An Insight into EDGE-Based Solutions for Augmented Reality

Pankaj Joshi, Sanskar Jain, and Simran Vanjani

Abstract The term "augmented reality" refers to a technology that combines digital and actual experiences. It is an immersive experience of a physical environment in which actual objects are enhanced with digital visual features, sound, or other sensory stimuli. The rapid advancement of augmented reality has piqued people's interest in recent years. It is a rapidly developing area among businesses that deal with mobile computing and commercial apps. Using AR, digital information can be placed in reality to improve a human's perspective of reality. This paper begins by defining augmented reality, its history, and its challenges. The paper then discusses some essential technology, development tools, and augmented reality applications in several industries. The main focus point of the paper is centered around the discussion on EDGE Technology as a solution to the limitations of AR. We have drawn a comparison between some frameworks that have been developed over time, merging AR with EDGE. Finally, it anticipates future advancements in augmented reality technologies, such as the Mobile AR.

Keywords Augmented reality · Virtual reality · EDGE devices · Head mount display · Mobile augmented reality

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1 Introduction

Augmented reality (AR) is a cutting-edge technology which enhances users' perceptions of engagement with real-world environments by including digital things, and it is the most organic way to connect with your virtual environment.

Augmented reality is a structure that:

1. integrates actual and digital objects in an actual world;
2. aligns actual and digital objects with one another;
3. runs dynamically, in 3D, and on a real-time basis.

There are three parts of this definition worth mentioning.

For starters, AR is not limited to specific display technology like a head-mounted display (HMD). AR can and may extend to all aspects, including sound, contact, and odor, and the term is not restricted to the sense of vision. Finally, AR includes the removal of real items in favor of virtual ones [1].

In this paper, we discuss some potential worldwide applications of augmented reality in education where computer-generated visuals in classrooms help students; tourism where enhanced augmented guides improve a tourist's experience; e-commerce. We also discuss domestic applications of AR which include agriculture where farmers can get a 3D overview of their field which will help them make the best decisions for themselves: Smart City Planning and E-Commerce.

We then address the fact that AR devices lack the processing power needed to provide users with authentic AR experiences and address the limitations of AR. These limitations can now be overcome with the help of EDGE devices.

Edge computing refers to a set of virtualized computing solutions that provide processing, memory storage, and web server resources at the network's edge. Edge servers are machines that give services to end devices. Edge computing tackles the essential issues of AI-based systems, and edge computing and AI combined offer a potential solution. Edge intelligence, also known as mobile intelligence, is the name given to this new intelligence paradigm [2]. The paper concludes with a discussion on the EDGE solutions and the scope of AR.

1.1 Overview of Augmented Reality

Augmented reality (AR) is a form of technology that mixes virtual and actual information. It involves real-time tracking and 3D modeling, sensing, intelligent interactions, and other multimedia. Its aim is to apply machine-generated virtual data to the real world following simulation, such as information, pictures, 3D models, audio, and video. In this way, the two information sources complement one another, resulting in a better real-world experience. The most popular way for AR to be implemented is through the use of a guiding anchor in the real universe. The most common sort of anchor is a unique pattern picture, and attaching virtual items to pattern photos makes it easy to position and connect virtual things to physical objects. A display of some form is used to allow the user to interact with the augmented reality systems.

AR development tools: In 2017, Apple announced ARKit, an AR programming tool. Engineers could use this set of techniques to make AR apps for devices with iOS like iPads and iPhones. ARKit helps engineers make AR apps that let two devices interact with the same virtual items, increasing the AR experience. Google also proposed a software foundation for creating AR applications named ARCore, which was similar to the one Apple proposed. It took the help of cloud-based software to portray physical images. The most widely used Software Development Kit is Vuforia, which is the most popular at the moment. Another one is the Wikitude SDK which can reconstruct its ideas utilizing an image recognition and tracking development framework as well as geolocation technologies [3].

AR Devices: Three types of devices are utilized in augmented reality: (i) head-worn devices also known as helmet-mounted display (HMD) devices, (ii) handheld devices that have portable displays, and (iii) spatial devices. These three devices use different methods to display information. Figure 1 shows an overview of these devices and the different displays they use [4].

The different types of displays work in the following way:

1. Video: The user experiences a complete digital view and the real and digital worlds are merged.
2. Optical: Digital objects are placed right above the real ones.
3. Retinal: Digital objects are portrayed right onto the retina with the help of a laser of low power.
4. Hologram: A photometric mixture of light patterns is used to display the digital objects.
5. Projector: A digital projector is used to portray digital objects directly.

