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A SURVEY OF AUGMENTED REALITY IN HEALTH CARE

Marius DANCIU, Mihaela GORDAN, Aurel VLAICU, Alexandru ANTONE

Technical University of Cluj-Napoca

Str. C.Daicoviciu nr.15, 0264/401309,

danciu.marius@com.utcluj.ro

Abstract: Although Augmented Reality technology was first developed over twenty years ago, there are no recent studies that give an overview of the research in the field of medicine. This paper surveys the state of the art in applications of virtual environments and related technologies in the Health Care domain. Virtual Reality (VR) and Augmented Reality (AR) have the potential to assist us in fields such as education, maintenance, design and reconnaissance to name only a few, but also in Health Care, improving surgical interventions and image-guided therapy by providing clinicians with interactive three-dimensional visualizations in all stages of treatment. Tools that respond to the needs of the present virtual environments systems are continuously refined and developed. Applications of these technologies improved the quality of Health Care and as we move forward into the second decade of VR, we may see more and more adopters of this technology as the cost came down. It also discuss the remaining challenges that need to be further studied and solved in order to make these systems attractive and efficient. This survey provides a starting point for anyone who work in researching or use Augmented Reality.

Keywords: *Augmented reality, virtual reality, human-machine interaction, segmentation, development suite.*

I.INTRODUCTION

1.1 Purpose

This paper highlights current state-of the art related to applications of virtual environments and related technologies in the Health Care domain. While several other introductory papers have been written on this subject [1][2][3][4], this survey is more up-to-date and is focused more on applicability of Augmented Reality in Health Care domain. It also provides a general introduction to Augmented Reality especially as it relates to Health Care.

Augmented reality (AR) is the technology used to create a "next generation, reality-based interface" [5] and it's_moving from laboratories around the world to various industries and consumer markets.

1.2 Definition

Augmented Reality can be represented as being somewhere between reality-vitality continuum by Milgram and Kishino [6] (Fig. 1). Augmented reality (AR) is a variation of Virtual Environments (VE), it is a part of the general area called mixed reality. While virtual reality (VR) has immersing a user into a computer-generated virtual world, as purpose, augmented reality follows the opposite approach, using computer generated objects as supplements for reality, rather than replacing them. Azuma described an AR system by its properties [1], [2]:

- combines real with virtual objects in a real environment;
- registers real with virtual objects;
  and
- runs interactively, in three dimensions, and in real time.

Figure 1. Reality-virtuality continuum [1].

Three aspects of this definition are important to mention.
It is not restricted to any particular display technologies such as a head-mounted display (HMD). Even if definition that describes Augmented Reality is focused more on the sense of sight, it is also applied to all other senses as hearing, touch, and smell.

At the end of 1990s it became possible to rapidly build AR applications thanks to freely available software. The technological demands for AR are much higher than the one for a virtual environment, which is why the field of AR took longer to mature than that of VR. However, building an AR system need the same key components as the prototype of Sutherland [7].
With all advances in technologies, displays, trackers, and graphics computers and software remain essential in many AR experiences.

Augmented reality inherits the philosophy that intelligence amplification (IA) of a user has more potential than artificial intelligence (AI) [8], because human experience and intuition can be coupled with the computational power of computers.

II OVERVIEW OF MEDICAL AR SYSTEMS AND TECHNOLOGIES

As early as 1938, Steinhaus [9] suggested a method for visualizing a piece of metal inside tissue registered to its real view even before the invention of computers. The method was based on the geometry of

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the setup and the registration and augmentation was assured by construction.

In the following years, different technologies appeared to permit medical augmentation of images. In this section it will be presented seven fundamental classes of technologies that permit medical augmentation with their specific advantages and limitations.

2.1 HMD Based AR System

First AR prototype based on head-mounted display was invented by Sutherland and his students at Harvard University of Utah in 1960's and used a optical see-through HMD to present 3D graphics (Fig. 2.), [7]. A stereoscopic monochrome HMD combined real and virtual images by means of a semi-transparent mirror as can be seen in (Fig. 3).

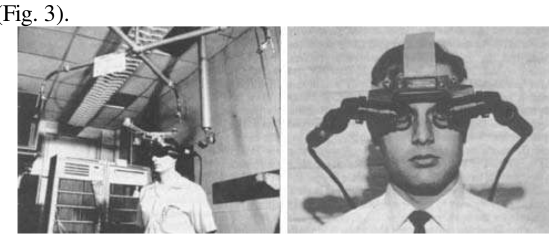

Figure 2. The world's first head-mounted display with the "Sword of Damocles" [151].

