ISSN 2706-6819 Vol.5, Issue 6: 65-76, DOI: 10.25236/IJFM.2023.050611

Application and development of augmented reality in the medical field

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Abstract: *This paper provides a systematic review of augmented reality (AR) technologies and their applications in medical diagnosis and treatment from 1988-2023. The paper is categorised by key technologies of augmented reality and medical diagnosis and treatment applications. For AR key technologies, 67 articles were researched. Among them, AR key technologies can be divided into three methods: display, calibration and tracking, with video perspective display technology dominating the field. For calibration technologies, 17 articles were included in the review, and we discussed methods based on graphic markers, optical markers and markerless calibration, respectively; for positional tracking technologies, 15 articles were counted, and we discussed methods based on markers, simultaneous localisation and map building, and optical flow-based tracking, respectively; for application areas of AR technologies, simulation teaching and training, surgical guidance and telemedicine were included in the review Scope.*

Keywords: *augmented reality, medical treatment, posture calibration, posture tracking, surgical guidance*

1. Introduction

Augmented Reality (AR) was first developed by Ivan Sutherland, a professor at Massachusetts Institute of Technology, and his students in 1968 when they developed The Sutherland of Damocles, the world's first optical see-through head-mounted display. Sutherland of Damocles). [1] The Sutherland of Damocles was developed by Ivan Sutherland and his students in 1968, when they developed the world's first optical see-through head-mounted display, the Sutherland of Damocles [1], which allowed people wearing the head-mounted display to view a simulated image produced by a computer technique superimposed on a realistic scene, and which changed depending on the number of viewpoints.

Augmented Reality [2] This new technology, based on real-time computer computing and multi-sensor fusion, has the primary objective of enhancing the user's perception of and interaction with the real world, providing an experience beyond the real world. In the medical field, AR technology can enhance the depth of perception of diseased organs or tissue structures for better diagnosis and treatment of diseases.

AR and VR (Virtual Reality, VR for short) [3] There are certain connections and differences between [4, 5]. AR allows direct or indirect observation of the real world and has a sense of presence; it is augmented by the availability of additional information in the area to be observed; and it is relevant through the computer's perception of the scene and the addition of corresponding content through 3D reconstruction. In contrast, VR presents a completely virtual image, which is virtual and more interesting.

2. AR Key Technologies

In the last ten years, AR technology has been rapidly developed, including three main aspects: display, calibration and tracking, relying on a complete technology chain to achieve accurate fusion display of virtual models and real patient space.

2.1. Display technology

To enhance the surgeon's visual field during surgery at, virtual models of organs can be effectively

ISSN 2706-6819 Vol.5, Issue 6: 65-76, DOI: 10.25236/IJFM.2023.050611

overlaid with real patients using augmented reality technology to assist the surgeon in differential diagnosis. [6]. AR display technology can be divided into three types of display depending on the display device: projection display, optical fluoroscopy and video display.

2.1.1. Projection display

The projection display technology uses spatial calibration algorithms and a projector as a medium to project a virtual organ model of the patient onto the surface of the real organ to provide the surgeon with a visualization of the fusion of reality and reality to assist in high-precision surgical operations.Wang et al. [7] proposed an augmented reality technique based on projection display and used it in oral surgery. This method allows the surgeon to view a 3D model of the organ on the patient by placing a projector around the patient, thereby improving the safety and precision of the surgical operation. yang et al. [8] proposed a novel augmented reality 3D reconstruction and rapid imaging system for subcutaneous veins, which precisely superimposes the vein structure on the patient's hand skin by inverse projection, overcoming the time-consuming and costly problems and allowing it to be used in cases of poor contour and contrast, improving the success and efficiency of intravenous injections. [9] proposed an augmented reality computer-assisted spine manual approach that projects a pre-operative 3D model of the patient onto an intraoperative scene by projecting pre-acquired CT images onto the patient's skeleton, as shown in Figure 1. To make it easier and faster for the surgeon to find the puncture point during the spinal puncture procedure. However, the virtual fusion of the organ will fail if the surgeon obscures the projected image during the procedure. liu et al. [10] and Wu Shouxuan et al. [11] The coaxial projection technique developed by Liu et al [10] and Wu [11] has effectively solved this problem.