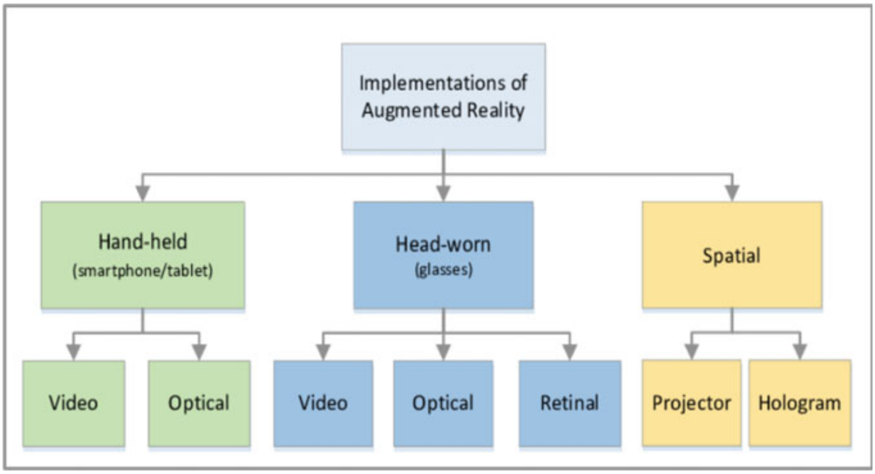

Fig. 1 Various AR devices and their displays (*Source* IEEE Access 2017, p. 3)

Each device and its display type has its benefits and drawbacks according to the needs of the applications. One such device is a head-mounted display device (HMD), it can be worn on your head or can be adjusted in your helmet, and it portrays both digital and real images to the user. HMDs have video-see-through devices inbuilt into them; this has two camera hatches to help see the augmented reality more organically. This AR is generated through a computer chip which enhances the outcome. Figure 2 shows a basic head-mounted display device that can be used for entertainment and educational purposes [5]. Image-guided surgery is shown in Fig. 3.

Smartphones with Android or iOS compatibility are now more commonly used than handheld screens, these phones can also serve as an AR display. The most powerful ones are personal computers or tablets; however, they are too expensive or too big to be used by just one hand. However, with the introduction of iPads, tablets are now a usable platform for augmented reality.

Fig. 2 Head-mounted display device (HMD) (*Source* IJITEE 2019, p.1331)

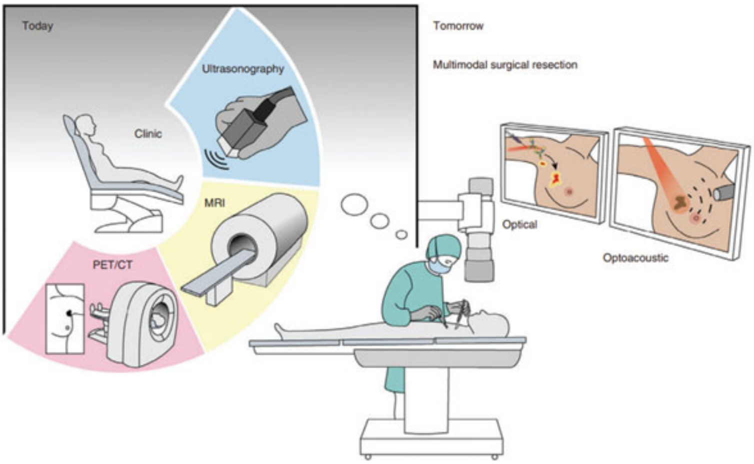

Fig. 3 Image-guided surgery (*Source* British Journal of Surgery, 2015 p58)

Visual data is displayed directly on actual objects in spatial augmented reality (SAR) without the user needing to wear or handle the device. The majority of technology is isolated from the user by spatial displays that integrate it into the environment. Such a technology can be used in image-guided surgeries where the doctors can use AR to better plan and operate on a patient [6].

Metrics used to measure performances of AR devices are:

