experience an unacceptable lag of the visualization when he moves. Another issue is how to share these virtual spaces with other users in collaboration. Human factors research is being done in how to present the information in such a way that the user is not confused about what is real and what is virtual information. Recently, the field of AR is evolving as its own discipline, with strong ties to these related research areas. In 1998 the First International Workshop on Augmented Reality (IWAR'98) [3] attracted 64 attendees, one year later the 2nd IWAR '99 had already 177 attendees. This is a sign for the increased attention this new field is receiving.

C. Broader Definition of the Term "Augmented Reality"

Although AR is often perceived to be in the visual domain, it actually includes the other senses as well. 3-dimensional audio, for example, which is based on the concept of head-related transfer function [4], can be used to provide a immersive sound field, in which the user can precisely locate events and communication streams [5]. Also haptic "displays", which provide a tactile user force feedback [6], or general tangible interfaces [7] can be considered as a part of AR technology. This wide cross-disciplinary aspect of the field of AR leads to the question, what actually can be considered AR, and where the boundaries are. It is in general considered as a sub-domain within the area of "Virtual Environments". In his survey about AR in1997, Azuma [8] defined the following three elements to be essential for AR: combining real and virtual, being interactive in real time, and being registered three dimensions. This definition includes AR applications based on head-worn display systems, but excludes the kind of 2D overlays in movies, which match synthetic rendering with real world footage, since the real-time interactive aspect is not given here. The registration problem for these matching algorithms is, however, the same as for other typical AR applications, and the technologies developed for this problem will eventually find their way also in real-time interactive AR applications [9]. The experts in the AR community still argue about the "gray zone" on what still can be considered under that term AR. Also bordering the AR domain are applications on handheld computers, which provide a context sensitive display content, but are not truly registered to the surroundings.

In the context of AR, often the term "Mixed Reality" (MR) is used. It is a superset of AR and covers the reality-virtuality continuum between completely real environments and completely virtual environments, a concept introduced by Milgram [10], which encompasses both Augmented Reality and Augmented Virtuality (AV). The degree of how much both elements – virtual and real objects – are within an MR application, define its classification as either AR or AV.

For AR visualization, two different modes are possible: the **optical see-through** AR, in which a see-through display overlays synthetic rendered information / objects directly onto the live view of a scenery, and **video see-through** AR, which employs video cameras to capture live images of a scene and performs the merging of both camera imagery and synthetic rendering into a completely opaque display. The video see-through AR has the advantage of providing a more seamless integration of real and virtual worlds, because the video can be matched in its perception (color, intensity) to the virtual rendering, and because computer vision techniques can be applied to provide eliminate jitter of the overlay. However, resolution of video is lower, and the quality of the perception of the real world is limited to the quality of the optical system (camera, display, etc.) [11]. A special case of video see-through displays is the use of hand-held computers with an attached camera, which provide a video image on the display of the handheld computer, which can be augmented with either annotations or other information.

This article tries to give an overview on Augmented Reality and the current state-of-the art of research and application implementations as of the year 2001.

II. State-of-the-Art of Current AR Applications

The technological hurdles, which will be discussed in section III, have so far prevented, that we see large numbers of existing AR applications. However, a lot of progress has been made in the past years in demonstrating solutions to certain problems of Augmented Reality applications. This section will give a brief overview of the achievements, issues, and benefits in various application areas of AR technology.

A. Manufacturing, Maintenance, Repair

Manufacturing, maintenance, and repair are fields which are very promising for utilizing the benefits of AR technology. Its applications would reduce training time, would speed up prototype development, and reduce errors in design, maintenance, and repair, and therefore lead to cost savings, which will be a trigger for industrial applications of such AR technology [13]. Instructions for assembly or disassembly can be given directly into the user's view, pointing to specific object parts and providing not only textual manuals, but also 3D drawings and animations superimposed on real objects. The interactivity allows step-by-step instructions to be displayed, depending on the progress. Such a system was tested in a pilot experiment in an actual airplane factory at Boeing: the system could provide information to the users on the assembly of wire harnesses [14]. The result was, that using this AR system, an untrained person could perform the wiring assembly task faster than an experienced worker who used the conventional method. However, several shortcomings of current technology still prevented employing such systems on a larger scale: human interface issues, ergonomics, and overall comfort still left something to be desired. Other explored applications in an industrial context are the evaluation and optimization of assembly sequences [15]. AR visualization can utilize the CAD design data sets of modules, which must be integrated into an existing real object, for example a car door lock assembly [16]. Government-funded initiatives worldwide, such as the research project in German, ARVIKA (http://www.arvika.de), are trying to stimulate research and development in AR for such industrial applications. With improvements on the human-computer interface, such systems will find their way into the factory floor of the future.

