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A SURVEY OF TECHNIQUES AND ARCHITECTURES FOR EXTENDED REALITY COMPUTING

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Abstract

Extended Reality (XR) is a huge trend in recent years. It collects Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality(MR). This survey aims to give a presentation and an overview of the world of Extended Reality. We will go through different fields of application exploring related research. In particular this survey explores, for each field, definitions and different configurations in order to elaborate a general visualization of the kind of works the scientists are into. In detail, in each field we present different works related to that topic and at the end we have one or more tables to collect information about XR set ups. Consequently we have created a tree that summarizes the most used technology faced during the explorations of all the researches in each field.

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Chapter 1

Introduction

Extended Reality (XR) is an umbrella term that encompasses various immersive technologies that blend the physical and digital worlds. It is an evolving concept that includes Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). VR refers to a computer-generated simulation of a three-dimensional environment that users can interact with using specialized hardware, such as VR headsets; it immerses users in a completely virtual world, blocking out the physical surroundings.Various companies, such as Facebook, YouTube, and Periscope, have established platforms to offer Virtual Reality (VR) services, garnering significant global interest. Presently, major corporations on a global scale, including Adobe, Apple, Amazon, Google, Microsoft, and Samsung, are making substantial investments in the development of VR. Notably, even the United States Army is adopting VR technology for soldier training purposes. This highlights the widespread acknowledgment and adoption of VR across diverse sectors, showcasing its growing importance and application in various fields.AR overlays digital content onto the real-world environment. Unlike VR, AR does not replace the real world but enhances it. Augmented Reality (AR) is designed to simplify users' lives by seamlessly incorporating virtual information into their immediate and peripheral views of the real world, including live-video streams. Unlike Virtual Reality (VR), which fully immerses users in a synthetic environment, AR enhances users' perception and interaction with the real world by overlaying virtual objects and cues in real-time. AR is not limited to specific display technologies like head-mounted displays (HMDs) and extends beyond visual augmentation to potentially include all senses such as smell, touch, and hearing. AR can be employed to augment or substitute missing senses in users, such as assisting blind individuals by providing audio cues or enhancing hearing for deaf users through visual cues. AR can be experienced through smartphones, tablets, smart glasses, or other devices with cameras.

MR is a spectrum that combines elements of both VR and AR. It allows digital and physical objects to coexist and interact in real-time. Users in MR environments can interact with both virtual and real-world elements simultaneously. XR technologies find applications in various fields and this survey aims to provide an overview of some XR applications and technologies in various fields; in particular the survey is organized in sections in which each contain presentations of different papers related to specific fields.

Chapter 2

Background

In 1838, scientist Sir Charles Wheatstone introduced the concept of "stereopsis" or "binocular vision"[26], which involves the brain merging two images, one from each eye, to create a unified 3D image. This discovery paved the way for the invention of stereoscopes, devices capable of transforming pairs of images into 3D visuals that convey a sense of depth. Today, stereoscopic displays play a crucial role in modern VR systems, enriching digital imagery with depth perception and contributing to a heightened sense of immersion experienced by users.Moving forward to 1935, American science fiction writer Stanley Weinbaum made a significant contribution to the concept of virtual reality with his work "Pygmalion's Spectacles"[27]. In this story, the protagonist ventures into a virtual world using a pair of goggles, marking one of the earliest anticipations of virtual reality as it is recognized in contemporary times. In 1956, cinematographer Morton Heilig introduced Sensorama, the pioneering VR machine, which offered an immersive experience by combining 3D, color video, audio, smells, and a vibrating chair. Heilig's innovative contributions also included patenting the first head-mounted display in 1960, integrating stereoscopic 3D images with stereo sound.Expanding on Heilig's work, engineers from Philco developed the Headsight headset in 1961[29], equipped with motion tracking technology, primarily designed for military applications. Concurrently, computer scientist Ivan Sutherland presented the concept of the "Ultimate Display" in the 1960s, envisioning a virtual world indistinguishable from reality, which laid the groundwork for modern VR. In 1968, Harvard professor Ivan Sutherland introduced "The Sword of Damocles," marking the inception of AR headsets. This pioneering device projected computer-generated graphics to enhance the user's perception of reality, foreshadowing the future of AR experiences.Transitioning to the 1970s, MIT introduced the Aspen Movie Map, utilizing computer-generated imagery derived from street photographs to create a virtual tour of Aspen, demonstrating the transformative potential of VR to transport users to distant locales.Fast-forwarding to the 1980s, VPL Research Inc. emerged as the first company to commercialize VR goggles and gloves in 1985. Co-founder Jaron Lanier coined the term "virtual reality" in 1987, further popularizing the field. Additionally, the early 1990s witnessed the advent of VR arcade machines like the SEGA VR-1 motion simulator, making immersive experiences accessible to the public.In 1998, Sportsvision introduced augmented reality to mainstream audiences by overlaying the yellow yard marker during live NFL broadcasts, revolutionizing sports broadcasting.Skipping ahead to the 2010s, Palmer Luckey developed the prototype for the Oculus Rift VR headset in 2010, reigniting interest in VR technology. The subsequent acquisition of Oculus VR by Facebook in 2014 marked a significant milestone for the industry.In the same year, Sony and Samsung announced plans to develop their own VR headsets, while Google introduced its Cardboard device, offering an affordable VR viewer for smartphones. Additionally, Google unveiled its Google Glass AR glasses, pioneering the integration of digital information into real-world environments. 2016 saw the release of Microsoft's HoloLens headset, offering an interactive mixed reality experience, along with the widespread popularity of the Pokémon GO AR game. The following year, AR made its mark in mainstream retail with the launch of the IKEA Place app, allowing users to visualize furniture in their homes before purchase.In 2019 there was the release of first Meta Quest (Oculus Quest) by Reality Labs-Meta and since then in 2020 there was the upgraded version with Meta Quest 2 and in 2023 we have the release of Meta Quest 3. In February 2024 Apple released its first VR product with Apple Vision Pro.

Chapter 3

XR Applications in Medicine

Computer visualization technologies in the field of medicine have been documented since 1970, coinciding with the advent of computer tomography (CT) and magnetic resonance imaging (MRI). Over the past two decades, these initiatives have evolved into sophisticated surgical systems, providing fresh avenues for training, diagnosis, planning, guidance, and the development of innovative treatments. Utilizing advancing technology, minimally invasive procedures, which aim to minimize patient trauma, can benefit greatly. Notably, these technologies expand physicians' understanding of anatomy and offer spatial references during treatment, aiding surgeons in acquiring new skills and refining surgical procedures. Augmented reality (AR) systems, in particular, offer a promising alternative by seamlessly integrating physical and virtual elements, facilitating tasks ranging from preoperative planning to postoperative verification and training. Even in this current time we have a large availability in technology it is uncertain what could be the best human -computer interaction in medical applications. Hand gesture-based navigation systems are the most common XR technology studied in this field. Several materials and instruments are used in applications such as visualization devices, Navigation system architecture, Hand gesture processing and Patient-specific 3D models. The first consists in a setup that involves using a high-tech virtual reality headset that has been upgraded with attached stereo cameras, allowing for an advanced form of augmented reality where digital elements are overlaid onto the real world. The second usually consists of a head-mounted display and stereo-vision cameras using some Oculus(as in visualizations device), some sort of bracelet to serve as a means to give the system simple commands, which are then utilized to control the navigation of the virtual models and head tracking sensor. The third implements, as in the previous point, some wearable device able to track hand and forearm movement, gesture and rotations. The fourth element is a platform able to load and navigate the reconstructed anatomical 3D model of the patient.

3.1 Related Researches

In this paragraph it is shown some studies regarding applications of XR in medicine; in particular each work that will be introduced represents a different approach in such a way to give an heterogeneous overview. Obviously the number of works will be just a part of several researches about this topic so it has been chosen from a limited number found through google scholar that could best explain this field.

3.1.1

[5] AR for Image-Guided Surgery

De Paolis et al. [5] introduce a novel AR-based and wireless gestures platform designed for image-guided surgery planning. The system underwent evaluation in two minimally invasive surgery scenarios: heart mitral valve repair and endovascular brain aneurysm repair, utilizing CT Angiography (CTA) images. They conducted twenty-one experiments involving heart surgeons and neurosurgeons to assess clinical pathology, anatomy exploration, interaction, and perceived usability. The experiments included tasks and scenarios evaluating the realism of 3D virtual models, hand manipulation, and navigation experience. The findings indicated positive evaluations across all aspects, with participants recognizing potential applications for enhancing planning and intraoperative interventions.
Below we show the architecture;

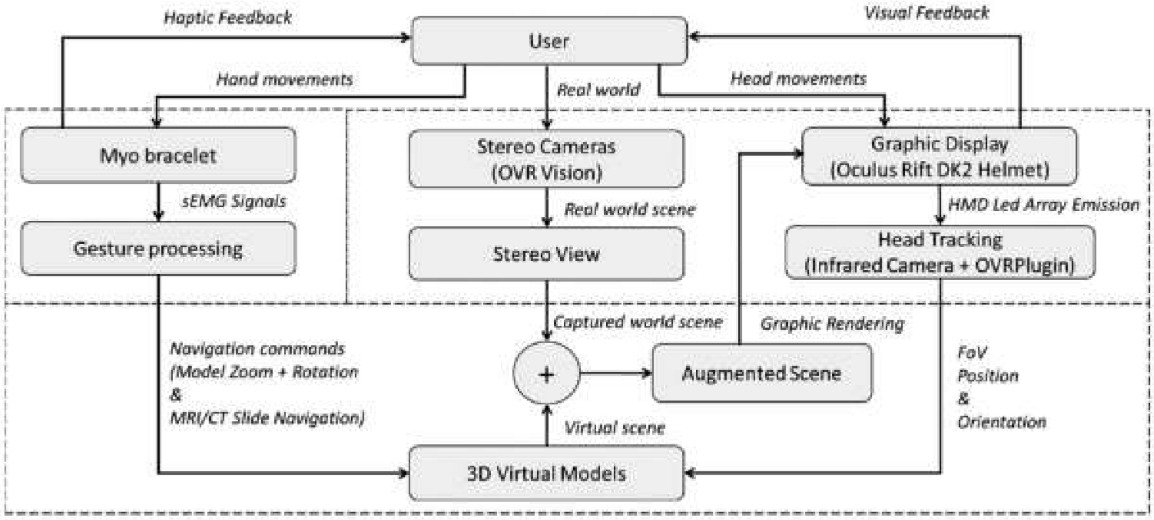


Figure 3.1: Architecture implemented in [5].

The structure of the augmented reality setup comprises three main components: Firstly, there's the augmented reality headset setup, which includes an Oculus Rift DK2 headset equipped with the OVRPlugin for head tracking, along with additional stereo vision cameras for capturing real-world environments. Secondly, there's specialized software designed for creating blended scenes that merge real-world captured footage with virtual 3D models. Lastly, there's an electromyographic surface signals monitoring system, embodied in the Myo bracelet, which detects hand gestures and recognizes commands for navigation. Below the system:

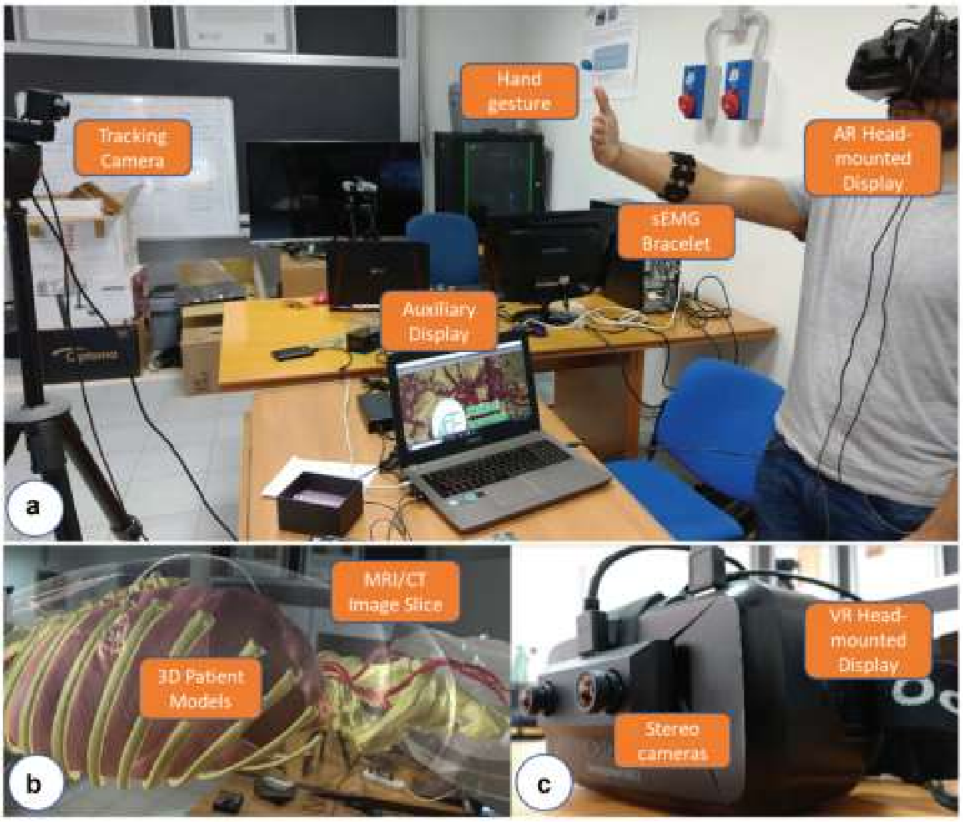


Figure 3.2: a) Virtual Reality (VR)environment. b) patient-specific CTA (Computed Tomography Angiography) images dataset study. c) The VR helmet.

3.1.2

[13] Trustworthy and Intelligent COVID-19 Diagnostic

An interesting application of XR in medicine are the telemedicine applications; telemedicine systems represent a widely acknowledged technological advancement geared towards enhancing healthcare accessibility and minimizing expenses. The necessity for telemedicine became apparent during the COVID-19 crisis, where face-to-face interactions posed significant risks. Traditionally, telemedicine primarily utilized two-dimensional methods, such as video conferencing, as a substitute for in-person consultations, encompassing audio and single-perspective video transmission. However, the drawback of this approach lies in its restricted capacity to provide comprehensive information about the patient's condition, in contrast to the depth of insight gained through physical examinations. The telemedicine usually presents two point of work; the first is the "doctor" side or someone in charge of the analysis, then the second is the patience side in which are captured and detected the physical characteristic that will be used to reconstruct the 3D model of the body. Capturing three-dimensional data in real-time is essential, yet it often comes at the expense of reduced precision in the acquired data. To address this, time-of-flight (ToF) cameras or stereo cameras are commonly employed, although their limited field of view necessitates the use of multi-camera setups.