1. Camera Position Tracking: A video-based AR system essentially has two cameras: a real one, which generates video of the real environment, and a virtual one, which generates the 3D graphics to be merged with the live video stream. Both cameras must have the same internal and external parameters in order for the real and virtual objects to be properly aligned. To achieve this, an initial calibration of the real camera and a dynamic update of its external parameters are required. There are two crucial problems of AR applications with respect to camera tracking: (1) the accurate alignment of real and virtual coordinate frames for overlay, and (2) capturing the 3D motion for each video frame of a camera including camera position. The latter is very important for interactive AR applications, where users can manipulate virtual objects in an augmented real 3D environment. This issue has never been successfully addressed using only video input measurements. The system used by Dieter Koller et al. successfully tracks in real time at approximately 10 Hz; it showed that robustness can be achieved by using a Kalman filter along with landmark detection and tracking which is model-driven instead of using a complete data-driven motion estimation. Camera parameters are evaluated using an automated camera calibration procedure using landmark detection. These parameters are of two types: intrinsic and extrinsic. Extrinsic parameters can be manipulated and built in a 3D environment which will assist in collision detection taking room boundary into consideration. If the virtual objects would be floating in front of real ones, it would result in disorientation for the user. Intrinsic parameters are taken to be independent in terms of position and orientation. These parameters are associated with the internal geometry of the camera, like focal length, pixel size, and resolution [7].
2. Latency: In augmented reality (AR) systems, registration (or alignment) of the artificial picture with the real world is essential. It is necessary to register the user's perspective of the environment both temporally and spatially with the input from user-input devices, surveillance devices, and imaging equipment. Each device experiences a delay between when it observes the world and when a change in the data first appears to have an impact on the AR display it is showing the user. The variations in latency are referred to as relative latencies. Relative delay contributes to misregistration and needs to be minimized. In a functioning AR system, we provide general techniques for managing multiple data streams with various latency values.
3. QoA: QoA or quality of augmentation consists of two major components:

    (1) Virtual Object Pose Accuracy: The virtual object's deviation from the ideal position or orientation is quantified by the pose accuracy. The actual pose is provided by initiating the handset.

(2) Virtual Object Pose Jitter and Drift: The motion of the virtual object between succeeding frames is measured by pose jitter. The pose drift estimates how much position and orientation error has accumulated with time. Low jitter and drift indicate that over time, regardless of user movement, the virtual item maintains its position with regard to the physical world.

2 A Brief History of AR

Augmented reality (AR) was first discussed in 1950s by Morton Heilg, who he film as something that will immerse the audience in the theater's screen by utilizing all of their sensations. Owing to this thought, Morton built "The Sehensorama," a pre-digital computer model in 1962, which was described by him as "The Cinema of the Future," in 1955.

The first head-mounted display was designed in 1966, and in 1968, the first AR-based system was developed; both of these designs were proposed by Ivan Sutherland. He used a head-mounted display in his designs.

A virtual environment was developed in 1975 referred to as "The Video Place"; it offered the population to interact with digital items for the very first time. This was proposed by Myron Krueger [8].

Bruce Thomas debuted ARQuake, the very first outdoor mobile-based AR game, at the International Symposium on Wearable Computers in 2000. AR technologies will become more generally available in the next four to five years, according to the Horizon Report, and camera systems that can evaluate physical situations in real-time and link locations between things and surroundings were introduced the same year, validating that prediction. This style of camera system has served as the foundation for combining virtual objects with reality in AR systems. In the years thereafter, several AR apps have been developed, primarily for mobile devices (such as Wikitude AR Travel Guide, which was released in 2008), but also for medical applications (in 2007).

With the help of recent technological advancements, an increasing number of AR systems and applications are being developed, in all possible sectors.

3 Components of AR

Augmented reality is an amalgamation of output and input components.

Output Components: These are responsible for the presentation of the virtual world and how it is perceived by the user; these components are responsible to provide the best experience possible to the user. Output components can be categorized on how they are perceived by the user; hence, they can be divided on the basis of the five human senses.

(1) Vision: Most of the information which our brain processes is owed to our vision. So an AR system must be successful in capturing the visuals by perfectly combining real and virtual environment. This can be achieved using head-mounted display (HMD). HMDs have video-see-through devices inbuilt into them; this has two camera hatches to help see the augmented reality more organically.
(2) Touch: The human touch is an extremely important perception channel; the tactile and kinesthetic senses of the human haptic system show that the ability of touch increases the sense of presence. The PHANTOM, manufactured by Sensable Technologies, looks like a robotic arm (copy figure) helps in giving the users a very real-like sense of actually interacting and touching the virtual objects.
(3) Sound: It is one of the most important senses to offer user a real-life experience. The basic steps required for successful simulation of virtual sounds are: sound generation, spatial propagation, and mapping of parameters. It is evident that combination of sound and graphic enhances the sense of presence.
(4) Smell and touch also play a crucial role in increasing the user experience and some flow delivery systems have been put into use for the same. A few examples of which are “taste interfaces” and “food simulators.”

Input Components: Input components are in charge of engagement and determine how a user interacts with virtual objects. Ideally, all of these devices should come together to make user environment control as simple and natural as possible. Some of these components are:

(1) Live Input: Video Camera

It is used to obtain continuous visual images which are further collaborated with virtual images to produce the augmented view as an end result. The resolution of the video image and the speed of transmission to the video compositor engine, so that they can be augmented and displayed to the user in real time, are two important factors to think of when selecting the camera. Along with this, camera model and calibration should also be taken into consideration.