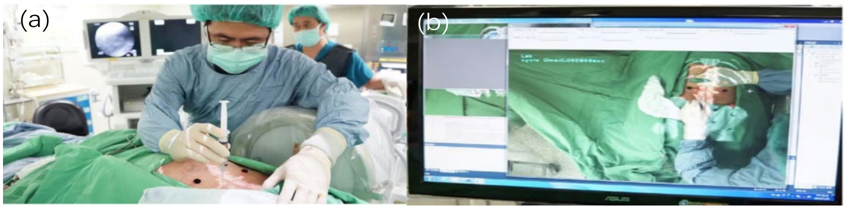

Figure 1: Surgeon performing a surgical procedure based on the projected information (a) and the image under the camera projection system (b) [9]

2.1.2. Optical fluoroscopy

Optical fluoroscopic display technology wirelessly transmits a virtual model of a patient's organs to an optical fluoroscopic display device, such as HoloLens, and then uses spatial alignment techniques to match the virtual model to the real patient space, thus allowing the physician to visualize a fused virtual-real scene of the organs in the optical fluoroscopic device. SIELHORST et al. [12] in 2013 proposed an augmented reality-based virtual protractor guidance technique for vertebroplasty with percutaneous radicular puncture. This method uses a head-mount display (HMD) to view the virtual insertion point and 3D model, overcoming the disadvantages of previous time-consuming and expensive X-ray fluoroscopic guidance. With the prevalence of cardiac disease in recent years, Liu et al. [13]. have developed a new method of image guidance that uses 3D holograms to display the patient's heart and catheters. This method aligns fluoroscopic images with CT images and displays information about the heart and catheter on the HMD, enhancing the safety and accuracy of the procedure by displaying the lesion in different angles. In recent years, holographic head-mounted display devices such as HoloLens have received increasing attention. Perkins et al. [14] use HoloLens devices to match preoperative MRI images with breast tumours in real time during surgery to guide the surgeon to accurately remove the tumour. In order to obtain a more stable display of fusion of reality and reality in neuronavigation systems, Frantz et al. [15] used Vuforia image processing technology to enable real-time matching and tracking of preoperative images with intraoperative 2D images.

2.1.3. Video display

The video display technology has the advantages of simplicity, good image quality and accuracy. The technology mainly involves superimposing a 3D reconstructed model onto the patient's body surface during surgery and displaying the images in real time in a video format as the surgeon moves the instruments in his hands. [16].. However, there are some disadvantages to this technique, such as fatigue for the surgeon. There are two forms of video display, namely fixed displays and mobile hand-held displays. Xie et al. [17] in 2019 proposed a method to localise the location of the haematoma by fitting the scalp anatomy to the reconstructed image on a cell phone screen. However, this method has a delay and a limited range of motion. [18]. proposed an augmented reality system for oral surgery based on IV images, as shown in Figure 2, in order to overcome the drawbacks of traditional display methods that are unable to obtain visual depth information. This allows the surgeon to observe soft tissues and important nerves during oral maxillofacial surgery, ensuring that the procedure is performed quickly and accurately. A GPU-based rendering algorithm was also added to address the problem of device latency. On top of the fixed display, 3D glasses were generally required to give the surgeon a more accurate perception of the depth of the lesion. [19]. used this approach successfully in hepatectomy using a semi-automatic alignment of the smart liver navigation system, but the method requires specific room light, which limits the surgeon's field of view and makes it more suitable for endoscopic manual surgery.

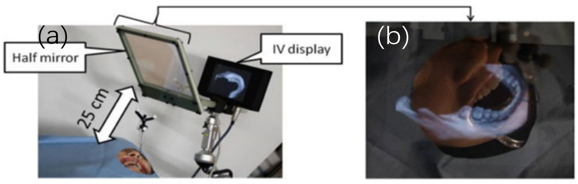

Figure 2: Left experimental setup Right virtual graphics overlay at the surgical site [18]

2.2. Calibration

In order to accurately locate a target, spatial calibration techniques are crucial. Due to the limitations of human eye observation, we generally cannot directly obtain the specific position of the observation target in space and need to construct a correspondence between the physical environment, the tracking system and the human eye imaging through calibration techniques. Calibration techniques include graphical marker-based, optical marker-based and markerless calibrations.