Tai et al. [13] develop a very interesting work related to Covid-19 consisting in an innovative solution that combines Extended Reality (XR) and Deep Learning with Internet-of-Medical-Things (IoMT) technology to address COVID-19 telemedicine diagnostics. This approach integrates virtual reality and augmented reality for remote surgical planning and rehearsal, along with custom-built 5G cloud computing infrastructure and advanced deep learning algorithms. The aim is to offer real-time insights into COVID-19 treatment strategies. In particular Internet-of-Medical-Things (IoMT) technology is utilized to detect primary symptoms universally by collecting data from infected areas. This data can then be aggregated to customize treatment plans based on IoMT data analysis. A K-Nearest Neighbors (KNN)-based Auxiliary Classifier Generative Adversarial Network (ACGAN) model is created to assess the accuracy of COVID-19 predictions. The Extended Reality (XR) platform is utilized for remote diagnosis. Subsequently, 5G transmission is employed to transfer and process medical data for COVID-19 prediction via the 5G cloud. Augmented Reality (AR) remote diagnostics and XR surgical procedures evaluate performance using various deep neural algorithms. Below the system:

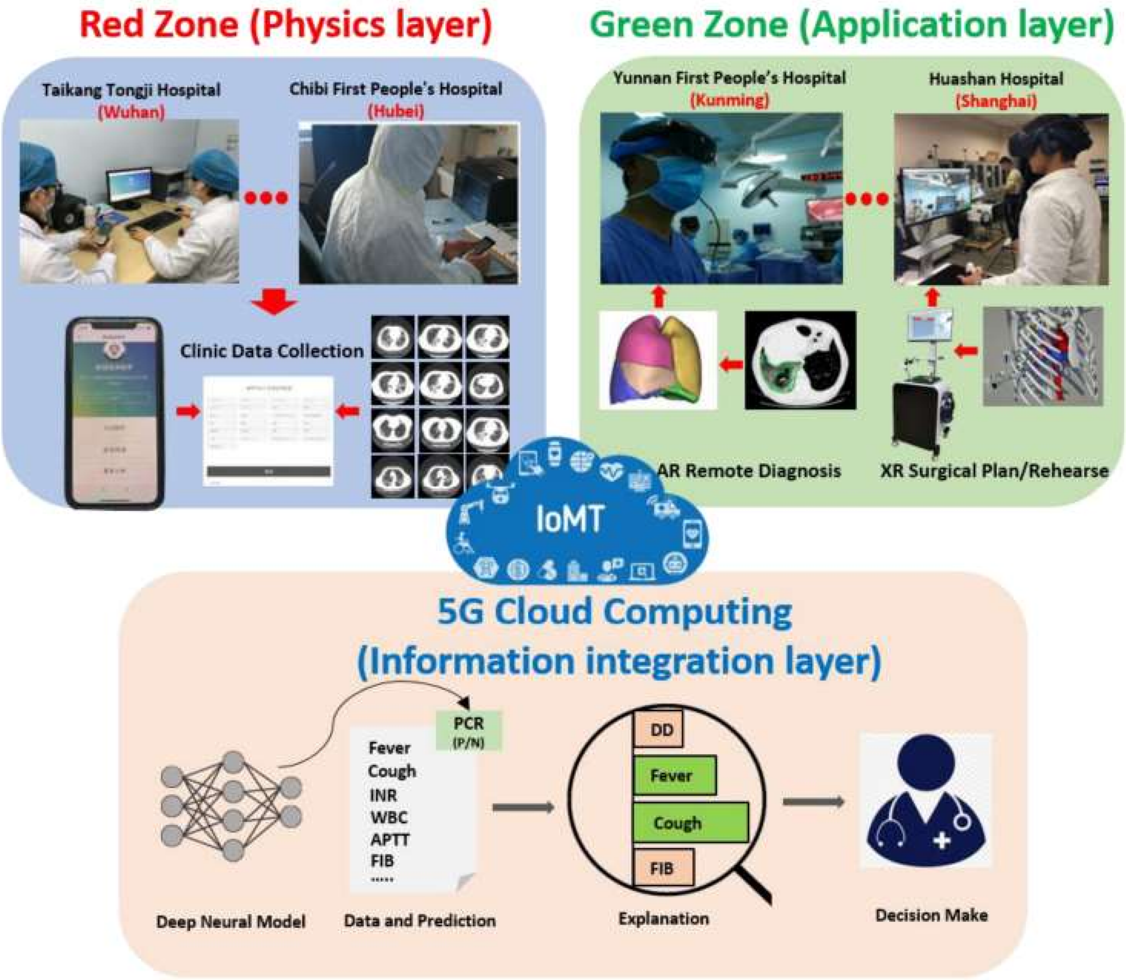


Figure 3.3: Zone definitions of the research

The VATS-XR systems developed in this article involve both hardware and software components. The system framework is illustrated in Fig. , highlighting the importance of tactile and visual feedback. Visual aspects are managed using the OpenHaptic plugin to interact with virtual objects, enabling functions such as collision detection, soft-tissue cutting, and deformation. To enhance realism, shader language is utilized for rendering interactive objects more realistically, resembling physical models closely. The user interface (UI) design is created using UGUI and implemented in Unity3D. Surgical instruments and force feedback devices are connected via a linker, allowing operators to manipulate the surgical instrument to perform transformation operations across three axes of the force-feedback device. When the virtual surgical instrument interacts with virtual objects, the OpenHaptic plugin calls the force feedback device to provide corresponding tactile feedback, enhancing the operator's sense of realism. XR display methods are achieved using HTC VIVE and a Logitech camera.

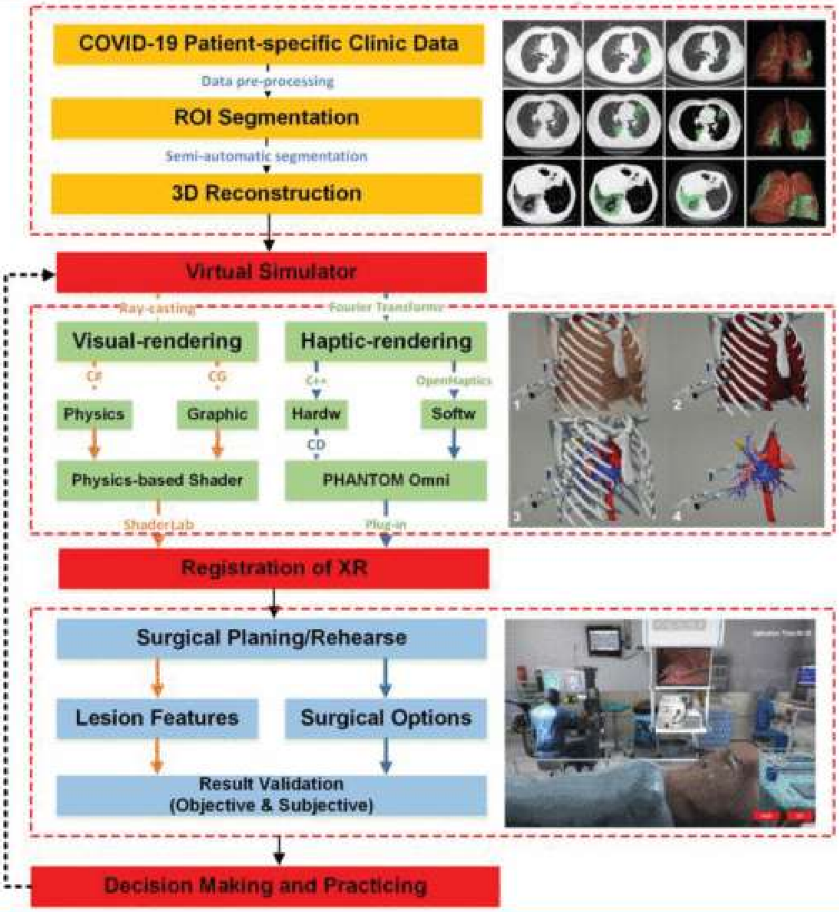


Figure 3.4: XR COVID-19 surgical IoMT simulator framework: the first part is the COVID-19 patient-specific medical image processing from the clinic data collection. The second part is the XR visuo-haptic reconstruction with the medical data. The third part is the audio rendering procedure, stored the audio details of OR-based heart monitor, anesthesia, and breathing apparatus, and line four is the surgical environment reconstruction.

3.1.3

[6] Extended Reality Telemedicine Collaboration System Using Patient Avatar Based on 3D Body Pose Estimation

The reconstruction of three-dimensional imagery involves processing vast amounts of captured data, leading to extended processing durations and increased latency. Transmitting this 3D data poses three primary challenges: managing ultra-high bandwidth requirements, minimizing ultra-low latency, and optimizing network performance.

Šarić et al. [6] show a new method to avoid the 3D model reconstructions but instead there is a 3D body pose estimation for the creation of a patient avatar and consequently eliminates the need for specialized equipment and reduces computational and network resources.

The proposed solution aims to facilitate patient examinations by remote experts without requiring physical presence. The system comprises three main components (see Figure 1): an AR interface user application (AR client) utilized by a local doctor conducting a physical examination, a VR interface user application (VR client) used by a remote expert, and an XR collaboration system (backend) operated on a workstation/server. A local doctor, equipped with AR glasses (Microsoft HoloLens 2), initiates a telemedicine session to receive guidance from the remote expert. The patient's webcam view is streamed to the remote location, where the expert uses VR glasses (HTC VIVE Pro). Simultaneously, the camera stream is processed on the server to extract the necessary data for controlling a 3D avatar representing the patient. This data is then transmitted to both the VR and AR interfaces to synchronize the avatar's pose with the patient's pose. Throughout collaboration, both parties share a common XR space and observe the same avatar. Furthermore, real-time data exchange occurs between the AR and VR interfaces regarding the relative positions of user/control modalities, enabling the transmission of hands/controllers. As a result, both users perceive virtual hands, facilitating interaction with the 3D avatar. Additionally, both parties have the capability to annotate the 3D model in real time. Frame grabbing, person detection, person identification, and 3D pose estimation services were run on the following server configurations: AMD CPU Ryzen 9 5900X, RAM 3200 Mhz 4 × 16 GB, GPU NVIDIA RTX A5000 24 GB, and SAMSUNG SSD 980 PRO 1TB M.2. Peer-to-peer delay (WebRTC) and MOCAP data message exchange delay are measured on the LAN network. The unity 3D model transformation on the VR side was run on a laptop with the following configurations: CPU Intel(R) Core(TM) i5-9300H CPU @ 2.40GHz, GPU NVIDIA GeForce GTX 1650, SSD NVMe Micron_2200 _MTFD _16GB, and RAM DDR4 16 GB 3.2 GHz. The VIVE Pro headset was connected to a laptop to present the 3D model to a remote specialist.

Below the architecture of the system:

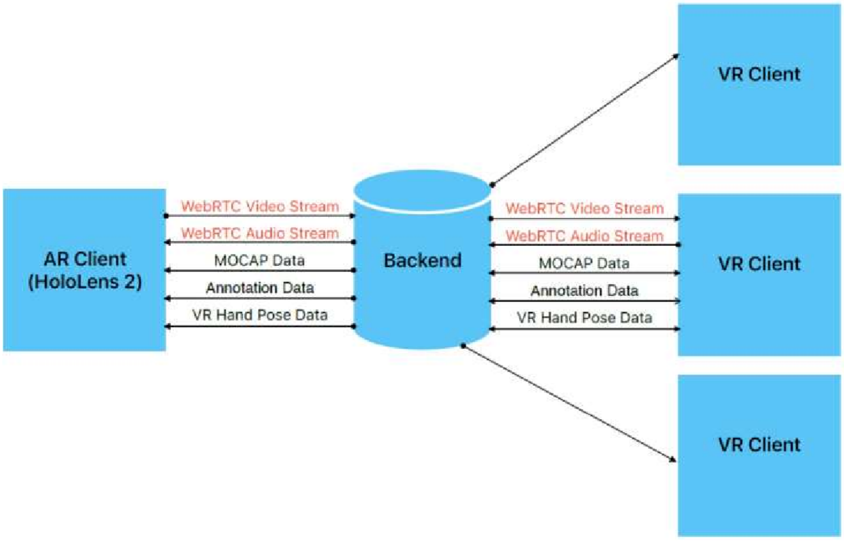
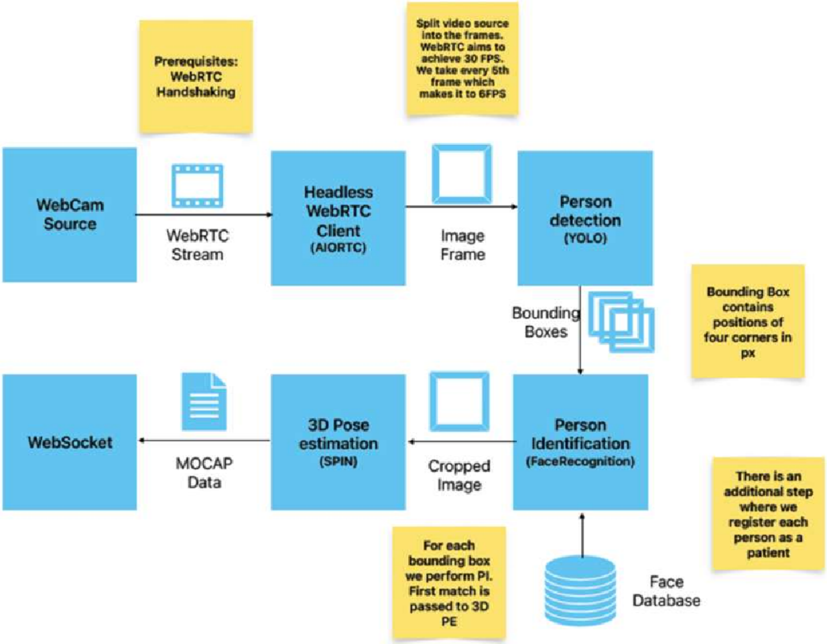


Figure 3.5: Architecture of the proposed system



Prerequisites: WebRTC Handshaking

Split video source into the frames. WebRTC aims to achieve 30 FPS. We take every 5th frame which makes it to 6FPS

Bounding Box contains positions of four corners in px

There is an additional step where we register each person as a patient

For each bounding box we perform PI. First match is passed to 3D PE

Figure 3.6: Avatar control workflow.

Two essential points highlighted are the Avatar Control and Pose estimation.

3.2 Collections of papers

In this paragraph it is shown a table that collects a certain number of paper works related to the field applications of this chapter in order to have an overview and source of information useful in the exploring of Extended reality technologies. In particular in the table there is a paper reference with the corresponding software and hardware apparatus utilized in that research. It is been chosen to put maximum 10 papers per table and consequently they will be chosen in order to cover as many different configurations as possible in such a way to give an heterogeneous classifications of the researches;

Table 3.1 : Collections of paper works applied in medicine with their XR software and hardware apparatus

	Head-mounted devices	**Softwares used**	**Brief description of paper**	**Hardware devices used**
[5]	Oculus Rift DK2. OVR Vision Pro VR stereo cameras. Oculus IR camera	Unity. MeshLab. Blender.	descripted before	Myo Armband. RGB stereo cameras
[6]	Microsoft HoloLens 2. HTC VIVE Pro	Unity. Blender	descripted before	Kinect depth camera. Logitech camera.
[20]	Microsoft HoloLens	MIMIC, UNITY	HMD in survival coaching	
[21]	Microsoft HoloLens	Mimics.Unity. Visual Studio	MR in tumor treatment	
[22]		RealView Holographic	Computer-generated real-time digital holography	
[23]	Microsoft HoloLens	UNITY. CARTO®, Visual studio.	MR for electroanatomical view	
[24]	Microsoft HoloLens	CarnaLife® Holo	MR for 3D angiography	
[57]	HTC VIVE	OpenHaptic.Unity. Vuforia. SteamVR.	XR surgery simulator	Logitech camera. Marker. Geomagic Touch.
[13]	HTC VIVE	OpenHaptic. Unity.	described before	Logitech camera.
[58]	Microsoft HoloLens	Unity	AR guidance in AD patiences	

Chapter 4

XR Applications in Teaching Activities

Another consequence given by the expansion of Covid-19 is the increase in the utilization of remote technology for teaching (or general lessons activities). Here Extended reality (XR) technologies find a fitted spot in this field.

Educational institutions worldwide are exploring alternative methods to deliver lessons beyond traditional classroom settings and this led to a growth in the use of remote learning methods. There are advancements surpassing conventional online learning platforms, delving into the realm of cutting-edge technologies to introduce learners to novel digital educational experiences. Among these advancements is the adoption of spatial and immersive computing technologies, now referred to as extended reality (XR) technologies. These innovations are being shaped by the expansion of web-based learning tools and remote learning environments. One of the main obstacles faced during teaching activities is the lack of interest of students for the subjects, especially those in the scientific field where visualization of a concept could appear very difficult. XR technology can add in the learning process fundamental aspects such as experimentations, interoperability, interactivity and a 3D data configuration much more intuitive to interact with that consequently increase the interest and performances of the students.

4.1 Related Researches

In this paragraph it is shown some studies regarding applications of XR in medicine; in particular each work that will be introduced represents a different approach in such a way to give an heterogeneous overview. Obviously the number of works will be just a part of several researches about this topic so it has been chosen from a limited number found through google scholar that could best explain this field.