(2) Trackers: These are devices which are used to keep track of the user’s head (or wherever the camera is fixed) in order to correctly detect and calculate the position and orientation of the real-world scenario. They also track other body parts to enhance user experience. Trackers help in improving Update Rate, Latency, Accuracy, and Range. Some sensor-based trackers include Magnetic Trackers, Ultrasonic Tracker, Mechanical Tracker, and Inertial, Optical, and Vision-based Tracker [9].

4 Applications of Augmented Reality

4.1 General Application

Education: Many schools are implementing new technology to improve students' learning experiences. AR allows digital visuals to be placed on the actual environment in one's field of vision. Vector graphics, concept visualization, annotations, virtual instructions, and X-ray vision are examples of AR features that may be employed in current classroom circumstances to give an interactive and spatial learning experience. Students may undertake laboratory experiments and exercises safely and reliably with the aid of augmented reality technology. Because of interactive overlays of virtual items on the actual environment, this is feasible. AR is most commonly used in the fields of science, mathematics, and humanities. AR is effective in motivating and improving learning performance in several studies [10].

Entertainment: Advanced technologies like augmented reality (AR) are expected to have an impact on the future of entertainment. The entertainment sector has been able to revolutionize the way people connect and participate in games, athletics, tours, and concerts, among other activities, thanks to technological advancements. AR is a 3D interactive technology that merges physical and digital worlds in 3D. AR is already being utilized to improve the efficacy of multimedia presentations and films, in addition to rethinking traditional games [11]. It may, however, be applied to a far broader range of entertainment industries, such as how we listen to songs and how we travel. To develop diverse and physical interfaces, interface and visualization tech, as well as certain fundamental supporting technologies, are being included. AR can also be utilized in a group setting to provide individualized data to each user. Furthermore, by emphasizing or introducing information, it improves broadcasting during athletic events, concerts, as well as other events. As a result, AR's application in the entertainment business has advanced tremendously, as seen by the most recent well-known success, which is a location-based gaming example. Non-AR experiences restrict people to a screen, whereas AR converts books into an AR play area, urging individuals to venture outside and read more. Many AR entertainment systems contain on-device components, such as localized game control and player tracking; but, when shared resources, location-based gaming, and continuous synchronization are necessary, a server connection is used [12].

Tourism: AR plays an important role in the tourist business, and new generation smartphones and tablets, which are commonly equipped with GPS sensors and swift system connections, have made a significant contribution. These devices are equipped to assist with location-based AR administrations. A tourist experience may be enhanced by incorporating interactive media and redesigned content based on the demands of the visitors. The most common type of AR application for travel is augmented guides; an enhanced guide searches for, retrieves, and photographs data gathered from select online sources as shown in Fig. 5. Accommodations, restaurants, and other services aimed at attracting tourists might reap significant benefits. They may evolve as places to visit rather than demands of travel. AR would also most certainly see a lot more open and direct communication between such authorities and visitors. AR used in gaming utility is shown in Fig. 4 [13].

E-commerce: The management of corporate websites or e-commerce systems can be improved by new purchasing techniques with varied properties compared to traditional online buying. E-commerce is a choice-based innovation that relies on AR cooperation to eliminate physical connection with the goods. For quite some time, the use of the Internet for purchasing has been rising rapidly. AR could be the most critical factor in changing how people shop online. The growth of new AR technology will be helpful if it can duplicate the features that have made online shopping the most popular shopping option in recent years. It is a simple method of constructing a 3D model in front of a person who may be successfully similar, resulting in a better appearance of the object by reconstructing it in reality. The use of AR purchasing

Fig. 4 AR being used as a gaming utility (*Source* MRV 2019, p. 39)

Fig. 5 An augmented reality application in tourism (*Source* IEEE Potentials 38(1):43–47, 2019 p.45)

is revolutionizing the online industry by assisting web merchants in reducing their rising profit margins and providing their customers with a more engaging and advantageous way to purchase through their devices. Clients may see their items in real time, from the luxury of their own home, thanks to imaginative AR setups. With a specialty area, it might play a big part in the industrial revolution [14, 15].

4.2 Domestic Application

Agriculture: In India, augmented agriculture is a revolutionary technological breakthrough that will advise farmers on the best pesticides and insect treatments. Additionally, this technology has the potential to reach both urban and rural populations about India's diverse flora and wildlife.