B. Medical

For the medical community, AR applications would bring the benefit of visualizing 3-dimensional data from non-invasive sensors such as magnetic resonance imaging (MRI), computer tomography (CT), and ultrasound imaging directly projected onto the patient, so that the physician is able to see virtually into the patient ("X-ray vision"). This helping the physician during diagnosis to get more data, but could also be used as an aid for surgery to improve the precision [17], especially in minimal invasive surgery. Problematic in overlaying information on a patients body is the registration problem – one approach is to place markers on the body for visual tracking. Another problem is how to show the information to the physician without obstructing his clear view of the patient. Collaborations between universities and hospitals such as between MIT and the Brigham and Women's Hospital are exploring the technical issues in such applications. GE and Siemens [18] are developing medical equipment, which in the future will provide the capability of showing this "X-ray vision" on real patients.

C. Architecture

The fusion of real environment and virtual renditions of objects will find a very useful application in architecture, where CAD models of planned buildings can be overlaid directly in the view of the proposed site [19]. This allows to study the impact of the architecture right in the environment. Also for interior design, this technology can be used in order to design room decor and furnishing by placing virtual furniture into a real room. In general, construction, inspection, and renovation are prime applications candidates for AR technology in architecture [20]. A problem in architectural AR is how to implement occlusion: the synthetic object, that is placed into the real scene, may occlude real objects and also may be occluded partially by other buildings or structures.

D. Military and Aviation

The military area has long been the primary application area of AR technology, although it was not specifically labeled as such. The implementation of head-up displays (HUD) and helmet-mounted displays (HMD) in fighter jets and helicopters provided visual target and threat cues to the pilot, registered with the real world. In recent years, research programs have been funded by DARPA, ARL, and ONR to explicitly develop AR technology with the goal to increase the situational awareness of soldiers and commanders in outdoor scenarios and under water. Examples of such research programs are the DARPA-funded "Warfighter Visualization" program (initiated in 1997) with its subprogram "Geospatially Registered Information for Dismounted Soldiers", which focused on research for outdoor registration. The US Army Research Lab (ARL) funded a "Federated Laboratory for Advanced Displays and Interactive Displays" from 1996-2000 with significant portion in AR for outdoor applications, and ONR is funding a project "Mobile AR" for applications in an urban battlefield. The latest developments in this area focus on fusing VR visualization with Augmented Reality displays using a common scenario representation [21]. This involves filtering and tailoring the information display for avoiding cutter in the AR display [22]. Telerobotics and tele-presence is another important military application. For example, Thomson-CSF Corporate Research Laboratories is developing an AR system prototypes for military observation of low-intensity battlefields [23].

In commercial airplane cockpits, HUD displays are also more and more being used to provide visual navigation cues directly into the pilot's view. The latest developments are targeted to improve safety on the ground during taxiing operations [24]. NASA is funding further developments using "Enhanced Vision" and "Synthetic Vision", which are targeted towards improving cockpit displays using. These developments may also include Augmented Reality technology, for example overlaying synthetically rendered terrain onto image background, captured by a camera, which is mounted outside the airplane.

E. Entertainment / Infotainment

The paradigm of mixing virtual objects with the real world has a very large potential in entertainment applications, that is not yet tapped yet. Games could be developed, which would provide real-time interaction with both real objects and virtual simulation. The Mixed Reality Laboratory (Yokohama) has developed prototypes of such games [25], involving several players in a highly interactive game, in which the users can play in a real environment, augmented by virtual objects (for example AR Hockey, or shooting games).