2.2.1. Calibration techniques based on graphic markers

The calibration method based on planar graphic markers achieves preoperative medical image and patient space posture calibration and matching mainly through the recognition of graphic coded markers [20] . Pflugi et al. [21]. proposed a hybrid navigation technique based on the combination of graphic planar marker tracking and an internal inertial measurement unit (IMU) for the treatment of abnormal hip lesions, as shown in Figure 3. The method first places the graphic marker on the acetabular fragment and constructs a positional mapping model of the graphic marker, inertial measurement unit, binocular imaging system, preoperative medical images, and patient space through a multi-sensor fusion method, thereby assisting the physician in precise treatment. The system overcomes the problem of posture compensation when optical tracking is obscured by the inertial measurement unit. zhu et al. [22] proposed an augmented reality surgical navigation system based on an occlusal splint and applied it to oblique split mandibular osteotomy. The system first matched the teeth with the corresponding points of the occlusal splint through a marker point alignment method to construct an integrated model of the mandible with the graphic markers. The preoperative medical image is then robustly aligned with the patient's mandible by means of an extended Kalman filter to obtain a virtual reality fusion scene of the patient's mandible. This system has the advantage of fast and accurate alignment, but is not suitable for patients with an edentulous jaw. lin et al. [23] proposed an oral implant system that allows precise alignment between the surgical instruments and the implant sites with the help of a specific guide sleeve for positioning, which can improve surgical accuracy and efficiency.

The calibration method based on stereogram markers enables accurate integration of the virtual image with the actual scene through spatial 3D alignment. Abn et al. [24] proposed a navigation method that combines stereogram markers with AR technology and applied it to orthognathic surgery. The technique starts by reconstructing the preoperative CT data into a 3D image and then rigidly fixing the stereogram markers to the mandibular teeth. The method allows the surgeon to view the fused scenes of the patient's virtual model and the real organ from different perspectives, which helps the surgeon to perform surgical operations quickly and accurately.

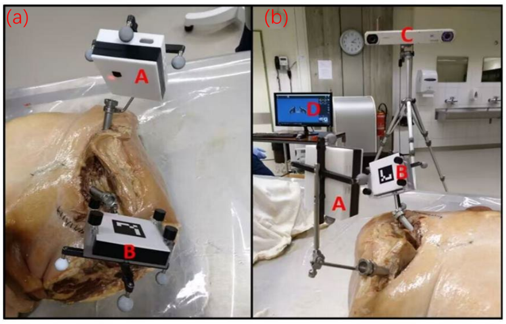

Figure 3: A: Tracking device B: Enhanced marker C: Tracking stereo camera D: Mainframe Left: A placed on the pelvis and B placed on the fragment connected to the DRB used for the optical tracking-based navigation system Right: Placement of the experimental equipment [21]

2.2.2. Calibration techniques based on optical markers

The optical marker-based labelling method aligns 3D stereoscopic images with real organs by finding optical marker points with high accuracy and has a wide range of applications.

In the context of chiropractic care, Ma et al. [25] proposed an ultrasound-based augmented reality surgical guidance system and used it for pedicle screw implantation. This system uses ultrasound to calibrate preoperative CT images with the organ. This computer-assisted surgical method improves surgical accuracy, reduces radiation dose and enables real-time, in situ image guidance, as shown in Figure 4. However, there are limitations to this method, with low ultrasound accuracy leading to large alignment errors. In oral surgery, Tran et al. [26] proposed an augmented reality system for oral surgery based on (integral image) IV images, where 3D virtual images of bones and soft tissues, superimposed on the patient using an integral video format, overcame the visual differences in horizontal and vertical motion generated over a large area and could help the surgeon to perform oral and maxillofacial surgery more easily.