Farmers will be able to come up with enhanced and greater harvest amounts if augmented reality (AR) is used in farming. This technique may be used to judge the integrity of a site and its soils for agricultural purposes, resulting in higher crop yields in a variety of climatic circumstances. AR can analyze and identify soil quality, fertility, and nutrition, all of which are necessary for crop development to be productive. It also can forecast the weather. It will provide complete information on any plants that you choose to grow. Figure 6 shows assessment of a wind farm layout onsite by augmented reality [16].

Smart City Planning: The concept of "Smart Cities" is particularly significant in India since it attempts to enhance people's living standards by improving infrastructure, administration, irrigation, energy, water, health, education, safety, and security, among other things as shown in Fig. 7. It is critical to have a tool to communicate with all stakeholders and understand their primary problems in a nation where settlements are not structured and developed haphazardly. As a result, augmented reality emerges as a solution to all stakeholders' concerns about smart city infrastructure mobility, connection, and security. Mobility encompasses not just the ability to travel from one location to another, but also the supply of amenities that facilitate mobility, such

Fig. 6 Wind farm layout onsite by AR (*Source* Journal of Physics Conference Series, 2016 p.8)

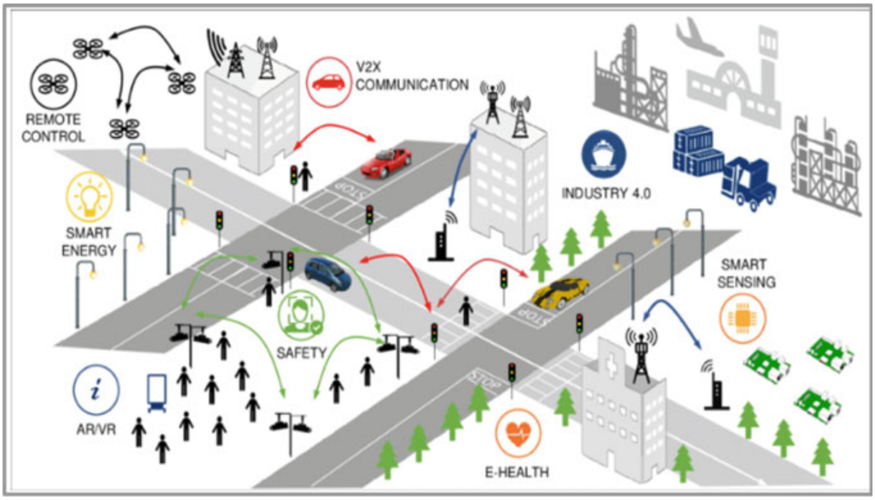

Fig. 7 IoT ecosystem assisted by AR in smart city (*Source* IEEE Communications Standards Magazine 3(2):26–34, 2019 p.27)

as educational opportunities, job training, professional progression, and company expansion. Permanent transportation systems such as roadways, railroads, and highways might be digitally connected through AR apps that give real-time information on timetables, disasters, and routes, as well as help navigation, using augmented reality applications. All the smart city technologies rely on real-time data transmission, which is only possible with a reliable connection. As a result, augmented reality aids smart networking and infrastructure management [17].

5 Limitations of AR

Augmented reality (AR) has been shown to be beneficial in various circumstances. However, current AR gear lacks the processing power needed to provide users with authentic AR experiences. Previously, devices like Google Glass introduced in 2012 executing highly demanding AR algorithms struggled from overheating and extremely limited battery life. However, even more, recent devices such as Microsoft HoloLens have limitations, such as the number of renderable polygons, and bringing AR apps into action and bringing them up to date locally on various mobile devices are quite expensive. Web AR will become one of the most important techniques for bringing AR to more people. However, even web AR suffers from certain limitations—**Computational Efficiency for CPU-Hungry Tasks on Mobile Web Browsers**: JavaScript, a popular programming language, performs poorly when dealing with sophisticated computations like matrices and floating-point calculations. To fulfill the requirement for computational efficiency, web browsers must be updated to a more effective computation paradigm. The hardware resources of end devices can be fully utilized by browser-kernel-based extension solutions for web augmented reality implementations to improve speed. As a web AR solution, we believe this has more potential. However, as distinct web AR applications can only be utilized by their own browser, a variety of existing browser-kernel-based extension solutions have substantial compatibility issues, which significantly limits the popularity of web AR. The aforementioned compatibility issue will be one of the most important issues to be resolved in the future in order to market web AR applications on a broad scale.

Network Constraints: The latency and bandwidth of the network are crucial to MAR. Wireless networks, however, have a negative impact on how well web AR apps work. Even while the present 4G networks are capable of good performance, they cannot yet satisfy the low-latency demands of novel applications like AR and VR. New methods for optimizing wireless network resources are made possible by technologies including software-defined networking (SDN), device-to-device (D2D) communication, and mobile crowdsourcing mechanisms. However, there is still a lot of potential for optimization to boost the functionality of web AR applications [18].