This concept of augmenting the real world can be very well used in museums and art galleries, where information could be shown to the user, linked to the real art works and explaining and highlighting certain aspects. In expanding this concept to showing video clips and information, aligned with real buildings, Feiner introduced the concept of "situated documentaries" in a wearable AR system, that was able to show historic multimedia documentaries about the student revolt in 1968 on the campus of Columbia University [26]. It was based on the "Touring Machine" [27], which provided in a backpack solution navigation instructions in an urban environment. A different concept is employed by the prototype "NaviCam", developed by Rekimoto at SONY Computer Science Laboratory [12]. This system uses a handheld computer with an attached camera; the display shows video fromt his camera, annotated with information, which is obtained form visual readouts of ID markers in the scene.

III. Technological hurdles and possible solutions

The idea of AR is very intriguing for many possible applications. However, with the current technology there are still several hurdles to be overcome to make those applications become a reality. This section describes the major hurdles and possible solutions.

A. Registration

The main challenge in AR applications is to ensure, that the displayed information is aligned with the user's view of the surrounding world, because the human visual system is very sensitive to misalignment. This alignment is often referred to as "registration". Registration must be achieved with a high precision and must be maintained over time when the user is moving and changing his/her viewpoint without noticeable lag. This requires that the user's head is being tracking in all 6 degrees of freedom during the use of the AR system. Such trackers can be either external trackers, which require a certain "infrastructure" in the environment and, therefore, are usually limited to fixed locations. Other tracking systems can be more "autonomous", being only mounted on the user, and therefore being independent of cooperative infrastructure installations. A significant research effort is put into this field of registration, indicated by the number of research papers, presented at AR conferences. Related to registration is the problem of calibrating a head-worn display and dealing with slight shifts of the HMD relative to the eye which result in noticeable misalignment.

1. Computer Vision

Registration for AR can leverage from the vast amount of effort, put into computer vision research. One of the goals of computer vision (CV) is to reconstruct from video camera image sequences the orientation and position of a camera in real-time. The methods in computer vision employ image processing techniques for extraction of visual features, which are used to determine the structure of the environment, . If the camera is mounted on a user's head, such a system can determine the head position and orientation relative to the environment. In order to assist such a vision tracking system, one can use specifically designed visual markers, which are placed into the environment [28] or attached to objects [29]. This is, however, not always possible and feasible. Other methods have been developed to use natural visual features of objects to reconstruct the spatio-temporal relationship of the real world both for environments with supportive infrastructure (e.g. cameras mounted externally for tracking movable objects and subjects) [33] or for natural environments without any external man-made infrastructure.

The main challenges in computer vision for AR are real-time performance, which requires significant computing power, and robustness towards visual disturbances, such as low contrast and feature occlusion. The weight of high-performance work stations does not permit implementation of complex CV algorithms on a laptop yet; however, the increasing computation power of wearable computers may some time bring enough capability to wearable systems. A possible solution with current hardware is to employ a stationary high-performance computer to do the image processing from videos, transmitted from the mobile user. The results are then transmitted back to the user for visualization. This of course introduces a noticeable lag. Progress in wearable computing technology and software algorithms will pave the way for the use of computer vision in personal AR applications – however, there are still many problems to be solved.

2. Other sensors

For outdoor use, the predominant sensor for locating position is the Global Positioning System (GPS). Since the "selected availability" of the US system, which prevented precise non-military use of the GPS signal, was switched off in summer 2000, the signals can be received without distortion worldwide, providing precision of up to 1 m without the need of differential GPS. Orientation can be obtained from GPS only when the user (receiver) is in motion. A magnetic compass can provide orientation, but as Azuma pointed out [30], the compass errors due to magnetic distortions of the earth's magnetic field can be up to 20-30 degrees. But in combination with an inclinometer, which measure the angle between the gravity vector and can provide pitch and roll angle can provide pitch and roll, this type of sensor can work without any external sources in any environment. Therefore, it is very well suited for providing at least a "rough estimate" of the orientation. Problems occur during motion due to sensor relaxation time and communication lag. Here the use of inertial sensors, which measure linear acceleration and angular velocity, can help to improve the registration precision significantly. Intelligent processing of these sensor data helps to overcome their tendency to drift [31].