In head and neck surgery, the performance of head and neck surgery can be limited by geometric precision because the lesion is a soft tissue that is highly susceptible to deformation [27]. . Daly et al. [28]. developed a sub-millimetre precision endoscopic video and 3D cone beam CT calibration method that allows for less complex head and neck tumour surgery. The system is an infrared reflection-based marking method that achieves precise positioning between the X-ray projection image and the tracker, which has significant safety and clinical teaching advantages. brouwer et al. [29] proposed a fluorescence-based augmented reality localisation system, which uses an optical reference as a reference target and, after adding SPECT/CT images into the navigation system, uses the state of alignment between the preoperative 3D image and the optical tracking technique to localise the lesion, aiding preoperative surgical planning. During surgery, markers guide the surgeon in identifying the area of interest and determining the exact location information of the lesion.

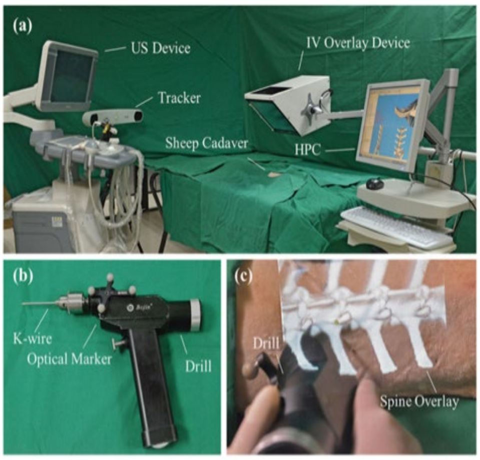

Figure 4: (a) Realistic surgical scenario using a sheep carcass (b) K-wire with optional marker points attached to the drill (c) AR-guided insertion of the K-wire using the drill [25]

ISSN 2706-6819 Vol.5, Issue 6: 65-76, DOI: 10.25236/IJFM.2023.050611

2.2.3. Calibration techniques based on no standards

The markerless-based method does not require the pre-positioning of markers and uses the natural features of the target to be observed for localisation. This localisation method can be divided into 3D2D alignment based [30, 31] and calibration based on image feature recognition.

Among the 3D2D alignment-based calibration methods, Livyatan et al. [32] proposed a gradient projection-based alignment approach that rigidly aligns the patient's preoperative CT images with the intraoperative state in real time and uses a C-arm with tracking performance to acquire X-ray fluoroscopic images, which consists of three basic steps: initial pose estimation, coarse contour alignment, and fine gradient projection alignment. The accuracy is higher compared to the geometry-based alignment and the speed and convergence range is wider compared to the intensity-based alignment. tomazevic et al. [33] aligned preoperative 3D CT images or MRI images with intraoperative 2D X-ray images without reference marks, using a reference function to measure surface normals and match them to the inverse projection intensity gradient of the X-ray map, as shown in Figure 5. The method requires no intraoperative segmentation and is fast to align. However, soft tissues, surgical instruments and implants have a significant impact on the alignment accuracy in this system. hipwell et al. [34] Based on Penney et al. [35] proposed an augmented reality system that matches 3D magnetic resonance angiography (MRA) with 2D X-ray digital subtraction angiography (DSA) for the diagnosis and treatment of vascular disease. The system is based on a digital reconstruction X-ray alignment method that directly aligns with the DSA image of the X-ray, which enhances the visualisation, accuracy and robustness of the organ.

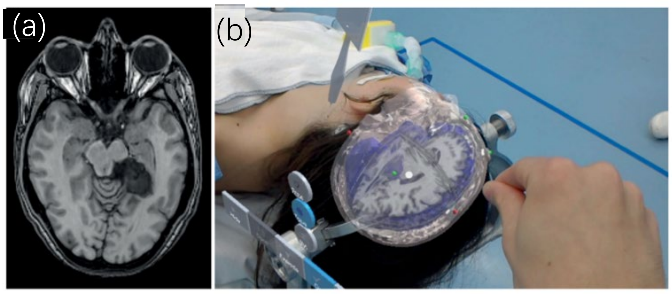

Figure 5: (a) Pre-operative MRI image (b) Hologram of MRI projected onto the patient's body surface [35]

Among the calibration methods based on image feature recognition, Chung et al. [36] proposed a multimodal image alignment method for estimating information about the joint strength distribution. The method is predictive from alignment training, i.e. the expected joint strengths obtained from two pre-aligned training images are used as a reference so that two arbitrary images are aligned and a good alignment between the expected and observed strength distributions is achieved. The method lacks some application and will need to be validated with a large amount of data in the future.