5.1 State-of-the-Art Solutions

Pure front-end solutions: AR.js is a popular marker-based MAR solution for quickly executing AR applications on the web, such as identification, monitoring, and 3D object rendering, using WebRTC and WebGL on any mobile device. JSARToolKit is a JavaScript-based AR framework that allows you to generate a 3D representation of a detected marker inside a camera feed in real time by determining the distance between the camera and the physical marker. CaffeJS attempts to conduct neural-network operations (e.g., image recognition) using a modified version of ConvNetJS to convert Caffe models to a web browser, which will save some network traffic and server resources.

Browser-kernel-based extension solutions: These days, a user's first step in connecting to the Internet is through their web browser. Web AR apps may frequently achieve almost natural performance on mobile devices and, as a result, a better user experience by extending the browser kernel to accommodate AR. Browser-kernel-based extension solutions, which are a subset of web AR solutions, rely heavily on browsers to perform the functionality of AR applications. Many browser-kernel-based web AR projects are already in closed beta stages as of right now. The variety of APIs offered by various browser-kernel-based extension solutions, however, would, in contrast, impede the large-scale promotion of web AR apps before the standardization of AR-supported browsers is complete. However, some standardization has already begun. To enable developers to create AR experiences using web technologies, Google is creating the experimental iOS and Android apps WebARonARKit and WebARonARCore. The Mozilla WebXR program, which promises to make it simple for web developers to construct web apps that adapt to the characteristics of any platform, has just been unveiled by Mozilla. A widespread online AR application deployment platform is offered by the AR-supporting web browser Argon4. The JavaScript library argon.js, which Argon implements, attempts to facilitate web AR apps in any web browser. These initiatives seek to give web AR developers a standard environment. But they have not yet been widely used in practice and are still in their infancy [19].

6 AR and EDGE

Over time, EDGE computing has been given several definitions. According to Satyanarayanan et al., "Edge computing is a new computing model that deploys computing and storage resources (such as cloudlets, micro data centers, or fog nodes, etc.) at the edge of the network closer to mobile devices or sensors" [19]. Zha et al. describe it as "Edge computing is a new computing model that unifies resources that are close to the user in geographical distance or network distance to provide computing, storage, and network for applications" [20]. However, the basic idea of EDGE remains the same throughout—to bring computing near the data source. Proximity affects factors such as latency, feasible bandwidth, and survivability.

Need for EDGE-based AR Systems: All of the previous web AR systems have limitations. Pure front-end solutions are inefficient in terms of computing, whereas browser-kernel-based extension solutions seem to be under development and are not generally used. The cloud computing paradigm substantially expands the computational capabilities of terminal devices. Although the cloud computing paradigm expands users' end-device compute and storage capabilities, it introduces substantial delay into the mobile network. MAR applications, on the other hand, need low latency [21–24]. Edge computing offers to scale back network delay by placing apps closer to consumers at the network edge, potentially improving web AR performance. We would be looking into the architecture and performance of two such EDGE-based AR solutions to overcome the current limitations.

EDGE-Based Solution

Working Principle: Qiao et al. proposed a framework consisting of three main components: Terminal, Edge Cloud Server, and Remote Cloud Server. The basic idea is to pass on computationally heavy tasks to the edge cloud for better performance [21].

Terminal Side: The terminal contains the scheduling layer which is responsible for web AR service scheduling. It also contains the processing module, for basic processing, which further contains sub-modules for capturing images, matching images, and rendering a 3D model. Due to the sub-modules using basic algorithms for matching, some images might not be sufficient for the application. This is where edge cloud services come into the picture.

Edge Cloud Side: The edge cloud server will immediately transmit any image-matching requests that it gets from the terminal side to the specific web AR application instance. All web AR applications have access to the AR cache on the edge cloud server. However, the abstract MAR service layer will forward the application deployment request to the distant cloud server if the desired web AR application has not yet been deployed. The decision regarding the deployment of the web AR application is made using the edge server's current performance, including the CPU, memory, and storage utilization. The application service provider (ASP), a remote cloud server, ultimately chooses where a certain program will be put while accounting for the entire deployment and transmission costs.

Another function of the layer is to manage the web AR application objects while the underlying layer contains modules for better working of instances present in the upper layer.

Remote Cloud Side: During deployment decision-making, the overall cost of deployment and transmission is taken into account. According to these decisions, particular web AR resources are combined into web AR applications by resource packaging service layer present in a remote cloud and deployed to an edge server. Successfully matched images are also sent to remote cloud servers from edge cloud servers as the terminal side cannot handle such images for time being.