Ideally, a registration system for an outdoor AR application will combine several sensors for optimal fusion: computer vision, GPS, compass, inclinometer, and inertial sensors. That way, the shortcomings of each single of these sensors can be compensated, and a relatively high precision can be obtained. Such systems are being developed in several research labs with the goal to achieve real-time performance. Also for indoor tracking, a sensor fusion approach promises to improve the tracking precision significantly [32].

B. Occlusion

When mixing real world perception with synthetically rendered objects, the problem of occlusion occurs. Simple head-worn displays in use for optical see-through AR only "fuse" the synthetic display and the real world just by merging them with a semi-transparent mirror. In this case, both renditions appear simultaneously, while the synthetic rendition appears to be transparent. Video see-through AR systems have the potential to block out parts of the real world imagery to make the synthetic renditions non-transparent, using color cueing. In most cases, this is what is supposed to be achieved: that the synthetic information shall stay "on top" of the real scene and be always visible. However, in some cases, for example in a complex structured real scenario, it is appropriate to occlude the virtual object partially by real objects to achieve a realistic impression. Possible solutions were addressed by creating a depth map of the surrounding environment and using either an active sensor at the user location [34] or stereo cameras for a large-scale outdoor scene for creating this depth image. This depth map can then be analytically analyzed for intersection with the object representation, and parts of the virtual object can be rendered as being "behind" the real objects. Another way of calculating the occlusion effect without an active sensor is to use an existing 3D model of the environment for determining the correct occlusion.

C. Wearability and other Human Factors

Physical hurdles have so far prevented the wide-spread use of AR technology in wearable computers. The weight of AR capable systems (15-20 lbs) is still only acceptable for prototype developers in research laboratories. In most cases, such systems are implemented on backpacks, which provides the easiest weight distribution. Wearable vests provide an alternative to those backpacks, distributing the weight more evenly on the user. Usability of such wearable system is another factor. The MIT Media Lab "Wearble Group" has addressed these factors in their research in the past years.

1. Wearable Displays

Users generally object wearing "head-mounted" displays, which cause discomfort and strain. Developments are on the way to develop displays which can be integrated into standard eye glasses. Micro-Optical Corporation is here leading the miniaturization efforts (http://www.microopticalcorp.com/). An alternative technology for head-worn see-through displays is pursued by Microvision (http://www.mvis.com/): the virtual retinal display. This type of display does not rely on a conventional display chip, but instead uses a low-energy laser beam to "draw" and image on the eye's retina by scanning, analog to a tube cathode ray. This technology was developed by U. Washington and promises high contrast, wide viewing angle, and omnifocus. Limitations in current design, however, force compromises in these capabilities. Commercially available is a monochrome red version, but color displays are in development.

2. Wearable Computer

Technology development of wearable computers suitable for AR is still in its infancy. Although there are quite a few handheld / PDA devices on the marked, they are not suitable to handle the complex computations, required for adequate AR visualization. In some cases, the wearable computer platforms are hihg-end laptops, mounted on a backpack. The computer manufacturers VIA and Xybernaut sell ruggedized wearable PCs, running Windows 98 on Pentium CPUs with currently up to 233 MHz. Non-ruggedized wearable PCs are available in ranges from the TIQIT PC [35] with its 66 MHz 486 processor up to the SaintSong "Espresso PC with its Pentium III (700 MHz). The trend in hardware miniaturization is not yet stopped – we will see amazing miniature computers appear on the market in the next few years, which will help to bring AR applications to larger groups of users.

3. Usability and Human Factors

An important issue in developing AR applications is to investigate how a suitable interface for these can be developed. The conventional interface which is nowadays employed by most computing systems, is the Windows-Icons-Mouse-Pointing (WIMP) paradigm. This does not work well in a wearable mobile system, where the main focus of the user's attention is on the real world. Speech input is seen as seamless means for controlling the information display of an AR system, in conjunction with context sensitive awareness of the system.