4.1.1

[7] FisicARtivo: Experiences of web-based extended reality technologies for physics education

Several studies have been done in this field and one of particular interest is, for example, Ramon et al. [7] focus on the use of XR to improve the understanding and assimilation of physics subjects. Describing the motions and applied forces acting upon an object involves combining different mathematical and visual representations, which can complicate understanding if these representations are not adequately depicted. Usually the parameter used to evaluate a certain learning process is motivation, in fact various studies in this field use the ARCS instructional model, previously utilized to evaluate motivation in other contexts. Below a representation of the architecture used in [7]:

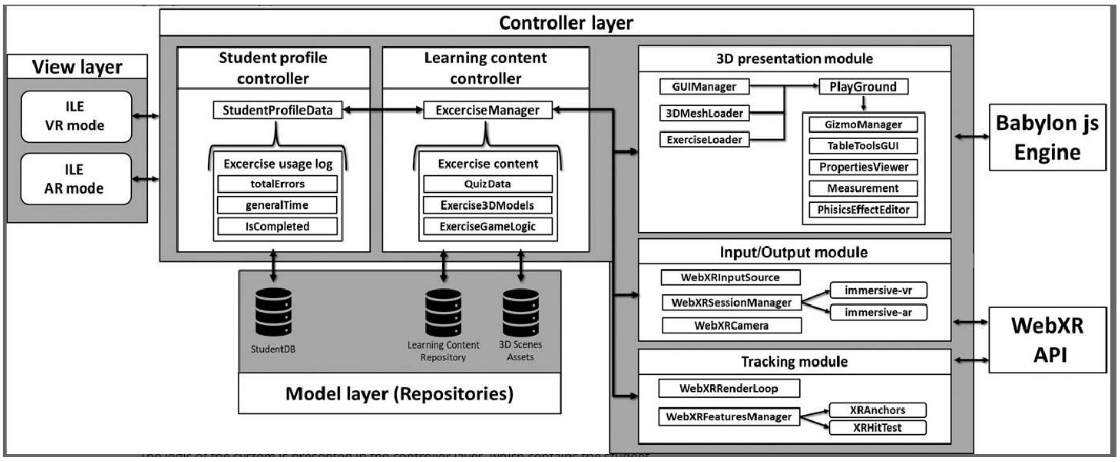


Figure 4.1: architecture in [7]

This is FisicARtivo, a web-based application and is structured around the model-view-controller (MVC) pattern. Within this pattern, each layer comprises various modules and subsystems. These components manage different functionalities aimed at creating interactive XR environments. The student profile controller is responsible for handling user authentication and recording the actions carried out during a session within the application. The learning content controller oversees the organization of interactive learning environments, ensuring smooth presentation and coordinating the necessary functions and procedures for conducting exercises, demonstrations, and activities. The Exercise3DModels component provides the virtual elements to be displayed on screen by loading the necessary 3D models and assigning physical properties. This component handles the rendering of elements in the scene, allowing properties to be set before or during rendering. On the other hand, ExerciseGameLogic is responsible for managing the logic of actions and functions in interactive scenes with physics simulations. It coordinates the properties and functionalities of both 3D models and virtual elements that form the graphical interface for user interaction with the system. The view layer consists of two modes of interactive learning environments within FisicARtivo: AR mode and VR mode. In AR mode, FisicARtivo transforms into an AR application, primarily intended for users accessing the web platform via mobile devices with AR capabilities. The primary goal of AR mode is to provide access to a learning environment on mobile devices, enabling users to engage with physics simulations overlaid onto the screen. This presents digital learning content in a unique manner compared to traditional isolated virtual environments. On the other hand, VR mode allows FisicARtivo to deliver its content through interactive virtual environments, tailored for desktop devices equipped with VR peripherals. Below the two view layer:

Figure 4.2: Comparison between augmented reality mode (left) and virtual reality mode (right) presented in FisicARtivo.

4.1.2

[9] MARPEX: A Mobile Augmented Reality Factors for Learning Motivation in Science Experiments.

Gopalan et al. [9] show another branch of XR application: the mobile extended reality, in particular here it is shown a mobile augmented reality (AR) application for conducting physics experiments, known as MARPEX, that was created to enhance science learning through interactive features. MARPEX concentrates on replicating laboratory apparatus and materials used in physics experiments, emphasizing the added informational enhancements made possible by AR technology compared to traditional experimental methods.

Technical Requirements

The MARPEX app is designed for Android smartphones and tablets, incorporating Graphical User Interfaces (GUI) for user interaction. GUI utilizes elements like buttons and icons for ease of use. It features navigation, information, and help buttons to enhance interactivity and experiential learning. The app utilizes the device screen to display virtual objects. Technical requirements ensure compatibility, with a minimum Android OS version of 4.1 and specific hardware specifications tested on Samsung Note 5.

AR markers, typically printed rectangles, are detected by the device camera to reveal digital content. Interaction involves scanning the marker with the camera, which triggers the display of 3D computer-generated objects on the screen. Marker size and font type are crucial for accurate recognition. Users initiate the app, scan markers, and view 3D objects, with the display adjusting as the camera moves within the marker area. The app's operation is detailed through user actions, device functions, and marker detection processes.

MARPEX App Architecture

The MARPEX app utilizes a two-dimensional (2D) architecture, initially conceptualized through sketches on A4 paper to guide development. This architectural framework encompasses various components, including content creation (text, audio, and animated 3D models), development tools, AR markers, and scenes, as depicted in Figure 1.The architecture undergoes multiple stages facilitated by a range of tools. Interaction with the app involves the device camera and AR markers, as emphasized in the development tools segment.

Specifically, the architecture necessitates the creation of a new database utilizing Vuforia, an online AR database, to establish target markers for each experiment. These markers, with customized widths and dimensions, are uploaded to the database to activate the author section within Unity 3D software.In the Unity 3D environment, simulation objects are displayed on mobile screens, enabling user interaction with the MAR app. Java Software Development Kit (JDK) and Android Software Development Kit (SDK) serve as the primary software development tools for constructing the MARPEX app for Android devices. JDK facilitates the description of objects or scenes during development, stores enhanced content in the database, and generates the apk file necessary for launching the MARPEX app on Android smartphones and tablets.

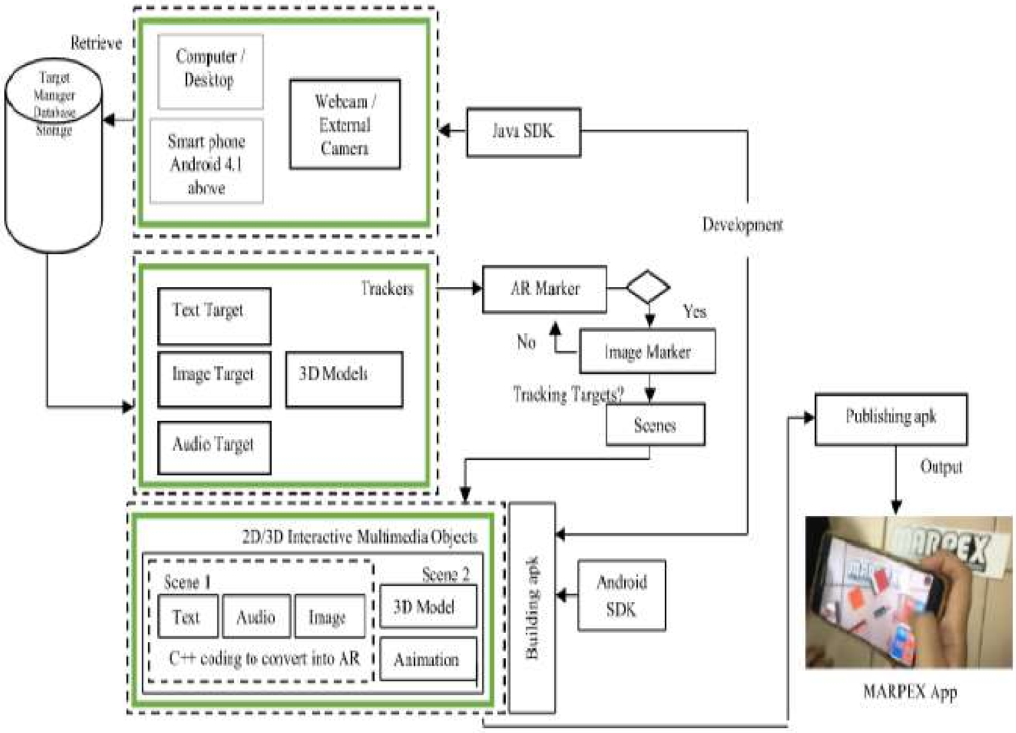


Figure 4.3: Architecture of MARPEX app.

App development

During the development phase of the MARPEX app, various software tools were employed to create and integrate content seamlessly onto Android devices. Key software utilized in this process includes Blender for science apparatus modeling, Vuforia SDK for Android app development, and Unity3D version 2014 for the integration of the MARPEX app onto Android devices. These tools were instrumental in creating a cohesive and engaging AR experience, ensuring compatibility with Android platforms and optimizing performance for users.

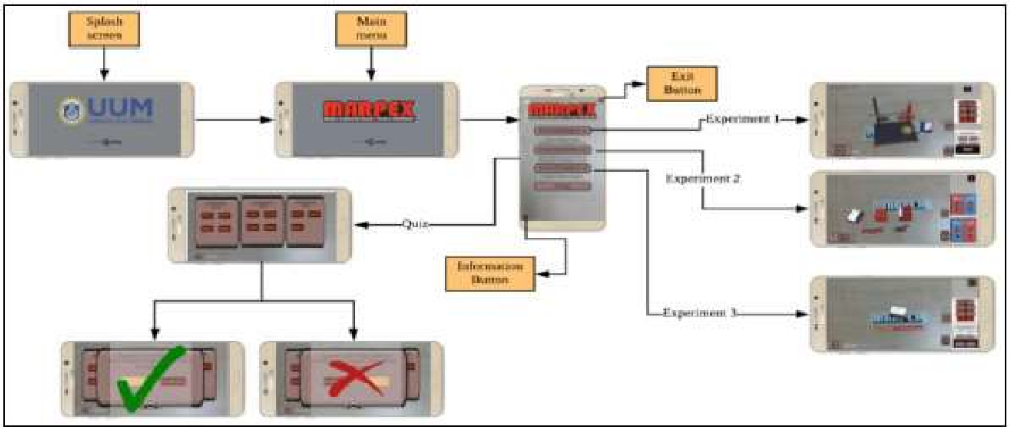


Figure 4.4: Wireframe of MARPEX

4.1.3

[12] Augmented reality lab work to foster the concepts of heat conduction.

Strzys et al. [12] show a very interesting AR technology usage where a holo.lab rendition of a conventional experiment on heat conduction in metals is tailored for an introductory laboratory course in thermodynamics. This version utilizes physical data sourced from external sensors, specifically an infrared (IR) camera, to analyze and exhibit physical phenomena to the users. This setup utilizes false-color representations as digital enhancements, presented in the form of HoloLens 'holograms positioned directly onto the real physical object. In particular these enhancements are all three-dimensional and accurately positioned within real space. This configuration allows students to observe the heat flux through a metal rod, heated on one side and simultaneously cooled on the other, from every perspective without any obstruction issues. Additionally, it can integrate extra representations such as graphs and numerical values as digital overlays onto the real experiment. This enables students to evaluate physical processes in real-time, as they can directly observe and analyze the heating process and the establishment of a steady state using these features. Furthermore, the smartglass setup utilizing HoloLens ensures a hands-free experience, enabling students to interact with the physical experiment setup while keeping track of the measurement data simultaneously. Below the setup:

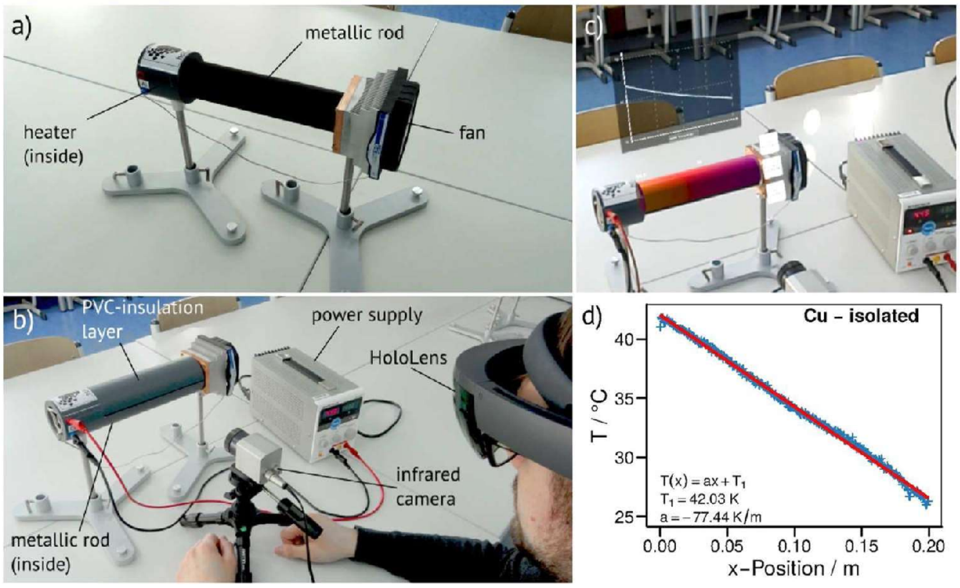


Figure 4.5: (a) Experimental setup (non isolated rod); (b) experimental setup (rod with PVC insulation) and user wearing a HoloLens; (c) holo.lab setup (non isolated rod) with MR experience; augmented representations: false-color representation of temperature along the rod, numerical values at three points above the rod, temperature graph; (d) temperature graph after equilibration (blue crosses) and linear fit (red line) for an isolated Cu-rod.

4.2 Collections of papers

In this paragraph it is shown a table that collects a certain number of paper works related to the field applications of this chapter in order to have an overview and source of information useful in the exploring of Extended reality technologies. In particular in the table there is a paper reference with the corresponding software and hardware apparatus utilized in that research. It is been chosen to put maximum 10 papers and consequently they will be chosen in order to cover as many different configurations as possible in such a way to give an heterogeneous classifications of the researches;

Table 4.1 : Collections of paper works in teaching activities (Physics) with their XR software and hardware apparatus

	Head-mounted sets/visualization device	**Software used**	**Brief description of the paper**	**Hardware devices used**
[7]		Babylon JavaScript graphics engine.	described above	detected camera and gyroscopic sensors
[9]	Samsung Note 5	Unity.Vuforia SDK.Blender	described above	
[12]	Microsoft Holo Lens		described above	Optris PI 450 IR camera
[10]	smartphone device	Unity,Vuforia Augmented Reality SDK	Physics Experiments Using Augmented Reality Game-Based	
[11]	Oculus VR glasses	Maya. Unity.	Learning physics with virtual environment	hearing aids, sensor

Table 4.2 :Collections of paper works in teaching activities (Architecture) with their XR software and hardware apparatus.

	Head-mounted sets/visualization device	**Software used**	**Brief description of the paper**	**Hardware devices used**
[14]	HTC Vive	Unity. IrisVR. Blocks (STEAM VR).	learning design with virtual reality	
[15]	VIVE	SketchUp. Unity.	Architectural Students Using Virtual Building Design	trackpads

Table 4.3: Collections of paper works in teaching activities (Chemistry) with their XR software and hardware apparatus.