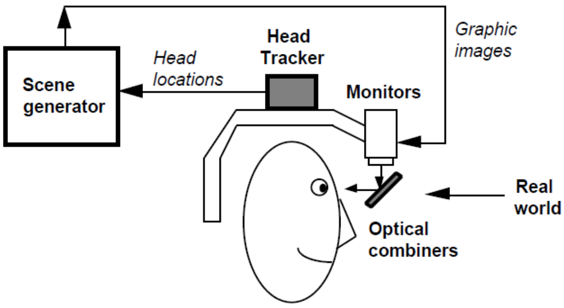

Figure 3. Optical see-trough HMD conceptual diagram [1].

Another prototype was reported in 1992 by Bajura *et al.* [10] and consisted in an video see-through system for the augmentation of ultrasound images (see Fig. 4).

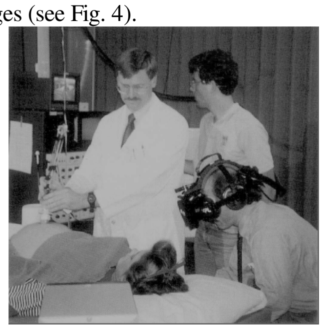

Figure 4. First video see-through HMD: Augmentation of ultrasound slices [12] 1992 ACM.

The system used a magnetic tracking system to determine the arrange of ultrasound probe and HMD. The idea of augmenting live video instead of optical image fusion does not appears feasible at first sight since it reduces image quality and introduces latency for the real view. (Figure 5) shows a conceptual diagram of a video see-through HMD.

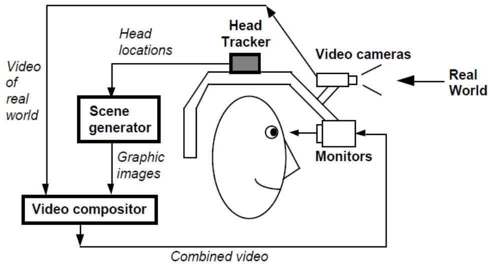

Figure 5. Video see-through HMD conceptual diagram [1].

In 1996, in a continuation of the work of Bajura *et al.* [10], State *et al.* [11] reported on a system with 10 frames per second (fps) creating VGA output.

In 2000, Sauer and colleagues [12] presented a video see through system that was capable to synchronize view of real and virtual images in real-time, i.e., 30 fps. A more advanced system is presented by Sebastian Vogt and colleges [13] that provide a compelling AR perception: the graphics appears firmly anchored in the scene, and there is no lag between video and graphics or any apparent jitter of the graphics. With the head-mounted display, the user has a natural and direct access to understanding the 3D structure of the scene, based on both stereo and kinetic depth cues as can be seen in (Fig 6).

Figure 6. Two types of marker configurations. Left: A cantaloupe is placed into the head-clamp of a neurosurgical iMR operating room and viewed with the video-see-through HMD. Head tracking works in conjunction with nine retro-reflective markers that are reproducibly attached to the top of the head-clamp. Right: A biopsy needle which is equipped with a set of retro-reflective markers. The head-mounted tracker camera tracks this marker cluster to estimate the position and orientation of the needle. [13].

Luo and Peli [14] use head mounted display visualization as an aid for visually impaired patients rather than supporting physicians.

They used an optical see-through system to superimpose contour images from an attached camera over natural vision. The system is meant to help patients with tunnel vision to improve visual search performance.

Another approach that use head mounted displays was taken into account by David Liu et al. [67], he reported that for continuous display of patient's vital signs over the anesthesiologist's field of view in critical situations an HMD that display specific sampled information is more suitable than a conventional displays.

Rolland and Fuchs [15] describe in detail the advantages and disadvantages of optical and video see-through technology.

Cakmakci and Rolland [16] realized a detailed review of head worn display technology and recent advance.
HMDs will be accepted in Health Care if they can serve the demands of the surgeon's work environment. HMDs need to be small and lightweight, easy to clean to avoid spreading infectious diseases, and most important, designed to accommodate the surgeon's workflow [67].

2.2 Augmented Optics

Operating microscopes and operating binoculars provide augmentation by inserting a semi-transparent mirror into the optics. The mirror transposes the virtual image into the optical sight of the real image. This method provides high optical quality of real images without further eye-to-display calibration, which is one of the major problems of optical see-through augmentation. Research on augmented optics evolved from stereotaxy in brain surgery in the early 1980s that brought the enabling technology together as for instance described by Kelly [17].

The first implementation of an augmented microscope was presented by Roberts et al. [18]. They developed a system that integrated segmented computed tomography (CT) images into the optics of an operating microscope.