Performance Evaluation: Theoretical results suggest that edge servers have better computational capability and decrease time requirements compared to the same algorithm being used on the terminal side and increased accuracy of the image-matching process. The algorithm used for matching is far more optimized and the server performs better due to its proximity to users. For matching multiple images, edge provides the great computational capability and shifting the web AR application from remote to edge decreased delay effectively.

Experimental analysis was done on a Samsung Note 4 smartphone, the browser being Chrome and the following results were achieved in terms of latency, fps, power consumption, and the number of matched key points. It was concluded that MEC is more efficient than its counterparts and can be the future of MAR as shown in Fig. 8.

Mobile Augmented Reality Based (MAR)

Working principle: Huang et al. proposed CLoudRid AR, a cloud-based MAR framework to deploy MAR applications. The objective of this framework is as follows:

- Provide built-in modules to give developers uniform interfaces to deploy MAR applications and to simplify work using a predefined task flow along with flexibility in changes using the dynamic registration mechanism.
- Limited battery usage and prolonging battery life by offloading computationally heavy tasks to cloud servers which also eliminates the need for severe hardware or software requirements on mobiles.
- Increase scalability on different handsets using abstract layers. The hardware abstraction layer is used to build upper modules for the diversification of platforms.

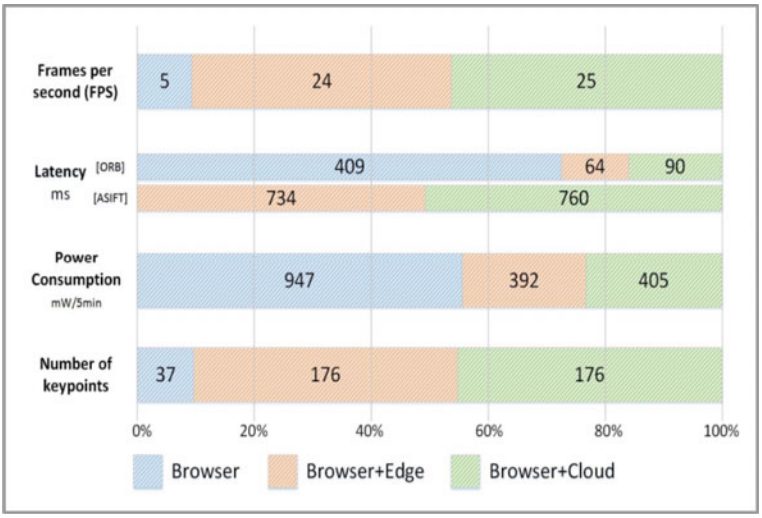

Fig. 8 Experimental results (*Source* IEEE Internet Computing, 2018 p. 53)

The workflow of the framework is predefined; however, its configuration is flexible according to user requirements. The data flow starts with initialization in which registered hardware calls its respective predefined functions to initialize their status. The decision whether to run the most computationally heavy task on the device or cloud is taken by the task allocation mechanism. Offloading tasks have to be synchronized to ensure that outsourced tasks are getting done before the next step. Real environment and rendering objects are mixed and displayed on display devices and open for users to interact with using voice, gestures, etc. [25]. Dataflow of the framework is shown in Fig. 9. The software stack of the framework is shown in Fig. 10.

Performance Evaluation: Two prototypes were successfully developed on this framework. The first one involved a virtual car on a mobile phone running on a real path. It is an immersive game in which players may create a dynamic course to influence how and where the vehicle travels. The second is a multiuser ping pong game. To strike the simulated Ping-Pong ball, participants can choose any solid flat object as a bat. The rendering process is handled on the mobile phone instead of the cloud in both prototypes since virtual content is quite basic and does not involve a lot of computation. Collision detection, as well as rigid body simulation, is conducted in the cloud in the latter prototype. As feature extraction involves significant computational overhead, it typically cannot attain real-time performance on mobile devices because they lack the processing power to complete the computation quickly. We offload the feature extraction to the cloud for processing acceleration by utilizing the cloud computing architecture. For example to direct the movement of the car, the coordinates of recognized line features are transmitted back to the phone and constructed as geometric paths. Users can have direct interactions with cars thanks to

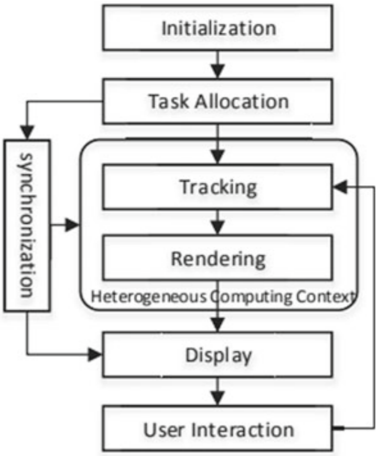

Fig. 9 Dataflow of the framework (*Source* ACM Press, 2014 p. 31)