	Head-mounted set/ visualization devices	**Software used**	**Brief description of the paper**	**Hardware devices used**
[8]	Microsoft HoloLens 1	Microsoft DirectX. SketchUp Pro.UCSF Chimera.	teaching 3D biomolecular structures with AR	
[64]	Oculus Quest	Unity	Virtual Reality to Demonstrate Glove Hygiene	6 DOF and inside out tracking
[59]	Microsoft HoloLens	Unity	augmented-reality (AR) program to increase enthusiasm and enhance the learning experience for laboratory safety	

Chapter 5

XR Applications in Manufacturing

Recent advancements in information and communication technologies (ICT) have propelled traditional manufacturing systems towards becoming "smart" systems capable of handling increasingly complex tasks with a high level of autonomy and intelligence. However, there remain certain tasks on the shop floor that either require human intervention or are simply not feasible to automate. In such scenarios, the primary objective of smart manufacturing is to enhance and facilitate manual operations rather than completely replacing human involvement. Leveraging artificial intelligence (AI), 5G connectivity, cloud computing, and the Internet-of-Things (IoT), extended reality (XR) applications have been effectively deployed to support a wide range of manual operations across the manufacturing sector.

5.1 Related Researches

In this paragraph it is shown some studies regarding applications of XR in manufacturing; in particular each work that will be introduced represent a different approach in such a way to give an heterogeneous overview. Obviously the number of works will be just a part of several researches about this topic so it has been chosen from a limited number found through google scholar that could best explain this field.

5.1.1

[30] Virtual Learning Environment for an Industrial Assembly Task.

Hirt et al. [30] introduce a virtual learning environment tailored for industrial assembly tasks, aiming to provide a user-friendly interface and an intuitive learning experience. The study demonstrates the versatility of such an environment, catering to both novice employees undergoing initial training and seasoned experts seeking advanced skill refinement for new products or assembly procedures. The efficacy of this application was evaluated through two phases of validation. Initially, a lab pilot study confirmed positive feedback from participants regarding the simplicity of interactions and the clarity of instructions. Subsequently, professionals from the industry were engaged to perform the tasks and assess the virtual learning environment's suitability for real-world industrial applications. The evaluations, based on standardized questionnaires and post-study interviews, yielded favorable results for both the lab pilot and industrial study, indicating effective performance and potential for further refinement in collaboration with industrial partners

Virtual environment

The virtual learning environment (VLE) was developed using an HTC Vive Pro headset along with controllers, configured for room-scale movement within a 4x4m area. The VLE utilizes SteamVR teleportation for navigation beyond this space, and SteamVR's grab function allows users to interact with virtual components.

Created in Unity, the VLE comprises three sequential scenes: Tutorial, Impossible Task, and Completion Task. Participants were required to assemble a ceiling-mounted installation system using various extruded profiles, rails, and angles, guided by a 2D layout plan. The Tutorial scene provided instructions on controller usage, movement (walking and teleporting), environment interaction, and assembly procedures. In the Impossible Task scenario, intentionally incorrect assembly instructions were given, rendering completion impossible with the provided components. Only in the Completion Task scenario could participants achieve a successful assembly and complete the ceiling-mounted installation system. Below the Virtual environment visualization:

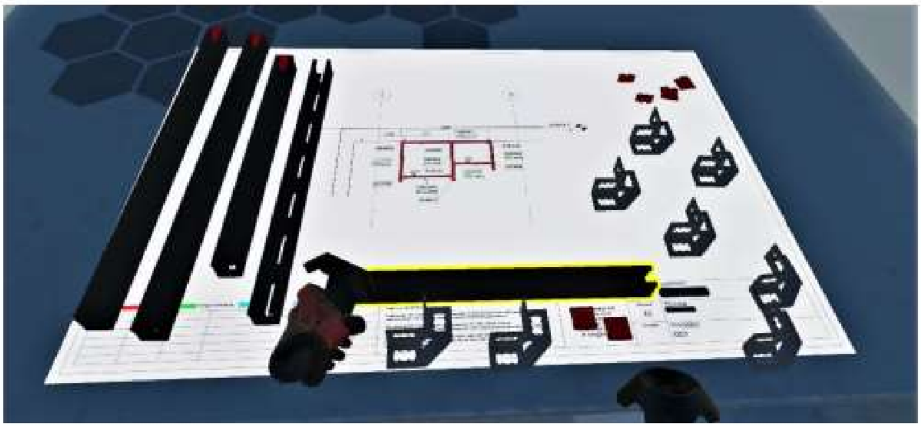


Figure 5.1: Starting desk with all components.

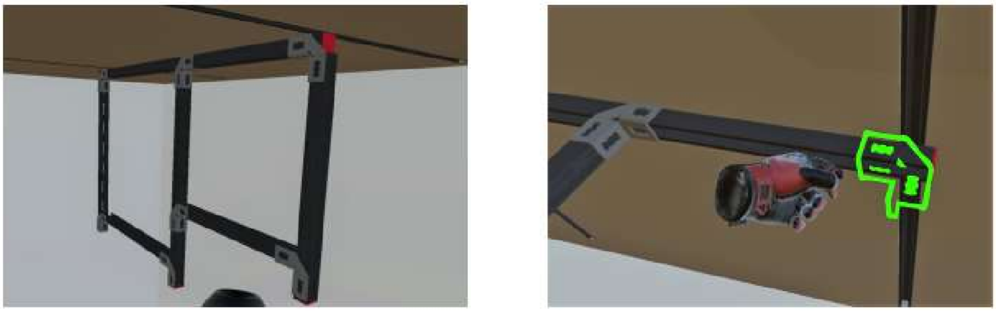


Figure 5.2: VLE visualization

5.1.2

[31] Industrial robot control and operator training using virtual reality interfaces.

In essence, a typical robot consists of mechanical components, electronics, motors, a controller, and a human-machine interface (HMI), often in the form of a console. However, Pérez et al. [31] proposed a work where the traditional console is replaced by a virtual reality (VR) system directly linked to the robot controller, serving as the HMI.

The proposed solution offers two primary functionalities. Firstly, it allows real-time visualization of trajectories generated by the robot controller. Users can select desired positions, and the controller guides the virtual robot accordingly. This feature aids in pre-detection of errors and prediction of potential accidents by replicating movements.Secondly, the system reproduces trajectories previously executed by the robot and stored in a database. Users can select desired trajectories along with date and time parameters, and the virtual robot replicates them. This functionality facilitates post-analysis and error detection by repeating movements.The system consists of two robots - the real one and the virtual one - both controlled by the same controller, which is connected to both the VR computer and the database server. VR glasses are connected to the VR computer to provide immersive visualization. External sensors connected to the robot controller offer additional information and feedback regarding safety, pose, accuracy, etc., especially when the real robot is operated using the VR system. Below the system architecture:

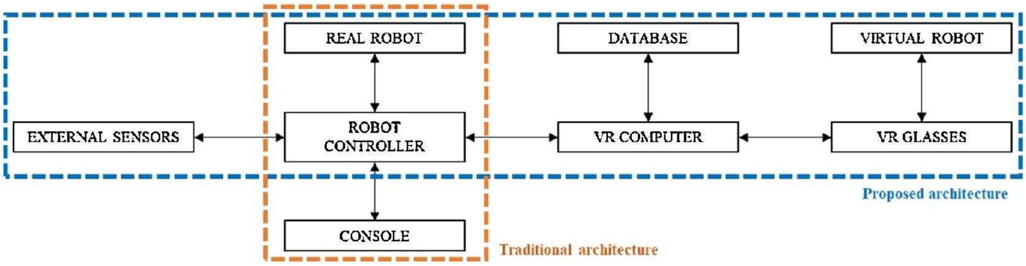


Figure 5.3: architecture proposed in this work

External sensors

A laser tracker (LT) system serves a crucial role in this setup by detecting the spatial position of the tooltip and correcting the robot's motion accordingly. Moreover, the LT system can offer feedback to the VR system, enabling the monitoring of the precise position and orientation of the real robot as an external and independent sensor. This information, when combined with other data sources such as visual feedback from a camera, plays a pivotal role in risk avoidance, estimating potential collisions, and ensuring safety in teleoperated robots. Given that the operator may not have direct visibility of the real environment in teleoperation scenarios, accidents can occur, making such comprehensive monitoring and feedback mechanisms essential for safety assurance.

The virtual reality environment

The creation of the virtual environment is shown below:

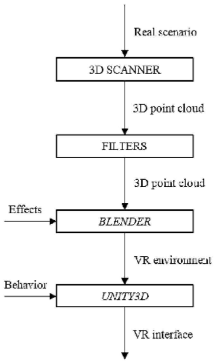


Figure 5.4: VR environment

The scenario depicted in Figure above was initially scanned using a FARO Focus3D X130 HDR scanner . The resulting 3D point cloud is processed and filtered with CloudCompare . Subsequently, the point cloud data was modeled using Blender , resulting in the creation of the virtual environments.. Notably, the virtual environment faithfully replicates the real environment, capturing even the minutest details. Finally, Unity3D , known for its extensive toolset and features, was utilized to develop the human-machine interaction interface. This interface includes various virtual buttons enabling navigation between menus, as illustrated. Users are afforded the capability to navigate the virtual area using the teleportation function, effectively recreating the real environment surrounding the robot. Below the real and virtual environment just described:

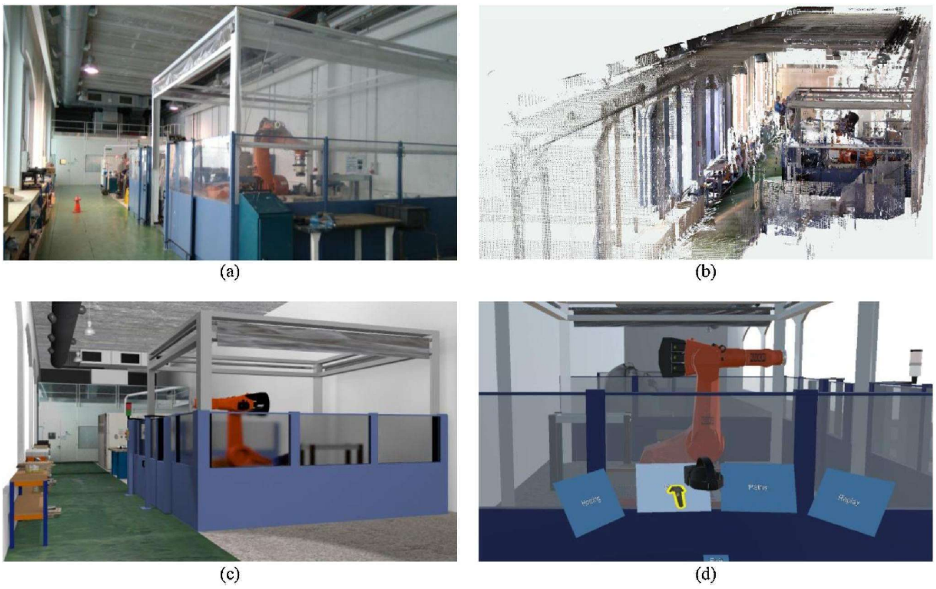

(a) (b) (c) (d)

Fig. 5.5: Real and virtual environments: (a) Real facilities, (b) Point cloud, (c) Virtual environment, and (d) Interaction interface.

In the traditional setup the operator and robot are physically separated due to safety concerns, a common practice. However, the operator is fully immersed in the VR environment, enabled by specialized glasses, and can navigate freely within the virtual workspace of the robot without any safety risks. In this virtual environment, the operator can simulate various positions, assess singularities, verify reachability, and analyze potential gripper collisions, among other tasks. This scenario has been devised to assess the effectiveness of the proposed system, evaluating both the immersive experience and the VR interface with real factory operators.

5.1.3

[46] A visuo-haptic extended reality–based training system for hands-on manual metal arc welding training

Shankhwar et al. [46] show a visuo-haptic extended reality (VHXR) system developed to provide hands-on welding training for novice welders. This system allows novice welders to practice manual arc welding tasks without being exposed to high temperatures and intense ultraviolet radiation. The VHXR system offers real-time and realistic force and visual feedback, aiding trainees in maintaining consistent arc length, travel speed, and electrode angle during the welding process. Virtual reality (VR) is utilized to present fundamental welding knowledge and tools graphically. However, for providing a realistic hands-on welding experience, augmented reality (AR) is employed to allow users to see the physical welding components. The training process commences with a VR module, where welding tools are showcased on a worktable along with instructional and safety information. Following the VR module, users transition into the AR module to engage in hands-on welding exercises. A real electrode holder is utilized to assist users in developing muscle memory. Along with force feedback, the AR scene displays virtual weld beads, sparkling particles, and an electric arc, enhancing the realism of the experience.The HTC Vive Pro head-mounted display (HMD) serves as the display device for the system. To construct the augmented reality (AR) environment, the Vive Input Utility (VIU) and SRWorks software development kit (SDK) are employed. The VHXR-based welding training system was created on a PC equipped with a 3.00 GHz Intel Core i7-9700F processor, 64 GB RAM, and 6.0 GB dedicated GPU memory. Scripts are developed in C# using the Unity3D game engine.

To replicate a genuine Manual Metal Arc Welding (MMAW) process accurately, a distance sensor, specifically the VL6180X, is affixed to the electrode's tip. This sensor measures the distance between the weld plates and the electrode. Rendering of the virtual weld bead, sparkling particles, and electric arc occurs only when the arc length is sustained within the desired range. Below the setup for the tracking:

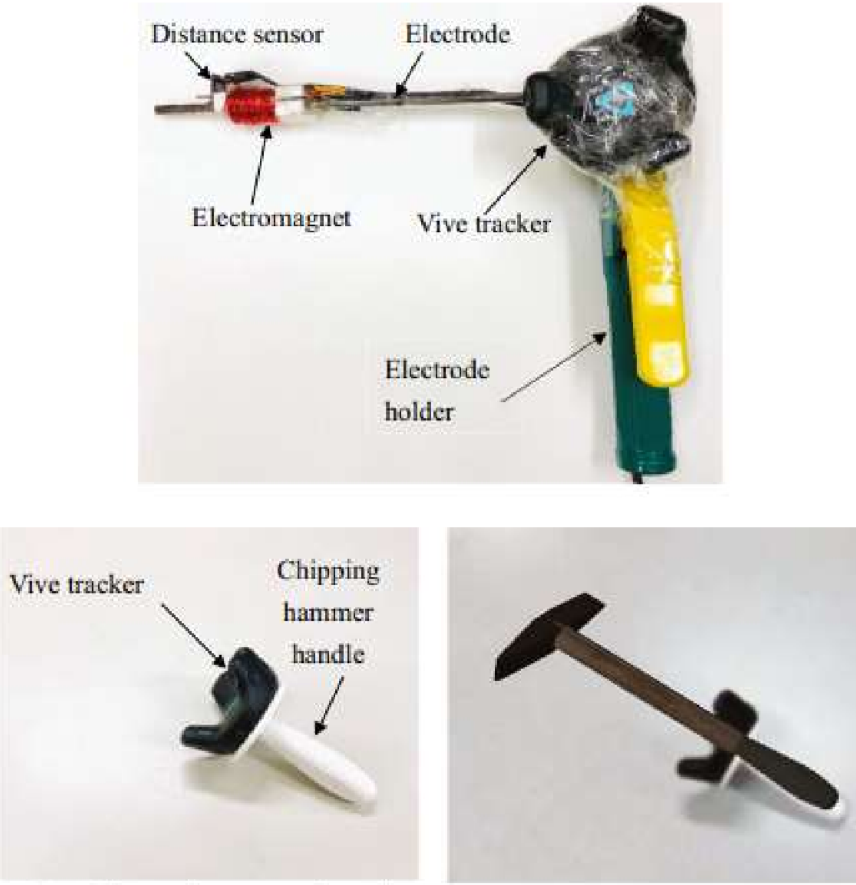


Figure 5.6 : Vive trackers for tracking the electrode and the virtual chipping hammer. a) A Vive tracker mounted on the electrode holder. b) A Vive tracker mounted on the chipping hammer handle. c) Virtual chipping hammer

The outcomes indicate a significant enhancement in the performance of novice welders through the VHXR system. The intuitive user interface facilitated easy adaptation to the real welding environment for the users.

5.2 Collections of papers

In this paragraph it is shown a table that collects a certain number of paper works related to the field applications of this chapter in order to have an overview and source of information useful in the exploring of Extended reality technologies. In particular in the table there is a paper reference with the corresponding software and hardware apparatus utilized in that research. It is been chosen to put maximum 10 paper per table and consequently they will be chosen in order to cover as many different configurations as possible in such a way to give an heterogeneous classifications of the researches;

Table 5.1:Collections of paper works in manufacturing with their XR apparatus.