In 1995, Edwards *et al.* [19] presented their augmented stereoscopic operating microscope for neurosurgical guidance. It allowed for multicolor representation of segmented 3D imaging data as wireframe surface models or labeled 3D points as seen in (Fig. 7).

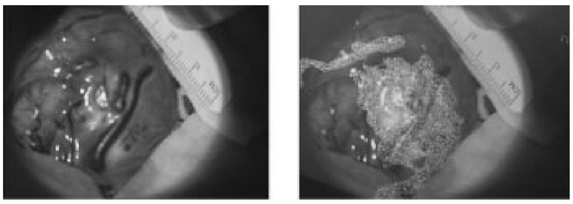

Figure 7. Augmented microscope: Ordinary and augmented view [20]© 2000 IEEE.

Birkfellner have developed an augmented operating binocular for maxillofacial surgery in 2000 [21]. It enables augmentation using variable zoom and focus as well as variable eye distances [22]. As opposed to the operating microscopes that are mounted on a swivel arm, an operating binocular is worn by the user. A disadvantage of augmented optics in comparison with other augmentation technology is the process of fusion of real and computed images.

In addition to the superior imaging quality of the real view, a significant advantage of augmented optics is easiness integration of its technology into the surgical workflow.

2.3 AR Windows

Another type of devices that allows for *in situ* visualization is an AR window. In 1995, Masutani *et al.* [23] presented a system with a semi-transparent mirror that is placed between the user and the object to be augmented. The virtual images are created by an autostereoscopic screen with built-in photographic technology (see Fig. 8). With micro lenses in front of an ordinary screen, different images are created for different viewing angles.

This reduces either the resolution or limits the effective angle of view of the user. However, no tracking system is necessary to complete the registration once it has been already established. Proper alignment is independent of the point of view. Therefore, these auto stereoscopic AR windows involve no lag when the viewer is moving. The first system could not compute the integral photography dynamically. It had to be pre-computed for a certain set of data.

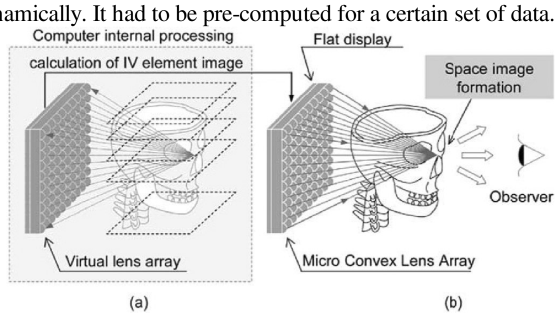

Figure 8. Concept of integral videography based augmentation and examples [24] ©2004 IEEE.

There are several ways to make AR windows. In detail, each one introduces a compromise: Autostereoscopic displays have disadvantages such as poorer image quality compared to other display technologies, but they offer visualization for multiple users. However, this leads to another compromise regarding image quality.
The healthcare branch of the iGLANCE project aims at making high quality high definition autostereoscopic displays available in the clinical operating room. The challenge that the iGLANCE project intends to address is the transmission of the autostereoscopic data through a bandwidth limited channel, while maintaining an image that does not contain significant image artifacts, like e.g. visible disocclusions[68].

All AR window designs have to take care of distracting reflections from different light sources. Last but not least, the display must be placed between the patient and the viewer. This can interfere with the surgeons' working area.

We believe that an optimal in-situ visualization device could consist of combination of an AR window and an HMD; an example may be an HMD attached to a boom.

2.4 Augmented Monitors

This kind of systems offers the possibility of augmentation of video images on normal monitors. The point of view is defined by an additional tracked video camera. Some of the researchers that brought contributions were Lorensen and Kikinis [26] who published their live video augmentation of segmented MRI data on monitors.
Sato et all [27] visualize segmented 3D ultrasound images registered to video camera images using a monitor for image guidance of breast cancer surgery.

As usual there are advantages of using augmented monitors as that the users don't need to wear an HMD or glasses, and disadvantages that they don't present stereoscopic vision.

2.5 Endoscopic Augmented Reality

Augmented endoscopes could be considered as a special case of monitor-based augmented reality or augmented imaging devices. Unlike augmented imaging devices, endoscopic images need a tracking system for providing augmentation.

In contrast with monitor-based AR, the endoscopic setup already have camera. Workflow of navigated interventions does not necessary need any additional hardware in order to provide augmentation.
Mourgues *et al.* [28] describe endoscope augmentation in a robotic surgery system. The tracking is realized by the robot since the endoscope is moved by the robot's arm. This system does not imply additional tracking system. A new prototype was developed by Naoki

Suzuki *et al.*[39] using micro fabrication technology and tele-presence technology. The surgical robot has an eye at the tip and robot arms on each side of the eye. Augmented reality was used for grasping the exact location of the surgical robot inside the human body and information on how the robot is reaching the location of surgery.