Researchers also investigate the way of presenting the information in the real world. One way of avoiding head-worn displays is to project the imagery in the environment by external projectors (Spatially Augmented Reality) and to provide correct perspective by tracking the user. This, however, allows only one user to see the displayed information in the correct perspective. Linking AR visualization to physical objects is an interesting method for enhancing the real world with information. This exploits intuitive learned abilities of users to handle real world objects like ink and paper [37]. In general, one may differentiate between **task-specific** AR applications, where the user may compromise certain conveniences as a price for more efficient performance of his/her task with the help of an AR system, and **user-centric** AR applications, which are tailored to the user's abilities in dealing with the daily life tasks.

An important issue will raise with the advent of more sophisticated rendering and tracking capabilities: the user may no longer be able to differentiate between the real world and the virtual representation and may confuse both. Depending on the applications, ways may have to be found to uniquely indicate what is part of the virtual world, and what is real.

D. User Collaboration

The collaboration between users in virtual spaces has been an important research topic in the past years. Examples of such collaborative environments include the "Studierstube" [38], a project for scientific 3D visualization, and a collaborative communication tool with video transmission and a common white-board [39]. The issue of mutual privacy among those participants in a virtual shared space has been addressed by allowing users to "hide" some of the objects within their "work space" from other users [40]. The interface between the users and such collaborative AR systems must not only provide ways of handling / interacting with the information, but also among the users themselves. Speech input is used as the most seamless way of user input, but also gesture recognition is a non-intrusive way of interacting with information and users. It is important, that such collaborative systems retain the "usual" interaction modes between human users, so that these systems augment the capabilities in a way that provides intuitive extension of these human capabilities.

IV. Summary, Conclusion, and Outlook

The prime time for Augmented Reality has yet to come – currently many technological hurdles have to be overcome before AR will play a significant role. But within the next 10 years, AR will surpass the importance of VR, because VR by its very nature is limited to certain applications, whereas AR will encompass the whole range of user applications, in daily work, and even in daily life. This will help users in many tasks, but also may have significant social implications [41].

V. References and Literature

The field of Augmented Reality research is expanding rapidly. Therefore, the following literature references can only be exemplary for the wide variety of work in this exciting field. The interested reader is encouraged to use these references just as an entry into the AR research.

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Pictures:

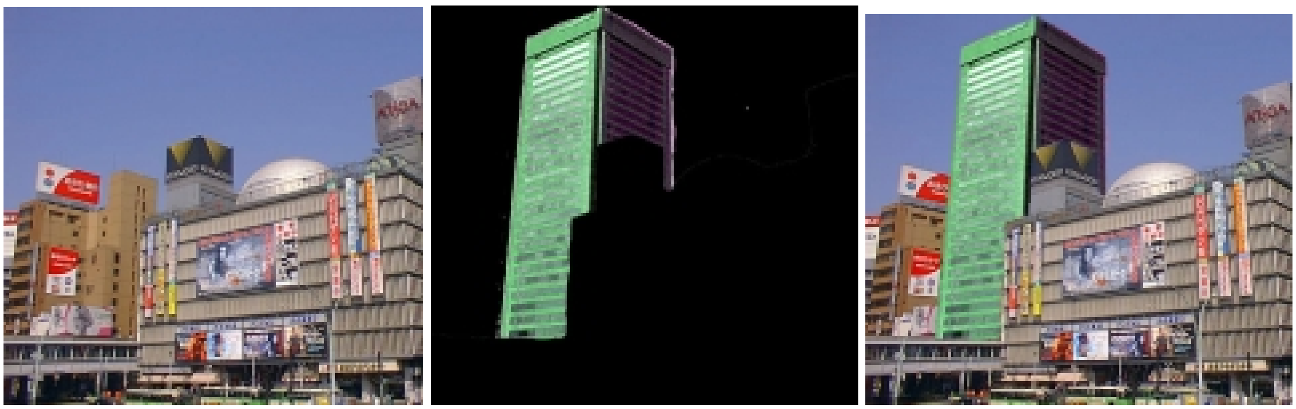

Figure 1. AR in architecture: Real scene (left), synthetic building (middle) with correct occlusion attributes, and merged result (right). (Courtesy Kiyoshi Kiyokawa, Communications Research Laboratory, Tokyo)