2.3. Tracking

Tracking is the process of locating a target in a specific environment. The main tracking techniques for augmented reality systems are based on graphical markers, Simultaneous Localization and Mapping (slam) and optical flow based tracking.

2.3.1. Tracking technology based on graphic markers

The graphical marker-based tracking method is a method of tracking by reading the image information of visual markers for the calculation of transformation trajectories. Tristan et al. [37] proposed a graphical marker tracking method for neurosurgical applications, where a virtual needle is projected onto a real pointer, the marker is continuously tracked and a hologram is displayed on a flat screen. The hologram and the use of gestures can be performed at any angle and in any direction with high accuracy, providing the surgeon with a continuous three-dimensional view. However, it is subject to correction for object motion and is not currently used clinically. Nicolau et al. [38] proposed a tracking system for guiding thermal ablation of liver tumours in interventional radiotherapy, which establishes the preoperative image of the patient in the same coordinate system as the puncture needle and tracks the needle in real time through the preoperative model generated in the camera where the opaque markers on the skin are located, as shown in Figure 6. This technique improves efficiency, reduces complications and radiation dose for the procedure.

ISSN 2706-6819 Vol.5, Issue 6: 65-76, DOI: 10.25236/IJFM.2023.050611

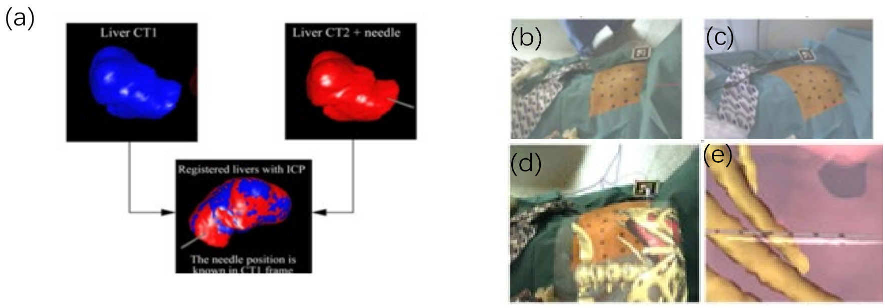

Figure 6: Left as shown in the legend, right: the upper part indicates 3D2D alignment of CT1+ needles in the camera frame using radio opaque markers, the lower part indicates the difference between the needles tracked by the camera and the needles recorded in CT1 as an assessment of the accuracy of the system [38]

Of the optical marker-based tracking methods, Jan et al. [39] proposed an augmented reality hybrid tracking scheme based on a certified medical tracking system that requires the addition of a built-in infrared camera system and where the final tracking results are based on the initial infrared tracking data and features in the camera images, resulting in an image-guided surgical device that performs pose estimation as an iterative numerical optimisation scheme that reduces the overall frame rate of the system.

2.3.2. Slam-based tracking technology

This technology refers to mobile devices with sensors that can obtain real information about the environment in real time to locate themselves and build a map of the scene in conditions of lack of information [40]. .

Ma et al. [41] proposed a navigation system based on motion-tolerant autonomous stereoscopic image overlay, which tracks the sequence of binocular images by tracking changes in the operating room environment, as shown in Figure 7. Distinguishing from conventional navigation systems [42, 43]. Of the tracking principle. A computer-generated integral photographic three-dimensional superimposed augmented reality system based on a computer-generated integrated photographic three-dimensional superimposed augmented reality system was also developed to overcome the problem of occlusion of the collimator.Wang et al. [44] proposed a feature tracking algorithm to improve the success rate of endoscopic anterior cranial surgery, and combined it with a robust estimation method for adaptive scale kernel consistency to form a complete system. The system was able to track accurately even in the presence of poorly displayed images and geometric distortions.Luo et al. [45] proposed a hybrid tracking technique for tracking bronchoscopes, which combines SIFT, para-polar geometric analysis, Kalman filtering [46] and image alignment techniques, effectively combining filter-based and feature-based motion tracking methods. The SIFT and pair-polar geometric analysis is used to obtain the pose displacement estimates, the Kalman filter is used to estimate the motion amplitude, and the resulting raw data is used for image alignment and tracking. The tracking performance of the method is improved.