For endoscopic augmentation, the problem of calibration, tracking, and visualization are somewhat different than for other types of AR devices:

a. *Calibration and Undistortion of Wide Angle Optics*
b. *Tracking of Flexible Endoscopes*
c. *Endoscopy Related Visualization Issues*

One of the reasons for augmenting endoscope images is to provide the anatomical context since the point of view and the horizon are changing. Recovering each of these issues requires a heightened degree of concentration from surgeons since their field of view is very limited and the operating surgeon generally does not personally move the endoscope. The three-dimensional model of the surface as seen through the laparoscope is realized with a pattern projector. Dey *et al.* [29] project endoscope images on segmented surfaces for providing context and creating panoramic endoscopic images (see Fig. 11). Kawamata *et al.* [30] visualize the anatomical context by drawing virtual objects in a larger area of the screen than endoscope images are available. Ellsmere et al. [64] suggest augmenting laparoscopic ultrasound images into CT slices using segmented CT data for improved context sensing.

2.6 Augmented Medical Imaging Devices

This kind of devices can be described as imaging devices that provide augmentation of their images without the need of a tracking system.

A prototype for the overlay of fluoroscopic images on the scene has been proposed by Navab *et al.* [31] in 1999 (see Fig. 9).

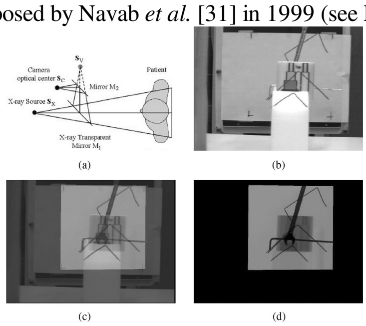

Figure 9. Camera-augmented c-arm (CamC) [78]. © 1999 IEEE. (a) Principle of CamC (CamC), (b) Camera image, (c) fused image, (d) Fluoroscopic X-ray image.

Tomographic reflection is a subgroup of augmented imaging devices. In 2000, Masamune et al, [32], [65] proposed an image overlay system that displays CT slices in-situ.

A semitransparent mirror allows for both of a direct view on the patient and the view on the superimposed CT slice (see Fig. 10).

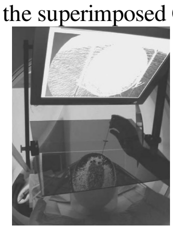

Figure 10. CT reflection [63]: Concept and prototypical setup. © 2005 IEEE.

A similar concept has been applied to create an augmented ultrasound echography device. Stetten *et al.* [33], [34] proposed in 2000 the overlay of ultrasound images on the patient with a semi-transparent mirror and a little screen that is attached to the ultrasound probe.

2.7 Projections on the Patient

The last system provides data augmentation directly onto the patient. The advantage of these systems is that the images are generally visible *in situ* without looking through an additional device such as glasses, HMD, microscope, loupes, etc. The user need not be tracked if visualization is meant to be on the skin rather than beneath. This feature is good because visualization can be used by multiple users. The simplicity of the system introduces certain limitations as a compromise, though.

Glossop *et al.* [35] proposed in 2003 a laser projector that moves a laser beam in any direction by controlled mirrors. Trajectories of the laser appear as lines due to the persistence of vision effect. The images are limited to a certain number of bright monochrome lines or dots and non-raster images. The system also includes an infrared laser for interactive patient digitization.

Sasama *et al.* [36] use two lasers for simple orientation. Each of these lasers creates a plane by means of moving mirror system. The intersection of both planes is used to guide laparoscopic instruments in two ways. The intersecting lines or the laser on the patient mark the spot of interest, for instance a cut point.

III. POTENTIAL BENEFITS OF AR VISUALIZATION

AR provides an intuitive human computer interface. It is known that intuition is difficult to measure and for an evaluation it is considered a subdivision of the differences between AR and ordinary display technology into four phenomena: Image fusion, 3D interaction, 3D visualization, and hand-eye coordination. (Fig. 11) depicts a simplified relationship between these phenomena and AR technology.

	HMD based	Augmented optics	AR windows	Augmented monitors	Augmented endoscopes	Tomographic reflection	Projection on the patient
Improved hand eye coordination	x	x	x			x	x
Extra value from image fusion	x	x	x	x	x	x	x
Implicit 3D interaction	x	x	x				
Stereoscopic visualization	x	x	x		in rare cases	only in plane	
Multiuser capability	additional AR device	additional AR device	limited	x	x	x	limited

Figure 11. Relationship between technology used and the four phenomena.