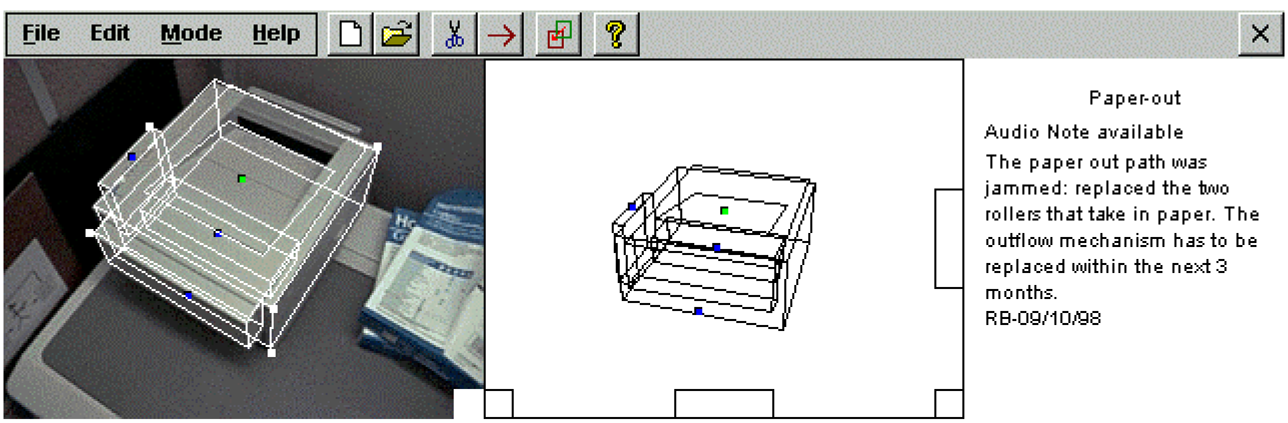

Figure 2. Screenshot from a handheld PC. The wireframe model is aligned with the image of the printer. Clicking on “hot spots” on the printer image allows retrieval of actual information, displayed in the text window on the right. (Courtesy Rockwell Science Center).

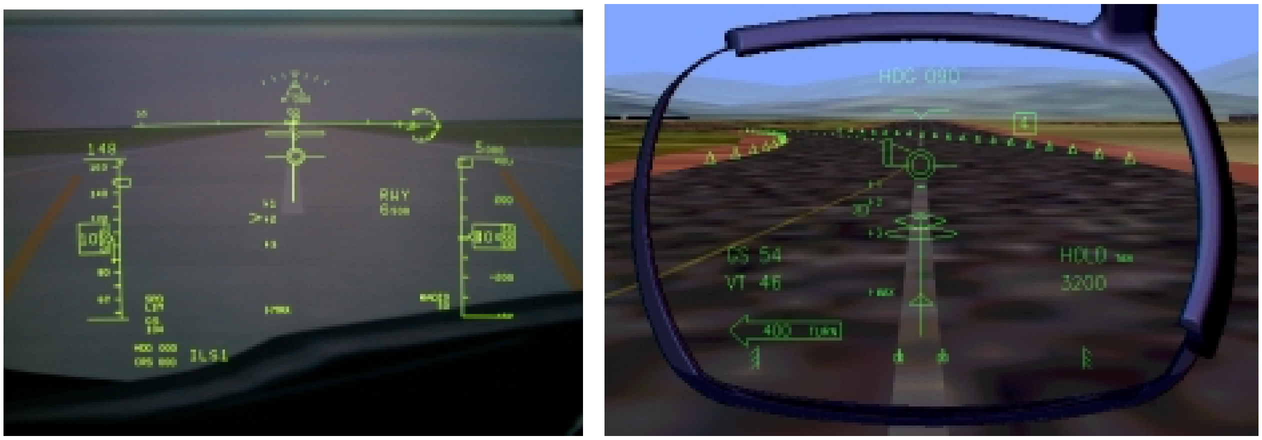

Figure 3. HUD displays in commercial airplane cockpits: current HUD with data display (left) and future HUD with registered information (right). (Courtesy Bob Wood, Rockwell Collins Flight Dynamics).

Figure 4. Head-worn displays, integrated into standard eye glasses. (Courtesy Mark Spitzer, Microoptical Corporation).