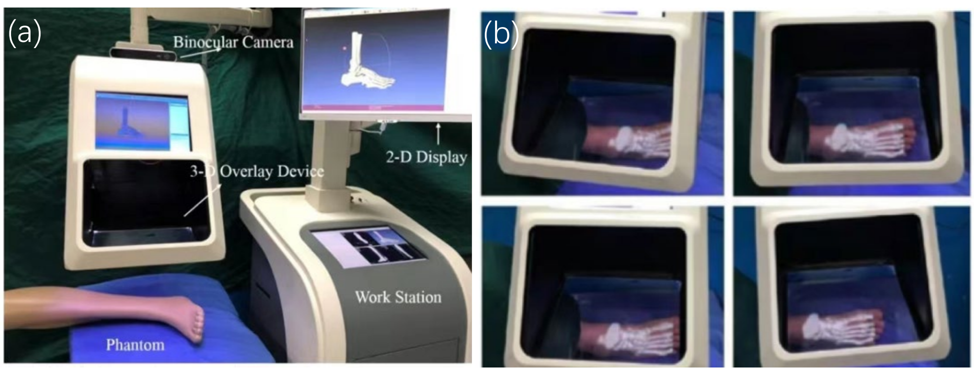

Figure 7: (a) Experimental set-up (b) Overlay device and patient fused 3D images at four different angles [41]

2.3.3. Optical flow based tracking technology

The optical flow method involves capturing a frame in the video stream as a feature point for tracking, finding the position of this point at the next frame and making a prediction [47].

Liu et al. [48] proposed an optical flow-based tracking method for computer vision algorithms to estimate the possible motion of objects by aligning optical and virtual colonoscopic images to assist the surgeon in colorectal surgery. The algorithm combines a sparse optical flow field with a dense optical flow field to independently calculate camera translation and rotation parameters to improve algorithm robustness, as shown in Figure 8. The optical flow method is less sensitive to changes in light and shape and has high alignment accuracy. However, it still has disadvantages such as poor real-time performance and inaccurate estimation when the displacement is large. To overcome this challenge, Xu et al. [49] proposed a technique for tracking the position of lung tumours in fluoroscopic video, which combines optical flow and stencil matching tracking algorithms to provide the specific position of the tumour within each frame. And the method has some gated delivery techniques and is non-invasive. Zheng et al. [50] proposed an optical flow combined with a dynamically trained convolutional neural network model and a spatial voting algorithm. The method first localises the polyp by single-frame target detection or other segmentation networks, and then tracks the polyp according to the optical flow and incorporates temporal factors to reduce problems due to motion, and its feasibility was verified experimentally.

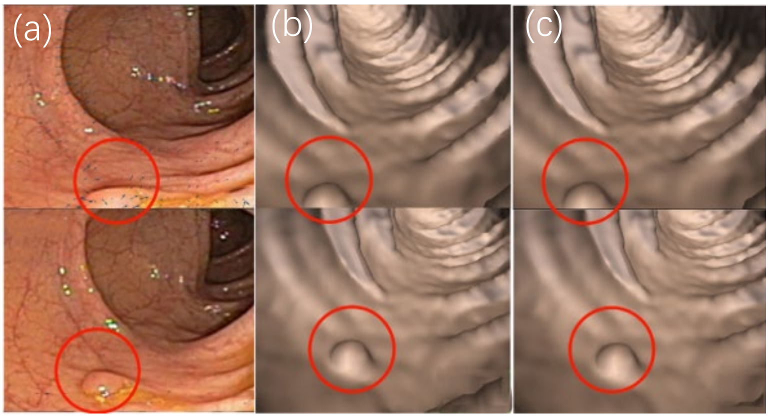

Figure 8: Comparison of tracking results using a cylindrical colon model and the depth values of the actual segmented colon. To generalize the tracking algorithm, we used a cylindrical model segmented from a 3D simulated colon, shown on two different frames (a) optical image (b) results of the virtual colon depth (c) results of the colon model Red circles: reference for estimating tracking accuracy [50]

3. AR application scenarios

3.1 Simulation teaching training

Medical students are currently taught with large specimens and clinical practice, but the training materials and processes of this method are not permanent and the lesions are not representative and limited. AR/VR augmented reality teaching is a new teaching method that combines artificial intelligence technology, multimedia technology and computer simulation technology. Its teaching principles mainly follow the idea of "complementing reality with emptiness and combining reality with emptiness". Through repeated simulation training, the trainee's comprehensive ability can be improved [51]. The teaching principle is based on the idea of "complementing reality with reality".