IV. SOFTWARE INFRASTRUCTURES AND FRAMEWORKS FOR AUGMENTED REALITY AND HAPTICS

This section contains infrastructures which are mainly used for implementing AR systems and prototypes. AR Toolkit is a publicly available library for marker recognition and camera-based tracking with a large user community. Arvika is a large research consortium who developed two infrastructures for their own purposes. Dart wraps trackers and other AR functionality into a Macromedia Director programming environment, while Coterie provided tracker abstractions and distributed graphical objects in a Modula-3 environment. Dwarf provides a collection of reusable software components for the quick assembly of AR applications and has recently been interfaced with Studierstube, a scene-graph-based AR infrastructure. ImageTclAR provides AR functionalities in aTcl/TK environment, while Tinmith does so in C++ with a focus on performance. UbiCom provides Quality of Service (QOS) mechanisms on mobile and wearable devices, and Vrib provides reusable software components for AR prototyping in C++ and Java.

All these projects can easily be found by typing their names into any web browser.

In order to provide a rough historical perspective, (Fig. 12) gives a chronological time line of the project durations.

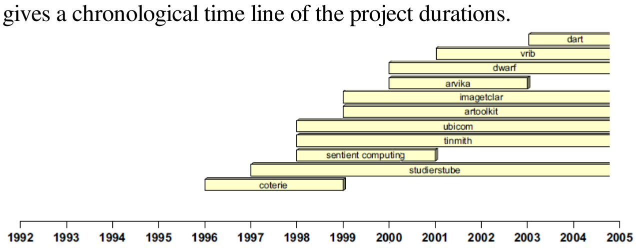

Figure 12: Time line of existed and existing systems for the fields of Augmented Reality (AR), Intelligent Environments, and Distributed Mobile Systems.

Several Application Programming Interfaces (APIs) have been produced to aid in the construction of haptically rendered virtual environments. They implement common methods of modeling forces, provide physics simulation, offer different methods of collision detection, and interface with most of the products. However, they can be slow to support new advances and so it is often preferable to develop the core simulation routines separately. Licensing methods also vary. SensAble Technology's OpenHaptics API is a commercial Cþþ library but it is free for academic use. OpenHaptics provides cross-platform support and with respect to programming it resembles the OpenGL graphics library. It only works with SensAble's force feedback devices but these are the most popular products today.

Chai3D [69], an open source library, includes both graphics (using OpenGL) and force feedback components and is written by academics in Cþþ to be platform independent. It is a comparatively lightweight API but it allows extensions to be easily added (such as ODE physics engine support), and also offers support for a range of commercial force feedback devices.

The H3DAPI, is a haptics development platform including graphics support. It is available under either an open source or commercial license dependent upon usage.

According to the development requirements X3D, Cþþ or Python can be used. The API is maintained by SenseGraphics and provides support for Force Dimension, Novint, Moog FCS Robotics, and SensAble force feedback devices. A scenegraph architecture is used to reduce the complexity of environment definition.

SensAble's devices are the most widely supported of all the haptic manufacturers and some additional APIs that provide singular support for these are XVR by VRMedia (Pisa, Italy), and OpenSceneGraph (through an additional sublibrary called osgHaptics).

ReachIn market two commercial haptic API's that support various device manufacturers. One, the self-titled "Reachin API" is compatible with Cþþ, VRML and Python with visual components rendered using OpenGL. The second is HaptX, a haptics only engine designed for the games market. Haptik [70] like HaptX also provides a basic abstraction layer for force feedback hardware. It is an open source library allowing a wide range of devices to be accessed through a common interface. The VirtualHand API, formerly from Immersion and now from CyberGlove Systems LLC, is a Cþþ simulation development API for hand interaction. It supports Cyber-Glove's gloves as well as their CyberForce system and various hands tracking hardware. MHAPTIC [71], is another hand interaction simulation environment catering for two handed manipulation. It is not freely available.

Specific to medical applications, OpenMAF [72], is an open source framework for computer-aided medicine and is based on the VTK toolkit. Haptic feedback is not the main focus in this project but is provided through SensAble's OpenHaptics interface.

More details about haptics programming interfaces could be found in paper of Timothy R. and Nigel W. in [73].

V. PROBLEMS AND CURRENT LIMITATIONS

In the next section is presented existing limitations and factors that are involved in the presented types but also some solutions to solve them.