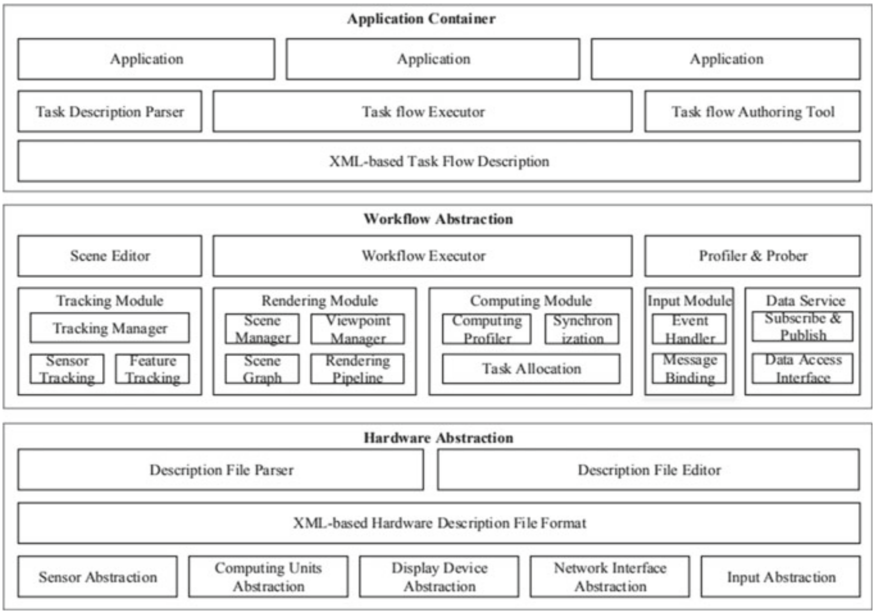

Fig. 10 Software stack of the framework (*Source* ACM Press, 2014 p. 32)

real-time feature extraction on the cloud. Consumption of higher computation power is also caused by high latency. Low latency would lead to inaccuracy. Since mobile devices have much less storage and processing power than AR-oriented devices, MAR faces unique difficulties. Additionally, MAR is projected to conserve battery life given that mobile platforms are used for a variety of daily chores in addition to MAR (such as social network applications and web search).

Alternate Solution: To overcome this, instead of image retrieval and a convolutional neural network (CNN), as was the case in earlier MAR work, we can use visual and inertial 6-DOF localization to recognize and track objects on the screen. By synchronizing the coordinate systems of the cloud and mobile device and being able to distinguish between instances of the same type, 6-DOF locations make it easier for them to work together. By employing heavy and slow local optical flow and cloud offloading selectively while using light and quick local inertial data processing, optical flow is only locally computed when the device collects enough position changes, and pictures are only offloaded when local results need to be calibrated. Due to this, both object recognition and tracking may now be done with latency as low as 100 ms. Low latency allows for the mobile device's energy consumption (including computing and offloading overhead) to be reduced without compromising accuracy. This was proposed by Chen et al. and is known as MARVEL (MAR with Viable Energy and Latency) [26].

7 Future Prospects

Because of its lightweight and cross-platform capabilities, web AR is becoming increasingly popular. We believe that it will provide MAR with a bright future. However, more effort needs to be done to further encourage the use of online AR. On mobile web browsers, computational efficiency for CPU-intensive tasks. For sophisticated computing tasks like matrix and floating-point computation, the commonly used JavaScript performs badly. To achieve the computational efficiency criteria, web browsers will need to implement a more efficient processing paradigm. Although certain sophisticated approaches like Web Assembly and Web Workers are currently implemented in several common web browsers, there remains indeed potential for improvement in terms of end-device compute efficiency. To achieve improved performance, browser-kernel-based extension solutions may make full advantage of end devices' hardware resources. As a web AR solution, we believe it has greater promise. However, there are serious compatibility issues with several current browser-kernel-based extension solutions. Different online AR apps can only be utilized with their browser, which severely restricts the adoption of web AR.

Constrictions in the Network: The latency and bandwidth of the network are critical to MAR. Wireless networks, on the other hand, have a negative effect on the productivity of web AR apps. Despite the fact that contemporary 4G networks are capable of high performance, they are still unable to match the low-latency needs of emerging applications like AR and VR. Nevertheless, there is still a lot of opportunity for improvement in the performance of augmented reality applications which will surely enhance the experience of users in the near future.

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