Surgical procedures are complex, with a high risk factor, and modern medical education focuses on the training of students' clinical hands-on ability, judgment and emergency response, in which a large number of operations are often required to improve the effectiveness of laboratory teaching [52] . Yuan et al. [53] applied AR teaching to spinal surgery, a teaching method that superimposes computer-generated simulated images on real-life scenarios to give students clearer images of the anatomical structures and adjacent locations of the nail pathway. It is not limited to textual descriptions and pictorial explanations, allowing the operator to be in the scene and increasing the interest and realism of learning. Wu et al. [54] applied AR technology to the educational teaching of CPR, in which students could clearly observe the inflow and outflow of blood in the heart, deepening their understanding and improving their skills. Zhang et al. [55] The use of augmented reality technology enables students to obtain information about the relevant organs in terms of vision, hearing and touch when learning acupuncture, enabling them to accurately grasp the location and names of acupoints, as shown in Figure 9.

ISSN 2706-6819 Vol.5, Issue 6: 65-76, DOI: 10.25236/IJFM.2023.050611

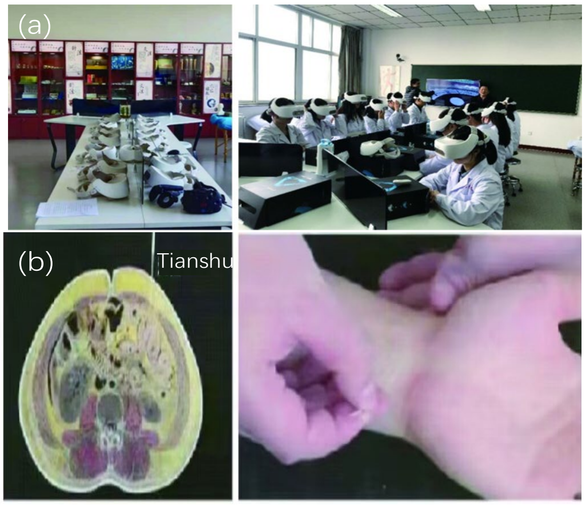

Figure 9: (a) Augmented Reality Acupuncture Teaching Lab (b) Acupoint Information Seeking

3.2 Surgical guidance

As modern technology continues to develop, minimally invasive surgery continues to rise in the treatment of disease, but due to the limitations of its operating space, AR technology is needed to enhance the surgeon's perception and improve surgical accuracy.

The application of AR technology to surgical navigation allows information about the lesion site to be viewed continuously during the procedure. Currently, the main focus is on combining preoperative CT and MRI image information with realistic intraoperative scenes to guide the surgeon in spatial positioning. The method is applicable to most parts of the body, such as the spine, chest and face.

The King and Others [56] proposed an augmented reality-based navigation system for minimally invasive spine surgery, which avoids the risk of intraoperative damage to surrounding structures due to operational errors and reduces the exposure dose for both the patient and the surgeon through three-dimensional reconstruction of the surgical site and the surgeon wearing certain imaging devices to assist in the surgical access operation. Zhou et al. [57] proposed a holographic imaging technique for use in the chest, which presents a fluoroscopic image of the diseased lung to the surgeon in real time and displays a three-dimensional holographic image of the lesion, allowing the surgeon to view the surgical site precisely. The method is less costly and does not require the cooperation of other departments, while making the operation simpler and lowering the technical threshold. 2013, Suenaga et al. [58] incorporated AR technology into oral and maxillofacial treatment by simulating the acquired CT data to produce a 3D model of the maxilla, which is projected onto the surgical site through a semi-gold-plated mirror for surgical navigation. The system is highly accurate and the three-dimensional image in the surgeon's field of vision does not change with visual changes.