5.1 Registration, Tracking and Calibration

The process of registration is the process of transforming different sets of data into one coordinate system. For augmented reality the registration of virtual and real objects is a key element of this technology. Maintz and Viergever [38] give a general analysis about medical image registration and its subclassification.

In the AR community the term tracking refers to the pose estimation of objects in real time. The registration can be accomplished using tracking data after an initial calibration step that provides the registration for a certain pose. This applies only if the object is moving but does not change. Calibration of a system can be carried out by computing the registration with known data sets, e.g., measurements of a calibration object. Tuceryan *et al.* [39] describe different calibration procedures that are necessary for video augmentation of tracked objects. These include determining image distortion, camera calibration, and object-to-fiducial calibration.

As the last piece in the arrangement chain of real and virtual there is the patient registration. The transformation between image data and patient data in the tracking coordinate system has to be computed. Two possibilities may apply:

1) Rigid Patient Registration: registration of patient data with the AR system can be performed with fiducials that are put on the skin or implanted [40].
2) Point based registration: however, the accuracy of a fiducial-based registration varies on the number of fiducials and quality of measurement of each fiducial, but also on the spatial arrangement of the fiducials [41].

The implicit assumption of a rigid structure is correct for bones and tissue exposed to the similar forces during registration and imaging, but not for soft tissue deformed by, e.g., respiration or heart beat. A well known example breaking this supposition is the brain shift in open brain surgery. Maurer *et al.* [42] show clearly that the deformation of the brain after opening the skull may cause a misalignment of several millimeters.

5.2 Time Synchronization

Video images and time synchronization of tracking data is an significant issue for an augmented endoscope system. In the unsynchronized case, data from different points of time would be visualized. Holloway *et al.* [43] described the source of errors for augmented reality systems. The time mismatch errors can rise to be the maximum error sources when the camera is moving.

An overcome to this problem was proposed by Jacobs *et al.* [44],he proposed methods to visualize data from multiple input streams with different latencies from only the same point of time. Sauer *et al.* [45] describe an system for augmentation that synchronizes tracking and video data by hardware triggering. Their software waits for the slowest component before the visualization is updated. For endoscopic surgery, Vogt [46] also uses hardware triggering for synchronizing tracking and video data by connecting the S-Video signal (PAL, 50 Hz) of the endoscope system to the card of synchronization used by tracking system, which can also run at 50 Hz. Therefore an optimal system should feature data synchronization and short latency.

5.3 Error Estimation

Tracking in medical AR is mostly based on fiducially because it can guarantees a good quality of tracking that is imposed, for the approval of a navigation system.

To estimate the total error of calibration, registration and tracking errors must be computed, propagated, and accumulated. Nicolau et all [47] propose a registration with error prediction for endoscopic augmentation. Fitzpatrick *et al.* [48] compute tracking based errors based on the spatial distribution of marker sets. Hoff *et al.* [49] predict the error for an HMD based navigation system.

Finally it is not enough to estimate the error, but the whole system has to be validated (cf. Jannin *et al.* [50]). The validation of the overall accuracy of an AR system must include the perception of the visualization. In the next section it is discussed the effect of misperception in spite of accurately correct positions in visualizations.

5.4 Visualization and Depth Perception

The topic of wrong depth perception has been addressed as early as 1992 when Bajura and colleagues [51] described their system. When merging real and virtual images the relative position in depth may not be perceived correctly although all positions are computed correctly. When creating their first setup also Edwards *et al.* [52] realized that "Experimentation with intra-operative graphics will be a major part of the continuation of the project".

Drascic and Milgram [53] provide an overview of perceptual issues in augmented reality system. While many problems of early systems have already been addressed, the issue of correct depth visualization remains unsolved. Depth cues are physical facts that the human visual system can use in order to refine the spatial model of the environment. These include muscular stimuli such as accommodation but also visual stimuli such as shading and convergence. Psychologists distinguish between a numbers of different depth cues. Vishton and Cutting evaluate and review psychologists' research on nine of the most relevant depth cues [54] revealing the relevance of different depth cues in comparison to each other. They recognize interposition as the most significant depth cue even though it is only an ordinary qualifier.

This means that it can only tell the order but not a relative or absolute distance. Stereo disparity and motion parallax are the next powerful depth cues in the personal space of up to two meters distance in the named order. The visual system calculates the spatial information together with the depth cues of relative size/density, accommodation, conversion, and areal perspective.

It is the very nature of AR to provide a view that does not represent the present physical conditions while the visual system expects natural behavior of its environment for correct depth perception. The visual system weights the estimates according to its importance and personal experience [54]. Incompatible cues could result into misperception, adaption, and motion sickness.