	Head-mounted set/visualization devices	**Software used**	**Brief description of paper**	**Hardware devices used**
[30]	HTC Vive Pro	Unity	described above	
[31]	HTC Vive Pro. Oculus Rift.	Unity3D. CloudCompare. Blender.	described above	FARO Focus3D X130 HDR
[46]	HTC Vive Pro	Unity3D	described above	Vive trackers. handheld controllers.
[47]	HTC Vive Pro	Unity. SteamVR. Blender	virtual reality training systems of industrial robot	
[48]	HTC VIVE	Unity. Steam Vr . Maya.	VR environment for simulation and control of industrial robot	Leap Motion sensors
[49]	Oculus head-mounted VR	Avatour	Interactive mixed reality live streaming technology	helmet-mounted camera
[50]	Huawei Nova Y70 smartphone	Unity. ARCore. Vuforia	industrial training and maintenance for NanoDrop spectrophotometer	camera HP 320 wired USB
[51]	Oculus headset	Unity	Monitoring console using virtual reality for automotive industry	Touch controllers
[52]	Oculus Quest 2		User interface for arc welding tasks	RGB-D sensor. HDR camera.
[53]	Oculus Quest.	OpenCV. ArUco.	cybersecurity risk (MR)-based smart manufacturing applications	ZED mini-stereo camera

Chapter 6

Extended Reality and Artificial Intelligence

Extended reality was introduced at the beginning of the survey so what is necessary to do first in order to explore the relation between these two fields is to give a definition and an introduction to AI. Defining AI presents a considerable challenge, as evidenced by numerous articles attempting to address this issue[17].Early definitions of AI suggested that it encompassed intelligence comparable to human actions or the ability to solve complex problems[18]. The ACM Computing Classification System lists AI and ML as computing methodologies, while in some contexts, ML is regarded as a sub-category of AI.

Extended Reality (XR) and Artificial Intelligence (AI) have risen to prominence as significant research areas within Human-Computer Interaction (HCI) and Computer Science overall[19]. Previously, research in these fields primarily occurred within their own respective domains. However, with the advent of tools and technologies such as Unity3D and Keras, XR and AI have become more accessible to researchers from diverse backgrounds and disciplines. As a result, a new research field has emerged at the intersection of XR and AI. Various researches in the field of Extended reality have been implemented in which the employment of AI is used to solve problems. Some works show a few of this problems, in particular [32] faces object tracking, [33] is about predicting virtual reality sick-ness, [34] foveated rendering. On the other side various researches in the field of AI have been implemented with the support of XR; [35] is a case for understandability problems that consists in visualizing neural networks in VR; explainability, for example, is shown by providing immersive interfaces to train machine learning (ML) models for non-experts [36].n. There are some reviews that summarize the literature on XR and AI for certain topics. For example, they analyze

intelligent embodied agents [37], production systems [38], or specific use cases, such as surgery simulations [39] or medical
education [40]. In [19] there is an interesting categorization that can give the idea of the possible combination of XR and AI:
(1) Using AI to create XR worlds;
(2) Using AI to understand users in XR ;
(3) Using AI to support interaction in XR;
(4) Interaction with IVAs;
(5) Using XR to support AI research.

6.1 Related Researches

In this paragraph we explore some works done in the categories presented above;

6.1.1 [41] DeProCams: a projector-camera systems for reconstruction in XR

1) Huang and Ling et al. [41] propose a new end-to-end trainable model called DeProCams, designed to learn the photometric and geometric mappings of ProCams explicitly.Image-based relighting, projector compensation, and depth/normal reconstruction are critical components of projector-camera systems (ProCams) and spatial augmented reality (SAR). While they follow a similar pipeline in terms of identifying projector-camera image mappings, they have traditionally been treated as separate tasks, each with its own set of requirements, devices, and image sampling methods. However, addressing them independently can be cumbersome for SAR applications, requiring separate handling of each task in succession.

Once trained, DeProCams can be simultaneously applied to three tasks. It breaks down the projector-camera image mappings into three subprocesses: estimating shading attributes, rough direct light, and photorealistic neural rendering. A significant challenge addressed by DeProCams is occlusion, which is tackled using the epipolar constraint and a novel differentiable projector direct light mask. This enables end-to-end learning alongside other modules. Additionally, to enhance convergence, it applies photometric and geometric constraints to ensure the intermediate results are realistic. It consists of two modules: DepthToAttribute and ShadingNet.

The DepthToAttribute module is responsible for computing shading attributes, including projector direct light rays, surface normals, view directions, and reflection directions. To overcome the challenge of occlusion in shading, it introduces a novel differentiable projector direct light mask, leveraging epipolar geometry. This mask is efficiently computed using techniques such as differentiable image warping, tensor sorting, and image gradient. Subsequently, initial rough direct light components are estimated to constrain both photometry and geometry. These components serve as a solid initialization for the photorealistic rendering of direct and indirect light by the ShadingNet.

The ShadingNet module functions to consolidate intermediate shading attributes and rough direct light, enabling the rendering of camera-captured images with photorealistic direct and indirect lighting effects. Additionally, to enhance model stability and convergence, we integrate various photometric and geometric constraints. These include ensuring consistency in the projector direct light mask, maintaining uniformity in rough diffuse shading, and ensuring smoothness in depth, normal, and pixel mapping. Due to the comprehensive modeling of light-geometry-material interactions and the incorporation of ample constraints, our depth map is learned effectively from sampled images even in the absence of ground truth data.

Below the architecture:

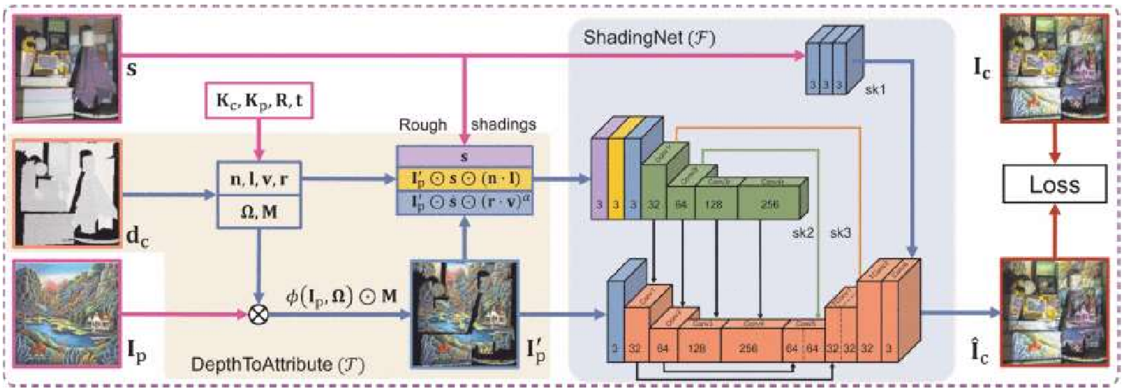


Figure 6.1: Deep projector-camera systems (DeProCams) architecture and training pipeline.

6.1.2 [42] Sick Moves! Motion Parameters as Indicators of Simulator Sickness

2) Feigl et al. [42] investigate motion parameters, specifically gait parameters, as an objective measure to evaluate simulator sickness in Virtual Reality (VR). They explore the potential correlations between simulator sickness, immersion, and presence and utilize two different methods for estimating camera pose (position and orientation) during motion tasks within a large-scale VR environment: a basic model and an optimized model that offers more accurate and natural sensory mapping. Participants engage in various motion tasks (walking, balancing, running) across three conditions: a physical reality baseline, VR with the basic model, and VR with the optimized model and analyze these conditions in terms of resulting sickness and gait, as well as perceived presence in the VR scenarios.

Architecture devices

The VR simulation was developed using the Unity3D engine. For display, it utilized a Samsung Galaxy Note 4 smartphone running Android 6.0.1, equipped with a Qualcomm Snapdragon 805 CPU and 3 GB RAM. The smartphone was mounted onto a Samsung GearVR HMD (version SM-R320), which incorporates a 6 DOF Bosch BMI055 inertial measurement unit (IMU) to track user orientation. Additionally, an InvenSense (MPU-6500) 6 DOF IMU was affixed to the HMD to aid in classifying user movement for pose estimation models. User positions were tracked using RedFIR, an RF-based real-time location system (RTLS) employing a single radio-frequency sensor, also attached to the HMD. Below the process raffiguration:

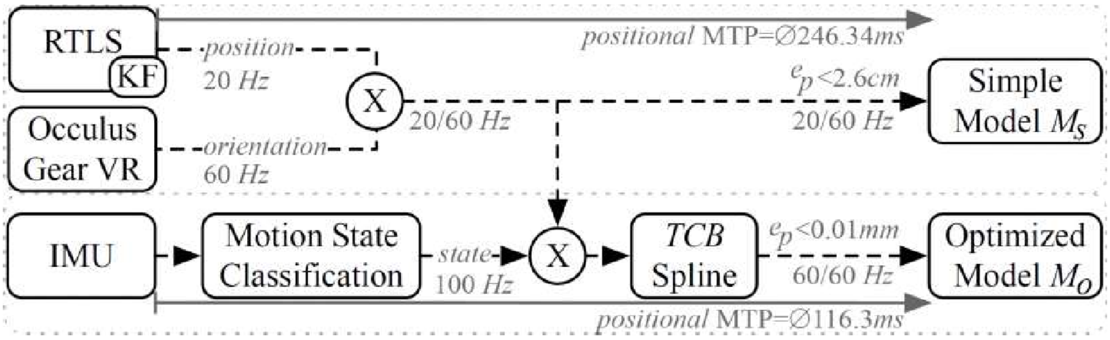
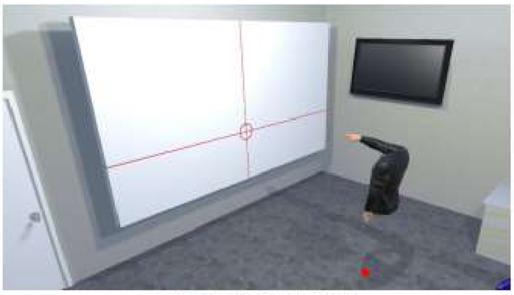


Figure 6.2: Pose estimation processing pipeline (precision error ep).

6.1.3 [43] Mid-Air Pointing in Real and Virtual Environments

3) Mayer et al. [43] investigate mid-air pointing in the real world and virtual reality by a pointing study that analyzes offsets and enhances pointing accuracy, demonstrating that users' pointing behavior is influenced by being in a virtual environment. In the subsequent investigation, they verify the established model's efficacy and scrutinize the impact of rectifying systematic offsets.For the setup, they employed a PC running Windows 10 linked to a projector, a head-mounted display (HMD), and a marker-based 6DOF motion capture system, specifically an OptiTrack system. The HMD utilized was an HTC Vive, and to ensure seamless VR performance, it relied on a NVIDIA GeForce GTX 1080. The tracking system provided the absolute position of the markers affixed to the participant at a rate of 30 frames per second (FPS). below the real and virtual visualization:

Figure 6.3: The seven rigid body markers



(a) Replicated Study Room

Figure 6.4: VR scene.

6.1.4 [44] Movement Interactions Between Avatars & Agents in Virtual Worlds

4) Narang et al. [44] introduce an interactive algorithm (Body Aware Movement, or BAM) designed to generate realistic movements for human-like agents interacting with other agents or avatars within a virtual environment. This method considers various constraints, including high-dimensional human motion constraints and biomechanical limitations, to calculate collision-free trajectories for each agent. They propose a novel algorithm for computing constrained velocities for full-body movements, which can easily integrate with existing motion synthesis techniques. Compared to previous local navigation methods, this approach minimizes artifacts in dense scenarios and close interactions, resulting in smoother and more realistic locomotive behaviors. Through evaluations in both single-agent and multi-agent environments, they have demonstrated the advantages of their algorithm. Specifically, the research shows a significant improvement in the perceived quality of simulations, particularly in dense scenarios. Furthermore, enables users to engage with agents from a first-person perspective in immersive settings. A user study investigating avatar-agent interactions indicates that our approach enhances the sense of co-presence experienced by users.

BAM minimizes the discrepancy between 2D navigation and complex motion synthesis by incorporating full-body motion constraints derived from real-world data and principles of biomechanics. These constraints are efficiently mapped to the 2D velocity plane, ensuring more realistic and coherent motion. It is versatile and can seamlessly integrate with various existing methods for full-body animation or simulation. Its adaptable nature allows for easy incorporation into different systems and workflows.This approach considers the presence of a tracked real user within an immersive virtual environment, resulting in the generation of collision-free and realistic avatar-agent interactions. This feature enhances the overall user experience by promoting natural and believable interactions. It is highly scalable and can be parallelized across multiple cores, enabling the simulation of hundreds of 2D agents at interactive rates. Additionally, it can handle the simulation and rendering of movement interactions involving 60 or more full-body agents at VR-friendly speeds, ensuring smooth and immersive simulations.

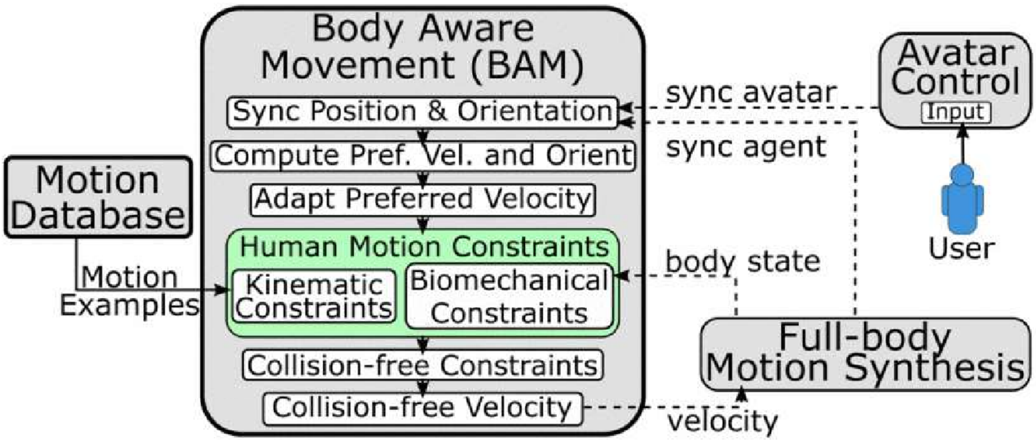


Figure 6.5: work environment.

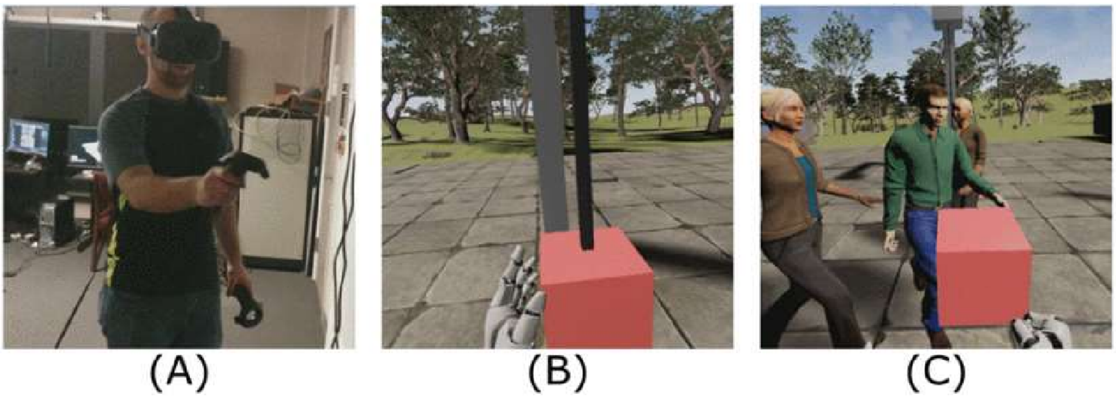


Figure 6.6: Avatar-agent interactions: (a) immersive room-scale VR experience from a first person perspective using the HTC vive. The tracked movement of the user is mapped to a virtual avatar.(b) the user is tasked with moving objects (red box) in a virtual environment. (C) Virtual agents account for the presence of the avatar, and compute smooth, collision-free full-body movements.