Laparoscopic surgery has also become more common in recent years, and the reliance on surgeon's experience can be effectively reduced by combining it with AR technology, which mainly applies preoperative CT, MRI, US, SPECT and other data through video overlay, with the characteristics of less trauma, faster recovery and higher infection rate [59] The method is widely used in the resection of liver and pancreaticoduodenum [60-63] This is shown in Figure 10.

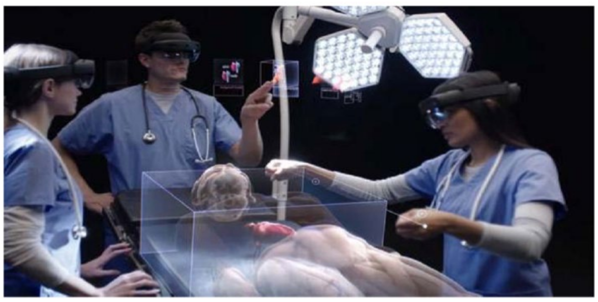

Figure 10: Surgical results based on augmented reality navigation technology [62]

ISSN 2706-6819 Vol.5, Issue 6: 65-76, DOI: 10.25236/IJFM.2023.050611

3.3 Telemedicine

The uneven regional distribution of medical resources is a common problem in China and around the world. Patients in remote or rural areas find it difficult to receive high quality medical services, making it difficult for patients with serious illnesses in these areas to travel to areas with superior medical conditions, increasing the difficulty of accessing medical care. Telemedicine [64] the use of AR technology can be an effective solution to this problem, as it is difficult to meet the needs of medical consultations with ordinary imaging equipment.

In the period of the New Crown epidemic, Shaw et al. [65] applied AR remote guidance technology to treatment. To overcome the challenges of doctor-patient transmission, the system fused audio-visual and AR real-time dynamics to transmit the condition of patients in contaminated areas to doctors in clean areas in real time, efficiently and visually, as shown in Figure 11. Effectively reducing the consumption of prevention supplies and reducing the risk of transmission, while enhancing the competence of young doctors andersen et al. [66, 67]. The local system is linked to the remote system through lossless video frame encoding technology, with the local field operation area and the remote specialist's operation displayed on a monitor, allowing the field physician to observe the monitor directly for operation. This method allowed the field physician to focus and operate at an improved level, reducing the incidence of errors.

Figure 11: (a) Contaminated area guide end (b) Clean area guide end [65] (b) Clean zone guidance end

4. Development trends and future challenges

In recent years, AR technology has come to have a significant impact in a wide range of industries. A review of recent medical literature shows that AR calibration and tracking technology is moving towards markerless, as well as reducing the cost of intraoperative navigation and easing the burden on patients. With the development of 5G networks, AR telemedicine is gradually emerging and will influence the way doctors and patients communicate in the future.

Based on recent literature on AR, it is clear that the core technology is divided into several areas: display, calibration and tracking. The current trend in display technology is to make the display device worn by the doctor lighter and the quality of the display image better, which allows the doctor to reduce the work pressure and improve the diagnosis of the lesion during the consultation. The calibration technology needs to enable more accurate alignment between real and imaginary objects, especially for complex scenes. The line of development for tracking technology is closely related to dynamic, real-time tracking. The main application areas regarding AR in medicine are divided into three areas: simulation and teaching, surgical guidance and telemedicine. Due to the lack of teaching resources, augmented reality teaching training allows students to perform a large number of simulated anatomical operations, which both reduces teaching costs and helps to improve student competence. In surgical guidance, displays need to be made more powerful and with minimal latency to ensure real time performance. In terms of telemedicine, with the rise of 5G networks, the likelihood of telemedicine being biased towards remote villages will increase, alleviating the problem of uneven distribution of medical resources.

There are still many problems with AR technology in the medical field, and many AR technologies are not yet available for clinical use. The main challenges are to improve the quality and clarity of the display device, and to improve the accuracy and robustness of tracking and calibration.

5. Discussion and summary

This paper provides an in-depth analysis of the application and development of augmented reality in the medical field, systematically analysing and summarising the main technologies of augmented reality and developing a description of the significant contributions of these technologies in the medical field. It also provides an in-depth analysis of the applications of augmented reality in the medical field, expanding on its analysis and collation. A comprehensive overview of the current trends and future challenges of augmented reality is presented.

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