Modern theories state that the sickness is not caused by the conflict of cues, but by the absence of better information to keep the body upright [55]. Therefore engineers should concentrate on providing more information to the sense of balance (e.g., by making the user sit, unobstructed peripheral view) rather than reducing conflicting visual cues in order to avoid motion sickness.
However, motion sickness does not seem to play a big role in AR.

For AR systems that are less immersive than the one that relay on an HMD and for systems with similar properties motion sickness is therefore expected to be unlikely.

VI VISUALIZATION AND DATA REPRESENTATION

Data represented by voxels cannot be displayed straight with an opaque value for each voxel as for 2D bitmaps. There are three major ways of 3D data representation:
a) Slice Rendering: Slice rendering is the simplest way of rendering. Only a slice of the entire volume is taken for visualization.

Radiologists frequently examine CT or MRI data represented by three orthogonal slices intersecting a certain point.
The main drawback of slice rendering is that this visualization does not show any data off the plane.
b) Surface Rendering: Surface rendering shows transitions between structures.

Often these transitions are segmented and converted to polygons. The desired tissue is segmented either manually, semi-automatically, or automatically depending on the image source and the desired tissue. The surface polygons of a segmented volume can be calculated by the marching cubes algorithm [56]. Graphic cards provide hardware support for this vertex based 3D data.

They include light effects based on the normals of the surfaces with only little more computation time.

Recently ray casting techniques became fast enough on graphic cards equipped with a programmable graphics processing unit (GPU) [57].
c) Volume Rendering: Direct volume rendering [58] creates the visualization by following rays from a certain viewpoint through 3D data. Depending on the source of data and the intended visualization different functions are available for generating a pixel from the ray. The most important function is the weighted sum of voxels. A transfer function assigns a color and transparency to each voxel's intensity. It may be further refined with the image gradient. A special kind of volume rendering is the digitally reconstructed radiograph (DRR) that provides projections of a CT data set that are similar to X-ray images.

VII USER INTERACTION IN MEDICAL AR ENVIRONMENTS

Besides registering virtual data with the user's real world perception, the system needs to provide some kind of interface with both virtual and real objects. Our technological advancing society needs new ways of interfacing with both the physical and digital world to enable people to interact with those environments [59].

7.1 New UI paradigm

WIMP (windows, icons, menus, and pointing), as the conventional desktop UI metaphor is referred to, does not apply that well to AR systems.

Moving beyond mouse and keyboard, the evolution of human-computer interaction (HCI) has been an interest research in recent years which witnessed the development from text-based like using a keyboard to graphic user interface (GUI) based on a mouse, from cumbersome data gloves and tracking devices to visual-based computer application.

Like in WIMP UIs, AR interfaces have to support selecting, positioning, and rotating of virtual objects, drawing paths or trajectories, assigning quantitative values (quantification) and text input. However as a general UI principle, AR interaction also includes the selection, annotation, and, possibly, direct manipulation of physical objects. This computing paradigm is still a challenge [60].

Figure 13. StudierStube's general-purpose Personal Interaction Panel with 2D and 3D widgets and a 6DOF pen [61].

Apart from 2D/3D issues, standard 2D computer interfaces such as mice are not suited for the OR because of sterility and ergonomic reasons. Fortunately, medical systems are highly specialized on the therapy. Since a specialized application has a limited number of meaningful visualization modes, the user interface can be highly specialized as well. Context aware systems can further reduce the degree of interaction. Automatic workflow recovery as suggested by Ahmadi *et al.* [62] could detect phases of the surgery and with this information the computer system could offer suitable information for each phase.

Recent studies are based on using human gesture (hand gesture, speech) for interacting with objects in augmented reality. At this moment different approaches were carried out trying to improve the mechanism of interaction between human and machine. Till the paradigm of "free hand" is solved, there were carried out studies regarding the utility and necessity of data gloves in medical image analysis as in the study of Gallo and Ciampyi [66] where 3D imaging data can be manipulated in a semi-immersive virtual environment by means of an off-the-shelf wireless data glove equipped with additional infrared Light Emitting Diodes (LED).

A detailed review that summarizes aspects to be considered in the development of haptics technologies in medical training is presented by Timothy R. and Nigel W. in [73].

VIII OTHER APPLICATIONS OF AUGMENTED REALITY IN HEALTHCARE

The use of AR in the medical field to provide better solutions to current problems than already existing solutions is infinite.

Existing solutions include applications that allow for you to see what someone would look like with a different nose, chin or other medical procedure. While these applications have been in use in doctor's offices, they are now coming more and more to the consumer level especially at the level of a mobile device application.