6.1.5 AIive: Interactive Visualization and Sonification of Neural Networks in Virtual Reality[45].

5) Lyu et al. [45] proposed a novel approach to represent artificial intelligence (AI) in a more experiential and engaging manner by conceptualizing it as a living entity. This involves imbuing neural networks (NNs) with dynamic attributes such as movement, color changes, and sounds, which evolve as the training process progresses and respond to user interaction. To materialize this concept, they present AIive, an interactive visualization tool designed to animate AI and provide users with a tactile and sensory experience. Leveraging fundamental human activities such as seeing, listening, and manual interaction, AIive offers an intuitive and enjoyable exploration of AI processes. Building upon the principles of immersive analytics, data visualization, and sonification in 3D environments, it extends the capabilities of existing 2D implementations like Immersions. This approach represents NNs as dynamic 3D force-directed graphs within a virtual reality (VR) environment, allowing users to observe the training process and manipulate the network architecture using virtual hands. Additionally, it incorporates real-time sonification of key metrics such as accuracy, loss, learning rate, and momentum, enabling users to fine-tune hyperparameters while engaging with the visualization.

Apparatus

The neural network (NN) model operates as the backend within the Python terminal of a laptop, while the 3D visualization and sonification components serve as the frontend, developed using Unity. The visualization and sonification are integrated into the Oculus Quest VR headset. Communication between the backend and frontend is established wirelessly through TCP connections. This setup enables seamless interaction between the NN model and the immersive VR environment, enhancing the user experience and facilitating real-time exploration of AI dynamics.

Model

The system consists of a simple fully-connected NN in python. The dataset utilized for training the model is a subset of the Toronto Faces Dataset (TFD), comprising 3374 grayscale images for training, 419 for validation, and 385 for testing. The neural network architecture consists of two hidden layers, with the number of neurons in each layer being adjustable.

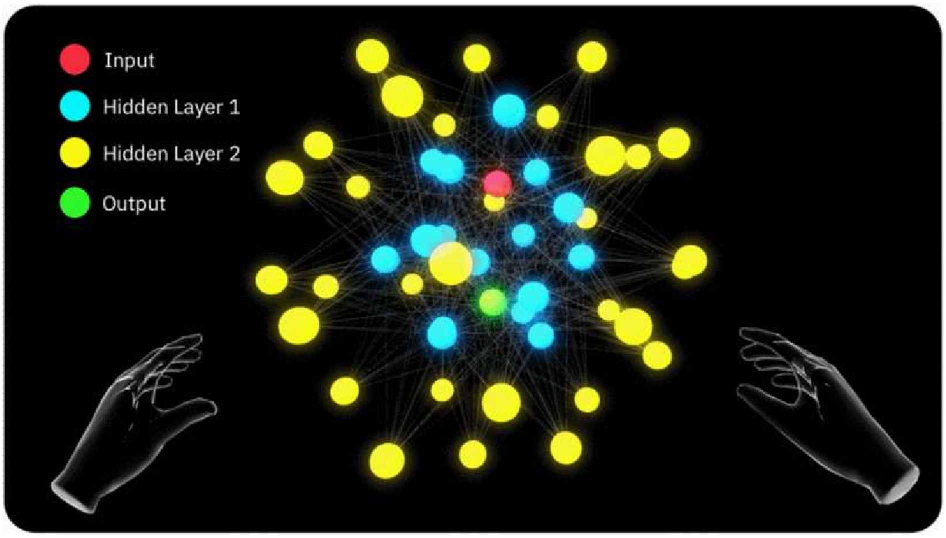


Figure 6.7: The Alive system, with the neural network at the center visualized as an interactive force-directed graph.

6.2 Accelerator Architectures for AR/VR technology

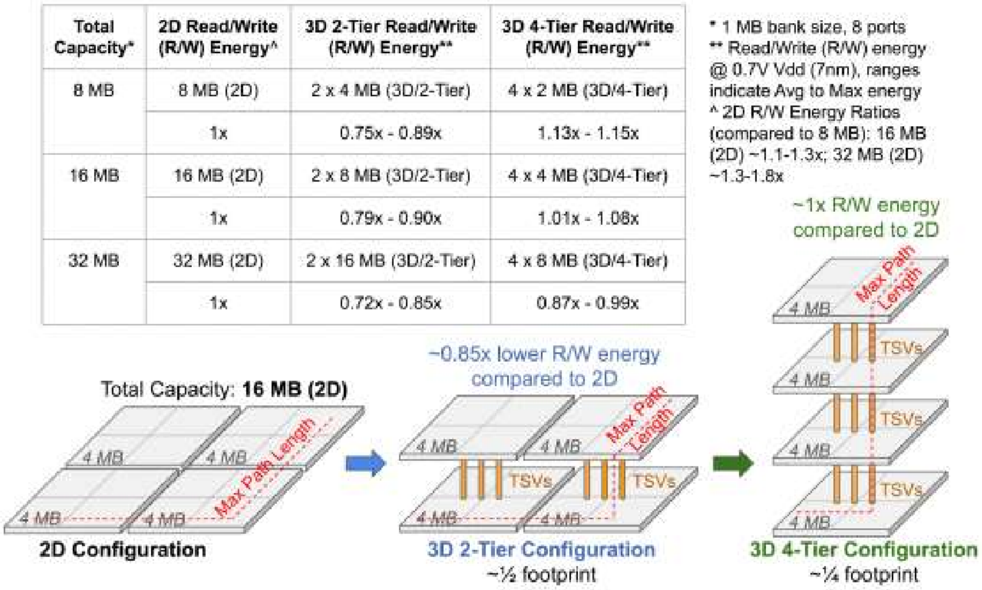
The advancement of deep learning algorithms has catalyzed significant progress in leveraging neural networks (NNs) for achieving state-of-the-art performance in augmented/virtual reality (AR/VR) applications. This has opened up new horizons for artificial intelligence (AI) and machine learning (ML) in the AR/VR domain, enabling various tasks such as object detection, image segmentation, eye and hand tracking, as well as depth estimation to be executed with unprecedented accuracy and efficiency. Deploying AR/VR neural networks (NNs) onto edge devices presents several key challenges. Firstly, there's the issue of large activation memory footprints, which arise from the high input/output resolution requirements of AR/VR applications. Secondly, there's a need to support a wide variety of convolution operations and different types of computer vision-based AR/VR models on a single accelerator. This requirement is driven by cost considerations, as deploying multiple specialized accelerators for each type of model may not be feasible. Therefore, edge devices must be equipped with powerful yet efficient hardware that can handle the computational demands of AR/VR NNs while also optimizing memory usage and resource allocation.

In this section we explore some research that aims to improve the computations problem that AR/VR applications have.

6.2.1 [55] Three-Dimensional Stacked Neural Network Accelerator Architectures for AR/VR Applications

Yang et al. [55] explore the design tradeoffs of 3-D stacked NN accelerator architectures for AR/VR workloads and highlight the improvements (energy, latency) enabled by 3-D hybrid bonding within a smaller or similar footprint to our 2-D baseline with no off-chip DRAM accesses.

To solve the footprint, BW, and scalability issues of increasing on-chip activation memory, they propose using 3-D integration to increase the internal SRAM capacity but within a similar X-Y footprint. Not only does 3-D stacking mitigate the footprint and BW restrictions, it can reduce both the latency and energy consumption with much shorter wavelengths and high-density connections.. Below the configuration:



Total Capacity*	2D Read/Write (R/W) Energy^	3D 2-Tier Read/Write (R/W) Energy**	3D 4-Tier Read/Write (R/W) Energy**
8 MB	8 MB (2D)	2 x 4 MB (3D/2-Tier)	4 x 2 MB (3D/4-Tier)
	1x	0.75x - 0.89x	1.13x - 1.15x
16 MB	16 MB (2D)	2 x 8 MB (3D/2-Tier)	4 x 4 MB (3D/4-Tier)
	1x	0.79x - 0.90x	1.01x - 1.08x
32 MB	32 MB (2D)	2 x 16 MB (3D/2-Tier)	4 x 8 MB (3D/4-Tier)
	1x	0.72x - 0.85x	0.87x - 0.99x

* 1 MB bank size, 8 ports
** Read/Write (R/W) energy @ 0.7V Vdd (7nm), ranges indicate Avg to Max energy
^ 2D R/W Energy Ratios (compared to 8 MB): 16 MB (2D) ~1.1-1.3x; 32 MB (2D) ~1.3-1.8x

Figure 6.8: Read/write energy comparison for the same memory capacity (8–32 MB) split across 3-D tiers (2–4 tier partitions).[3] Two-Tier 3-D access energy is lower than the 2-D equivalent due to shorter wavelengths but starts to increase or become iso-energy to the 2-D configuration at 4 tiers due to TSV energy overhead.

ML Accelerator Analytical Model for 3-D Stacking Simulation assesses various hardware metrics for the prototype ML accelerator executing AR/VR models. It estimates factors like how long tasks take to complete (latency), the energy consumed, the volume of data going in and out, and how efficiently resources are used. Below the configuration:

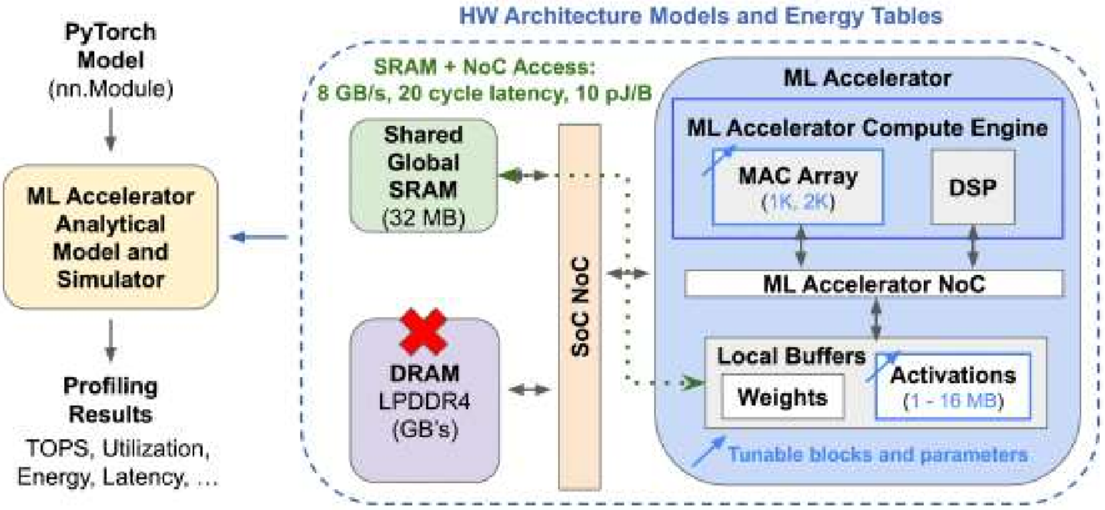


Figure 6.9 : ML accelerator simulator and model architecture setup based on a scaled-up version of the Sumbul et al.'s work[5] with distributed buffers. The local SRAM/buffers are scaled up to 16 MB for activations and the MAC array is scaled from 1K to 2K. Since DRAM accesses are prohibitively expensive, we assume all memory accesses external to the accelerator come from the shared global SRAM via the SoC NoC.

6.2.2 [56] Network Accelerator with SoC-Level Benchmarking for AR/VR Applications

Sumbul et al. [56] show a fully-digital computational-in-memory (CIM) based neural network (NN) accelerator tailored for AR/VR applications and evaluate its advantages at the system-on-chip (SoC) level in comparison to a state-of-the-art systolic-array based design. This approach begins with a fully-digital CIM macro and proposes an arrayed accelerator datapath with a row-pipelining scheme to efficiently handle computations for different NN layer sizes. Through an energy/latency estimation framework, it demonstrates that our CIM design achieves a significant improvement of up to approximately 2.1 times at the SoC level for typical AR/VR workloads. However, it also highlights that the high energy efficiency observed at the individual CIM macro level does not necessarily translate to the same degree at the SoC level. Therefore,it emphasizes the importance of thorough design-space exploration to drive algorithm-hardware co-optimization, which will be crucial for future integration into AR/VR devices.

This CIM-based design could serve as a building block for energy-efficient inference within an SoC, integrating with global memory structures and other on-chip components like CPUs, graphics pipelines, sensor drivers, etc., catering to various AR/VR applications. Below the configurations:

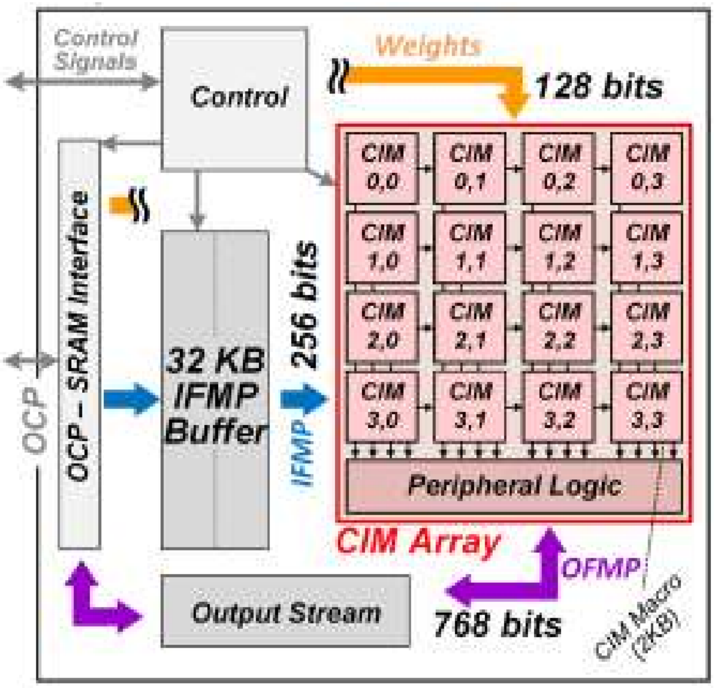


Figure 6.10: The proposed CIM-based NN accelerator

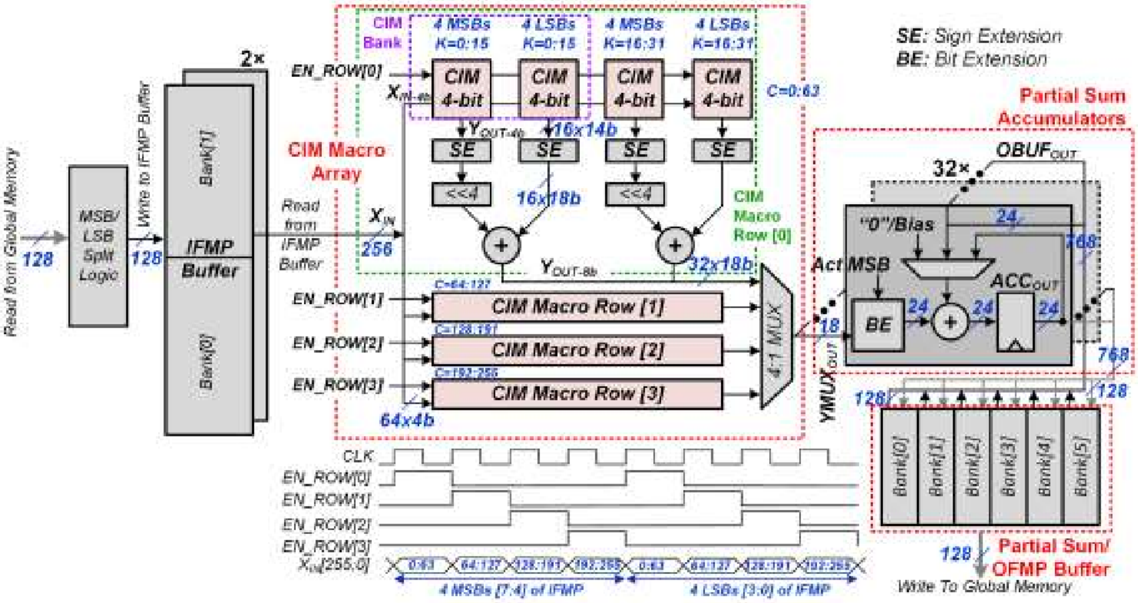


Figure 6.11: Microarchitecture of the proposed CIM array based NN accelerator supporting up to 8-bit weight/activation precision, showing the proposed “row pipelining" scheme, and mapping of input channels © and output channels (K) to the 16 CIM macros

6.3 Collections of papers

In this paragraph it is shown a table that collects a certain number of paper works related to the field applications of this chapter in order to have an overview and source of information useful in the exploring of Extended reality technologies. In particular in the table there is a paper reference with the corresponding software and hardware apparatus utilized in that research. It is been chosen to put maximum 10 paper consequently they will be chosen in order to cover as many different configurations as possible in such a way to give an heterogeneous classifications of the researches;

Table 6.1: :Collections of paper works in XR and AI with their XR apparatus.

	Head-mounted device	**Softwares used**	**Brief description of the work**	**Hardware devices used**
[42]	-Samsung GearVR HMD.	Unity3D	described above	-Samsung Galaxy Note 4. -InvenSense (MPU-6500) 6 DOF IMU. -RedFIR
[43]	HTC Vive	- OptiTrack system.	described above	NVIDIA GeForce GTX 1080. - OptiTrack system
[44]	HTC vive		described above	
[45]	Oculus Quest VR headset		described above	
[33]	Oculus Quest 2		VR Sickness Detection Using Predictive Models	photoelectric sensors
[34]	HTC Vive Pro	UNITY.SteamVR.	Visualization of Convolutional Neural Networks in Virtual Reality	
[60]	Microsoft Hololens	C# and Unity 5.6	Virtual Agent Positioning Driven by Scene Semantics in Mixed Reality	RGB cameras
[61]	SONY: HMZ-T2		AR Food Changer using Deep Learning	Microsoft: LifeCam Studio
[62]	Oculus Rift	Unity, iClone, Live2D		Kodenshi SG-105. optical sensors
[63]	HTC Vive Pro	Unity	Placement Retargeting of Virtual Avatars	

Chapter 7

XR devices

7.1 Summary of XR hardware and software configuration

In this paragraph we sketch a tree that summarizes all the information that we have collected in the tables of each chapter. In particular will be presented the hardware devices to visualize the environment (head-mounted devices or similar), the softwares utilized in the research and all other devices (camera tracker, pads ed etc…).

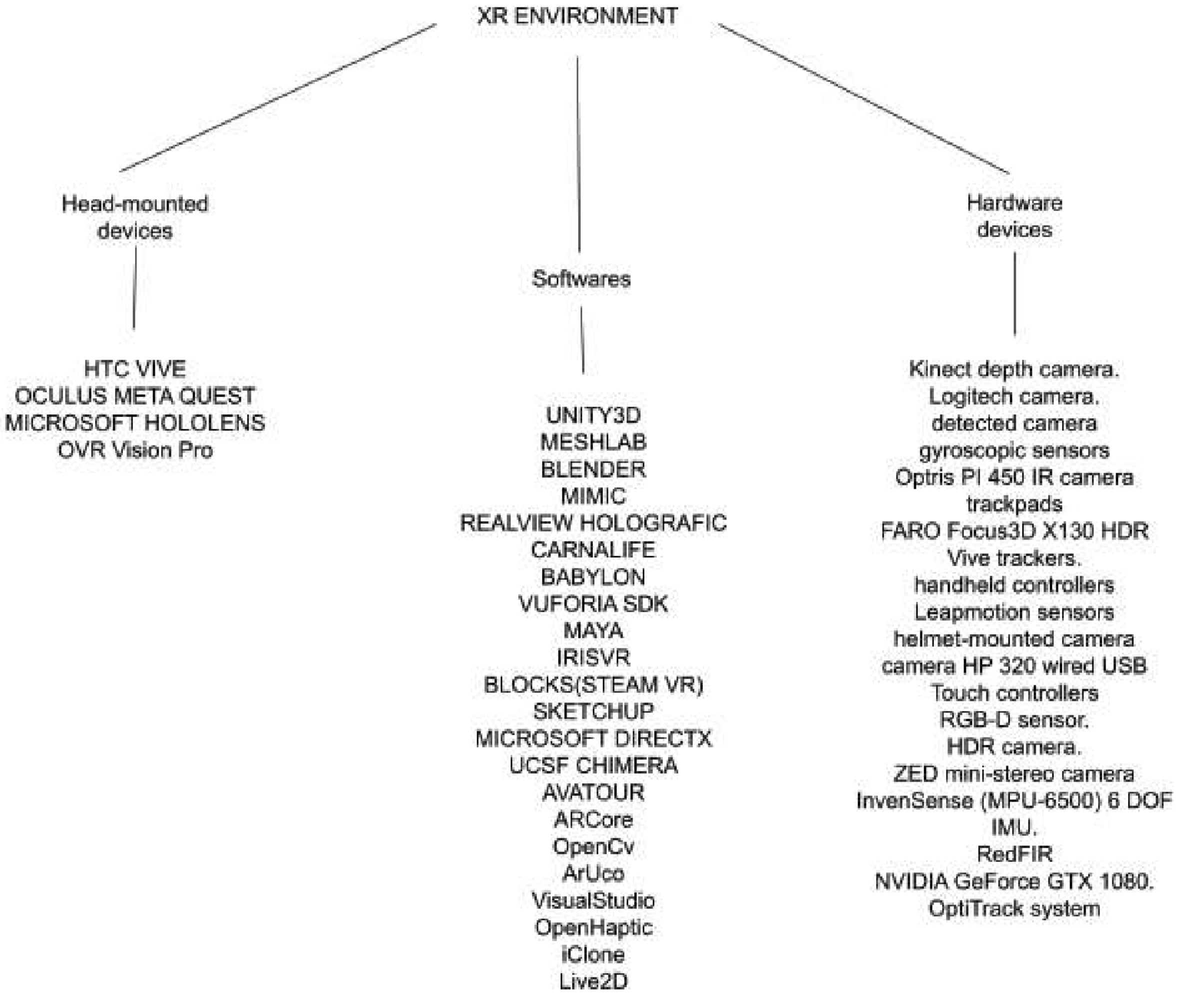


Figure 7.1: Tree of summary of all the papers.

7.2 Wearable devices in XR

The emergence of a virtual realm is now tangible with the widespread availability of augmented reality (AR) and virtual reality (VR) technology. Much like human interaction with the real world, AR and VR systems utilize human-machine interface (HMI) sensors for engagement in the virtual sphere. Presently, this connection is facilitated through advanced wearable visual and auditory devices, which, despite being cutting-edge, are often rigid, bulky, and cumbersome. This results in discomfort when practically applied.Furthermore, users are prone to experiencing dizziness and nausea while using the cumbersome Head-Mounted Display (HMD). These issues stem from factors like system latency, optical distortion of scene geometry, and persistence . Moreover, to create truly immersive systems, fulfilling human sensory needs goes beyond visual and auditory stimuli; it includes haptic, gustatory, and olfactory feedback.In response to the challenges mentioned earlier, there is a continuous effort in both academic and industrial settings to create the next generation of AR/VR devices that are characterized by being thin, soft, and lightweight. This reflects the ongoing pursuit of overcoming the mentioned limitations and enhancing the overall user experience. An interesting distinction that can be highlighted with a different point of view is the division between self-powered non self-powered wearable devices.

7.2.1 Self-Powered devices

These refer to wearables that can operate independently without needing to be connected to an external power source, typically by utilizing internal batteries, energy harvesting technologies, or other methods of self-power generation.

An example is in [54]; this study introduces a novel setup termed Non-Attached Electrode-Dielectric Triboelectric Sensor (NEDTS) and investigates its utilization in a specialized Human-Machine Interface (HMI) aimed at aiding individuals with disabilities in their daily activities. In this configuration, the conductive electrodes are not physically bonded to the dielectric materials through coating or sputtering processes. Instead, voltage generation occurs through triboelectric interaction between these moving components, inducing electrostatic voltage in a separate conductor without direct contact. This enables near-field remote sensing using triboelectric and electrostatic coupling. Leveraging this sensing technique, the researchers developed a sensor for detecting Orbicularis Oculi muscle motion to track both voluntary and involuntary eye blinks. This innovative transducer is integrated into a portable HMI system designed for hands-free computer cursor control, thereby assisting individuals with mobility impairments. Below the design:

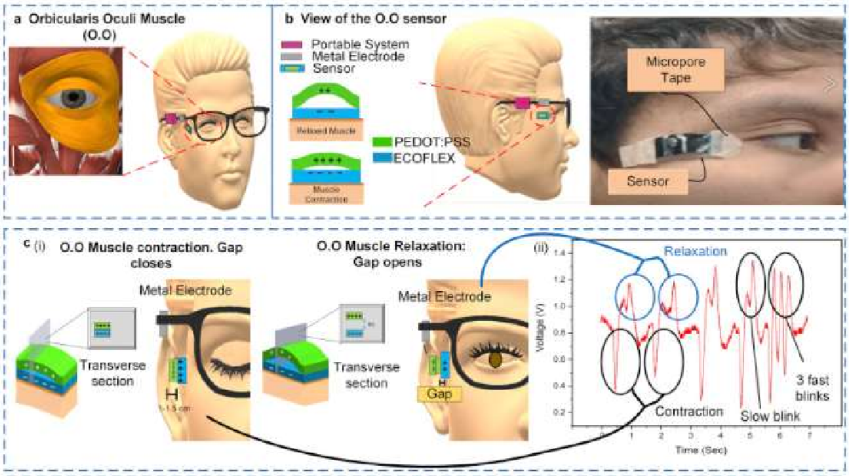


Figure 7.2 :Eye motion sensor design, placement, and results. (a) Orbicularis Oculi Muscle surrounds the surface beneath the eye. (b) Sensor overview, and placement. (c) (i) When the eye is closed, the muscle contracts and the sensor layers are stretched. When the eye is opened again, the muscle relaxes as well as the sensor layers. The transverse section is displayed. (ii) Contraction and relaxation signals. Fast and slow blink.

7.2.2 Non Self-powered devices

Wearable devices that are not self-powered typically rely on an external power source to function. They may need to be connected to a power outlet or require batteries that are not integrated into the device itself. These devices are often referred to simply as "wearable devices" or "powered wearable devices."To bring about the advancement of augmented reality/virtual reality systems of the future, the crucial technology needed is the creation of intelligent, flexible, groundbreaking wearable sensors. Material advancements frequently serve as essential components in achieving this goal[4]. Different materials have been investigated in the field of wearable technology such as nanoparticles, nanowires, carbon nanotubes and graphene. The criteria of choice of the materials relies on the electrical, mechanical and optical properties because they can be able to achieve good stretchability and flexibility. Below we present the most used head-mounted set/visor lens:

HTC VIVE [1]: The HTC Vive is a high-end virtual reality (VR) system developed by HTC and Valve Corporation. It consists of a headset equipped with a high-resolution display, precise tracking sensors, and motion controllers, providing users with immersive VR experiences. The Vive utilizes room-scale tracking technology, allowing users to move around freely in physical spaces while interacting with virtual environments.

MICROSOFT HOLOLENS[2]**:** HoloLens is a mixed reality headset developed by Microsoft. It blends virtual elements with the real world, allowing users to interact with digital holograms overlaid onto their physical environment. Equipped with sensors, cameras, and a transparent display, HoloLens enables users to see and manipulate holographic images, interact with applications, and collaborate in both professional and entertainment contexts. It's widely recognized for its innovative approach to mixed reality computing

OCULUS QUEST [3]**:** The Oculus Quest is a standalone virtual reality headset developed by Oculus, a division of Facebook Technologies. Offering six degrees of freedom (6DoF) tracking without the need for external sensors, the Quest provides users with an immersive VR experience in a wireless and portable package. It features high-resolution displays, built-in audio, and intuitive Touch controllers, allowing users to move freely and interact with virtual environments.

8 Conclusion

This survey was born with the scope to give a wide presentation of the Extended Reality world. It has explored different fields of application and we have faced different configurations. In each of them we noted an important division of the modalities of use of XR. In the case of medicine and manufacturing most of the research and experiments consist of training actions. This suggests that even if XR is trending it is still a challenge to integrate it in all the aspects of the handley job world. On the other hand, thanks to XR, education systems have a huge possibility to have an important upgrade to the modalities of learning in order to improve skills and performance of all kinds of students. Finally we have seen how AI and XR travel together in the road of progression helping each other in order to have performance and results that influence positively all the field.

9 References

[1] https://www.vive.com/us/product/#pro%20series

[2] https://learn.microsoft.com/en-us/hololens/

[3] https://www.meta.com/it/quest/products/quest-2/tech-specs/

[4] LING, Yunzhi, et al. Disruptive, soft, wearable sensors. Advanced Materials, 2020, 32.18: 1904664.

[5] Lucio Tommaso De Paolis, Sergio Teodoro Vite, Miguel Ángel Padilla Castañeda, César Fabian Domínguez Velasco, Salvatore Muscatello & Aldo Francisco Hernández Valencia (2022) An Augmented Reality Platform with Hand Gestures-Based Navigation for Applications in Image-Guided Surgery: Prospective Concept Evaluation by Surgeons, International Journal of Human–Computer Interaction, 38:2, 131-143, DOI: 10.1080/10447318.2021.1926116

[6] Šarić, Matko, Mladen Russo, Luka Kraljević, and Davor Meter. 2024. "Extended Reality Telemedicine Collaboration System Using Patient Avatar Based on 3D Body Pose Estimation" Sensors 24, no. 1: 27. https://doi.org/10.3390/s24010027

[7] R. Zatarain-Cabada, M. L. Barrón-Estrada, B. A. Cárdenas-Sainz, and M. E. Chavez-Echeagaray, Experiences of web-based extended reality technologies for physics education, Comput. Appl. Eng. Educ. 2023; 31: 63–82. https://doi.org/10.1002/cae.22571

[8] Peterson CN, Tavana SZ, Akinleye OP, Johnson WH, Berkmen MB. An idea to explore: Use of augmented reality for teaching three-dimensional biomolecular structures. Biochem Mol Biol Educ. 2020; 48: 276–282. https://doi.org/10.1002/bmb.21341

[9] Gopalan, V., Abu Bakar, J. & Zulkifli, A. (2020). Development of the MARPEX App Embedding the Mobile Augmented Reality Factors for Learning Motivation in Science Experiments. International Association of Online Engineering. Retrieved March 6, 2024 from https://www.learntechlib.org/p/218305/.

[10] Zafeiropoulou, M.; Volioti, C.; Keramopoulos, E.; Sapounidis, T. Developing Physics Experiments Using Augmented Reality Game-Based Learning Approach: A Pilot Study in Primary School. Computers 2021, 10, 126. https://doi.org/10.3390/computers10100126

[11] R. R. Calderón and M. Á. G. Ruíz, "Learning physics with virtual environment," 2019 IEEE World Conference on Engineering Education (EDUNINE), Lima, Peru, 2019, pp. 1-5, doi: 10.1109/EDUNINE.2019.8875824.

[12] Strzys, Kapp, S., Thees, M., Klein, P., Lukowicz, P., Knierim, P., Schmidt, A., & Kuhn, J. (2018). Physics holo.lab learning experience: using smart glasses for augmented reality labwork to foster the concepts of heat conduction. European Journal of Physics, 39(3), 35703. https://doi.org/10.1088/1361-6404/aaa8fb

[13] Y. Tai, B. Gao, Q. Li, Z. Yu, C. Zhu and V. Chang, "Trustworthy and Intelligent COVID-19 Diagnostic IoMT Through XR and Deep-Learning-Based Clinic Data Access," in IEEE Internet of Things Journal, vol. 8, no. 21, pp. 15965-15976, 1 Nov.1, 2021, doi: 10.1109/JIOT.2021.3055804.