Because many surgical specialties use imaging technology there is much potential for augmented reality. The technique has also been used in the superimposition of three dimensional tumor models on the breast, enabling a surgeon to perceive the position of a tumor through the skin.

In orthopedics, augmented reality could be used to guide and orient implantations. And using augmented reality to analyze and visualize a hip operation would make it possible to intra-operatively adjust the procedure to tailor it to a patient's specific needs.

One of the main uses of augmented reality in maxillofacial surgery is its ability to visualize deep structures and allow minimally invasive operations in, for example, tumor surgery, temporo-mandibular joint repair, dental work, and prosthetic and cosmetic surgery.

Augmented reality could also help in research. Studies in cognitive neuroscience have used image guidance techniques to help to understand and map the detailed function of brain structures [74]. Because of this extreme precision augmented reality can increase the efficiency, reliability, speed, and safety of neurosurgery. One way is in preoperative planning and training. Neurosurgery requires such precise and delicate operating, and it is imperative that no mistakes are made.

Rapid advances in simulator technology, combined with a demand for increased patient safety, have led to a growing interest in virtual reality (VR) simulation as a training tool to prepare physicians for complex procedures without harming the patient. A natural evolution in recent years has been the effort to scientifically validate these VR simulators as training tools.

Patient-specific procedure rehearsal is the opportunity to 'rehearse' the procedure in simulation, using the real patient's data, prior to performing the intervention on the patient [75]. Virtual reality training can supplement standard laparoscopic surgical training of apprenticeship and is at least as effective as video trainer training in supplementing standard laparoscopic training [81].

ICAR-CNR group of Naples [76, 77] is working on an AR interactive system for checking patient's hand and wrist for arthritis by overlaying in real time 3D MR imaging data directly on top of the patient's hand.

In [78], the authors use AR to provide a low cost and smaller in size solution to the post-stroke hand rehabilitation problem, which has the potential to being use in clinics and even at home.

In [79], the authors use AR to help patients fight against the phobia of cockroaches and thus show that AR can be used to treat psychological disorders as well.

Augmented reality could be implemented in routine surgical practice in the foreseeable future and complement and improve surgical procedures in many ways.

Telemedicine will also include telesurgery- the provision of VR-based systems to enable tele-present surgeons to perform surgery on remote patients.

VR environment's effectiveness in distracting from the pain of dental procedures or distraction intervention for burn patients.

AR could also be used to manage clients' medical history. Imagine if all a doctor had to do to check a patient's medical history was to put on a head mounted display and look over the patient to see virtual labels showing the patient's past injuries and illnesses.

Future developments for augmented reality may encompass the application of augmentation to other senses as well. In particular, adding and removing sound might be useful. Auditory signals could warn if a surgeon begins to stray from the augmented resection line, and this could also help in preoperative planning and the training of surgeons.

Augmented Reality in a Contact Lens, is a new generation of contact lens built with very small circuits and LEDs that promise bionic eyesight [80].

The uses mentioned here are just a fraction of the possibilities that augmented reality holds. The potential that augmented reality has in medical fields is limited only by the depth of our imaginations.

XI CONCLUSIONS

After two decades of research on medical AR the basic concepts seem to be well understood and the needed technologies are now available and present the basic requirements for a number of medical applications. There are more and more signs showing that medical

AR systems and solutions could be accepted by physicians, if they are integrated seamlessly into the clinical workflow and if they provide a significant benefit at least for one particular phase of this workflow. A medical AR user interface will be accepted only if the end user would not feel its existence, while providing additional in situ information.

To provide an effective AR experience there are a number of factors that must be taken into account:
(a) Graphics rendering hardware and software that can create the virtual content for overlaying the real world.
(b) Tracking techniques that will associate the viewer's position with the rendered graphics.
(c) Tracker calibration and registration tools for precisely aligning the real and virtual views when the user view is fixed.
(d) Display hardware for combining virtual images with views of the real world.
(e) Computer processing hardware for running AR simulation code and supporting input and output devices.
(f) Interaction techniques specifying how the user can manipulate the AR virtual content. In addition there are a number of secondary conditions that must be meet depending on the AR application being explored, such as usability evaluation, mobile/wearable systems, AR authoring tools, visualization techniques, multimodal AR input, and novel rendering methods, software architecture, etc.

After the basic problems with AR are solved, the ultimate goal will be to generate virtual objects that are so realistic that they are virtually indistinguishable from the real environment.

It is expected that the interest for augmented reality will reach a maximum in few years and that medical AR will be one of first maximum priority applications, saving lives of many future patients.

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