[14] Bobby Nisha (2019) The pedagogic value of learning design with virtual reality, Educational Psychology, 39:10, 1233-1254, DOI: 10.1080/01443410.2019.1661356

[15] Zhang, & Chen, B. (2019). Enhancing Learning and Teaching for Architectural Engineering Students Using Virtual Building Design and Construction. Higher Education Studies, 9(2), 45.

[16] A. Nagy et al., "AI-Powered Interfaces for Extended Reality to Support Remote Maintenance," 2023 IEEE/ACM 23rd International Symposium on Cluster, Cloud and Internet Computing Workshops (CCGridW), Bangalore, India, 2023, pp. 214-222, doi: 10.1109/CCGridW59191.2023.00045.

[17] Fogel, D.B. (2022). Defining Artificial Intelligence. In Machine Learning and the City, S. Carta (Ed.). https://doi.org/10.1002/9781119815075.ch7

[18] NEWELL, Allen; SIMON, Herbert A. Computer science as empirical inquiry: Symbols and search. In: ACM Turing award lectures. 2007. p. 1975.

[19] Teresa Hirzle, Florian Müller, Fiona Draxler, Martin Schmitz, Pascal Knierim, and Kasper Hornbæk. 2023. When XR and AI Meet - A Scoping Review on Extended Reality and Artificial Intelligence. In Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23). Association for Computing Machinery, New York, NY, USA, Article 730, 1–45. https://doi.org/10.1145/3544548.3581072

[20] Edgar Rojas-Muñoz, Maria E. Cabrera, Chengyuan Lin, Daniel Andersen, Voicu Popescu, Kathryn Anderson, Ben L. Zarzaur, Brian Mullis, Juan P. Wachs, The System for Telementoring with Augmented Reality (STAR): A head-mounted display to improve surgical coaching and confidence in remote areas, Surgery, Volume 167, Issue 4, 2020, Pages 724-731, ISSN 0039-6060, https://doi.org/10.1016/j.surg.2019.11.008.

[21] Sugahara K, Koyachi M, Koyama Y, Sugimoto M, Matsunaga S, Odaka K, Abe S, Katakura A. Mixed reality and three dimensional printed models for

resection of maxillary tumor: a case report. Quant Imaging Med Surg. 2021 May;11(5):2187-2194. doi: 10.21037/qims-20-597. PMID: 33936998; PMCID: PMC8047357.

[22] Elchanan Bruckheimer, Carmel Rotschild, Tamir Dagan, Gabriel Amir, Aviad Kaufman, Shaul Gelman, Einat Birk, Computer-generated real-time digital holography: first time use in clinical medical imaging, European Heart Journal - Cardiovascular Imaging, Volume 17, Issue 8, August 2016, Pages 845–849, https://doi.org/10.1093/ehjci/jew087

[23] A Malaweera, R Jogi, M Wright, M O'Neill, S Williams, A mixed-reality holographic viewing platform enabling interaction with 3D electroanatomical maps using the HoloLens, *European Heart Journal*, Volume 42, Issue Supplement_1, October 2021, ehab724.0371, https://doi.org/10.1093/eurheartj/ehab724.0371

[24] Jaroslaw D Kasprzak, Jan Witowski, Jaroslaw Pawlowski, Jan Z Peruga, Adriana Złahoda-Huzior, Percutaneous patent ductus arteriosus closure using intraprocedural mixed reality visualization of 3D computed tomography angiography data: first-in-man experience, European Heart Journal - Cardiovascular Imaging, Volume 20, Issue 7, July 2019, Page 839, https://doi.org/10.1093/ehjci/jez008

[25]https://bernardmarr.com/the-fascinating-history-and-evolution-of-extended-reality-xr-covering-ar-vr-and-mr/

[26]https://stereosite.com/collecting/the-birth-of-stereoscopy-wheatstone-on-binocular-vision-1838-original-source/

[27] https://www.historyofinformation.com/detail.php?id=4083

[28] https://www.historyofinformation.com/detail.php?id=2785

[29] https://www.virtual-reality-shop.co.uk/philco-headsight-1961/

[30] C. Hirt, V. Holzwarth, J. Gisler, J. Schneider and A. Kunz, "Virtual Learning Environment for an Industrial Assembly Task," 2019 IEEE 9th International Conference on Consumer Electronics (ICCE-Berlin), Berlin, Germany, 2019, pp. 337-342, doi: 10.1109/ICCE-Berlin47944.2019.8966169. keywords: {Virtual Reality;Industrial Application;Assembly Training},

[31] Luis Pérez, Eduardo Diez, Rubén Usamentiaga, Daniel F. García, Industrial robot control and operator training using virtual reality interfaces, Computers in Industry, Volume 109, 2019, Pages 114-120, ISSN 0166-3615, https://doi.org/10.1016/j.compind.2019.05.001.

[32] X. Li, Y. Tian, F. Zhang, S. Quan and Y. Xu, "Object Detection in the Context of Mobile Augmented Reality," 2020 IEEE International Symposium on Mixed and Augmented Reality (ISMAR), Porto de Galinhas, Brazil, 2020, pp. 156-163, doi: 10.1109/ISMAR50242.2020.00037.

[33] G. Li, O. Onuoha, M. McGill, S. Brewster, C. P. Chen and F. Pollick, "Comparing Autonomic Physiological and Electroencephalography Features for VR Sickness Detection Using Predictive Models," 2021 IEEE Symposium Series on Computational Intelligence (SSCI), Orlando, FL, USA, 2021, pp. 01-08, doi: 10.1109/SSCI50451.2021.9660126.

[34] Okan Tarhan Tursun, Elena Arabadzhiyska-Koleva, Marek Wernikowski, Radosław Mantiuk, Hans-Peter Seidel, Karol Myszkowski, and Piotr Didyk. 2019. Luminance-contrast-aware foveated rendering. ACM Trans. Graph. 38, 4, Article 98 (August 2019), 14 pages. https://doi.org/10.1145/3306346.3322985

[35] N. Meissler, A. Wohlan, N. Hochgeschwender and A. Schreiber, "Using Visualization of Convolutional Neural Networks in Virtual Reality for Machine Learning Newcomers," 2019 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR), San Diego, CA, USA, 2019, pp. 152-1526, doi: 10.1109/AIVR46125.2019.00031. keywords: {Data visualization;Visualization;Virtual environments;Neurons;Convolutional neural networks;neural networks, visualization, virtual reality, knowledge learning},

[36] Clarice Hilton, Nicola Plant, Carlos González Díaz, Phoenix Perry, Ruth Gibson, Bruno Martelli, Michael Zbyszynski, Rebecca Fiebrink, and Marco Gillies. 2021. InteractML: Making machine learning accessible for creative practitioners working with movement interaction in immersive media. In Proceedings of the 27th ACM Symposium on Virtual Reality Software and Technology (VRST '21). Association for Computing Machinery, New York, NY, USA, Article 23, 1–10. https://doi.org/10.1145/3489849.3489879

[37] Norouzi, Nahal, et al. "A systematic literature review of embodied augmented reality agents in head-mounted display environments." Proceedings of the International Conference on Artificial Reality and Telexistence & Eurographics Symposium on Virtual Environments. 2020.

[38] Taina Ribeiro de Oliveira, Matheus Moura da Silva, Rafael Antonio Nepomuceno Spinasse, Gabriel Giesen Ludke, Mateus Ruy Soares Gaudio, Guilherme Iglesias Rocha Gomes, Luan Guio Cotini, Daniel Vargens, MARCELO QUEIROZ SCHIMIDT, Rodrigo Varejao Andreao, and Mario Mestria. 2022. Systematic Review of Virtual Reality Solutions Employing Artificial Intelligence Methods. In Proceedings of the 23rd Symposium on Virtual and Augmented Reality (SVR '21). Association for Computing Machinery, New York, NY, USA, 42–55. https://doi.org/10.1145/3488162.3488209

[39] Alexander Winkler-Schwartz, Vincent Bissonnette, Nykan Mirchi, Nirros Ponnudurai, Recai Yilmaz, Nicole Ledwos, Samaneh Siyar, Hamed Azarnoush, Bekir Karlik, Rolando F. Del Maestro, Artificial Intelligence in Medical Education: Best Practices Using Machine Learning to Assess Surgical Expertise in Virtual Reality Simulation, Journal of Surgical Education, Volume 76, Issue 6, 2019, Pages 1681-1690,ISSN 1931-7204, https://doi.org/10.1016/j.jsurg.2019.05.015.

[40] Narayan H. Gandedkar, Matthew T. Wong, M. Ali Darendeliler,
Role of virtual reality (VR), augmented reality (AR) and artificial intelligence (AI) in tertiary education and research of orthodontics: An insight, Seminars in Orthodontics, Volume 27, Issue 2, 2021, Pages 69-77, ISSN 1073-8746, https://doi.org/10.1053/j.sodo.2021.05.003.

[41] B. Huang and H. Ling, "DeProCams: Simultaneous Relighting, Compensation and Shape Reconstruction for Projector-Camera Systems," in IEEE Transactions on Visualization and Computer Graphics, vol. 27, no. 5, pp. 2725-2735, May 2021, doi: 10.1109/TVCG.2021.3067771.

[42] T. Feigl et al., "Sick Moves! Motion Parameters as Indicators of Simulator Sickness," in IEEE Transactions on Visualization and Computer Graphics, vol. 25, no. 11, pp. 3146-3157, Nov. 2019, doi: 10.1109/TVCG.2019.2932224.

[43] Sven Mayer, Valentin Schwind, Robin Schweigert, and Niels Henze. 2018. The Effect of Offset Correction and Cursor on Mid-Air Pointing in Real and Virtual Environments. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18). Association for Computing Machinery, New York, NY, USA, Paper 653, 1–13. https://doi.org/10.1145/3173574.3174227

[44] S. Narang, A. Best and D. Manocha, "Simulating Movement Interactions Between Avatars & Agents in Virtual Worlds Using Human Motion Constraints,"

2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Tuebingen/Reutlingen, Germany, 2018, pp. 9-16, doi: 10.1109/VR.2018.8446152.

[45] Z. Lyu, J. Li and B. Wang, "AIive: Interactive Visualization and Sonification of Neural Networks in Virtual Reality," 2021 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR), Taichung, Taiwan, 2021, pp. 251-255, doi: 10.1109/AIVR52153.2021.00057.

[46] Shankhwar, K., Chuang, TJ., Tsai, YY. et al. A visuo-haptic extended reality–based training system for hands-on manual metal arc welding training. Int J Adv Manuf Technol 121, 249–265 (2022). https://doi.org/10.1007/s00170-022-09328-4

[47] F. Gabriele Pratticò, Fabrizio Lamberti, Towards the adoption of virtual reality training systems for the self-tuition of industrial robot operators: A case study at KUKA, Computers in Industry, Volume 129, 2021, 103446, ISSN 0166-3615, https://doi.org/10.1016/j.compind.2021.103446.

[48] Youshaa Murhij, Vladimir Serebrenny, An application to simulate and control industrial robot in virtual reality environment integrated with IR stereo camera sensor∗∗The reported study was funded by RFBR according to the research project 19-01-00767., IFAC-PapersOnLine, Volume 52, Issue 25, 2019, Pages 203-207, ISSN 2405-8963, https://doi.org/10.1016/j.ifacol.2019.12.473.

[49] Torbjørn Netland, Michael Stegmaier, Cesare Primultini, Omid Maghazei, Interactive mixed reality live streaming technology in manufacturing, Manufacturing Letters, Volume 38, 2023, Pages 6-10, ISSN 2213-8463, https://doi.org/10.1016/j.mfglet.2023.08.141.

[50] Alatawi, H.; Albalawi, N.; Shahata, G.; Aljohani, K.; Alhakamy, A.; Tuceryan, M. Augmented Reality-Assisted Deep Reinforcement Learning-Based Model

towards Industrial Training and Maintenance for NanoDrop Spectrophotometer. Sensors 2023, 23, 6024. https://doi.org/10.3390/s23136024

[51] Belu, N., et al. "Monitoring console using Virtual Reality for automotive industry." IOP Conference Series: Materials Science and Engineering. Vol. 1182. No. 1. IOP Publishing, 2021.

[52] H. -Y. Lee, P. Zhou, A. Duan, J. Wang, V. Wu and D. Navarro-Alarcon, "A Multisensor Interface to Improve the Learning Experience in Arc Welding Training Tasks," in IEEE Transactions on Human-Machine Systems, vol. 53, no. 3, pp. 619-628, June 2023, doi: 10.1109/THMS.2023.3251955.

[53] Yang, W., Dengxiong, X., Wang, X., Hu, Y., and Zhang, Y. (October 10, 2023). "“I Can See Your Password”: A Case Study About Cybersecurity Risks in Mid-Air Interactions of Mixed Reality-Based Smart Manufacturing Applications." ASME. J. Comput. Inf. Sci. Eng. March 2024; 24(3): 031004. https://doi.org/10.1115/1.4062658

[54] David Vera Anaya, Tianyiyi He, Chengkuo Lee, Mehmet R. Yuce, Self-powered eye motion sensor based on triboelectric interaction and near-field electrostatic induction for wearable assistive technologies, Nano Energy, Volume 72, 2020, 104675, ISSN 2211-2855, https://doi.org/10.1016/j.nanoen.2020.104675.

[55] L. Yang et al., "Three-Dimensional Stacked Neural Network Accelerator Architectures for AR/VR Applications," in IEEE Micro, vol. 42, no. 6, pp. 116-124, 1 Nov.-Dec. 2022, doi: 10.1109/MM.2022.3202254.

[56] H. E. Sumbul, J. -s. Seo, D. H. Morris and E. Beigne, "A Fully-Digital and Row-Pipelined Compute-in-Memory Neural Network Accelerator with SoC-Level Benchmarking for AR/VR Applications," in IEEE Micro, doi: 10.1109/MM.2023.3338059.

[57] Qin Z, Wang Y, Du J, Tai Y, Shi J. Development and Validation for Extended Reality-Based MIS Simulator Using Cumulative Summation. International Journal of Human-Computer Interaction. 2022;38(5):456-467. doi:10.1080/10447318.2021.1948688

[58] Rohrbach, N., Gulde, P., Armstrong, A.R. et al. An augmented reality approach for ADL support in Alzheimer’s disease: a crossover trial. J NeuroEngineering Rehabil 16, 66 (2019). https://doi.org/10.1186/s12984-019-0530-z

[59] Zhu, Bolin, et al. "Increasing enthusiasm and enhancing learning for biochemistry-laboratory safety with an augmented-reality program." Journal of Chemical Education 95.10 (2018): 1747-1754.

[60] Y. Lang, W. Liang and L. -F. Yu, "Virtual Agent Positioning Driven by Scene Semantics in Mixed Reality," 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Osaka, Japan, 2019, pp. 767-775, doi: 10.1109/VR.2019.8798018.

[61] J. Ueda and K. Okajima, "AR Food Changer using Deep Learning And Cross-Modal Effects," 2019 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR), San Diego, CA, USA, 2019, pp. 110-1107, doi: 10.1109/AIVR46125.2019.00025.

[62] K. Suzuki et al., "Recognition and mapping of facial expressions to avatar by embedded photo reflective sensors in head mounted display," 2017 IEEE Virtual Reality (VR), Los Angeles, CA, USA, 2017, pp. 177-185, doi: 10.1109/VR.2017.7892245.

[63] L. Yoon, D. Yang, J. Kim, C. Chung and S. -H. Lee, "Placement Retargeting of Virtual Avatars to Dissimilar Indoor Environments," in IEEE Transactions on Visualization and Computer Graphics, vol. 28, no. 3, pp. 1619-1633, 1 March 2022, doi: 10.1109/TVCG.2020.3018458.

[64] Broyer, Rebecca M., et al. "Using virtual reality to demonstrate glove hygiene in introductory chemistry laboratories." (2020): 224-229.