International Journal for Housing Science and Its Applications
Publish August 6, 2025. Volume 46, Issue 3 Pages 8726-8737

https,//doi.org/10.70517/ijhsa463746

Optimization of Mobile Augmented Reality Experience by Integrating Virtual Reality and 5G Networks

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Abstract Traditional mobile augmented reality (MAR) has limited processing and graphics rendering capabilities, leading to issues such as stuttering, latency, or crashes during runtime, affecting the user experience. By integrating virtual reality (VR) and 5G networks, users can obtain higher quality images, smoother interactions, and lower latency when using mobile devices, further enhancing user perception and optimizing user experience. The dynamic routing algorithm based on Multi-Armed Bandit (MAB) was used to generate network routing strategies, and global network resource routing was controlled and managed for reasonable routing selection and resource allocation, reducing network transmission latency. The average latency of MAR downloading videos of different sizes under 5G was 41.1% lower than that under 4G. The integration of VR and 5G network for MAR experience optimization is of great significance for improving user experience, expanding application scenarios, and reducing network transmission latency.

Index Terms Mobile Augmented Reality, Multi-Armed Bandit, Three-dimensional Registration Algorithm, Virtual Reality, User Experience

I. Introduction

As augmented reality (AR) technology continues to develop and the performance of terminals continues to improve, the perceptual ability of AR has been studied in depth. However, due to the complexity of AR tasks themselves, computationally intensive tasks such as object detection, tracking, and drawing often need to be uploaded to the server, resulting in a large amount of data. However, due to the instability of the network environment, it is difficult for users to achieve good real-time performance during use, and high latency also brings a huge energy burden to terminals. With the rapid development of VR and AR, mobile applications are becoming increasingly popular. The widespread deployment and high-speed transmission capabilities of 5G networks provide better support for mobile VR and AR applications. Combining VR with AR and leveraging the advantages of 5G networks can greatly improve the user experience on mobile devices.

The application of AR technology has received extensive research and industry attention. MAR is one of the most explosive growth areas for AR applications in mobile environments such as smartphones. Zhang Wenxiao introduced a collaborative framework for expanding multi user AR experiences. Most AR systems benefit from computer vision algorithms to detect, classify, or recognize physical objects for enhancement. However, when offloading AR tasks from a large number of concurrent users to the edge, end-to-end latency may sharply increase [1]. The technological advancements in smartphones, tablets, and smart glasses hardware have provided advantages for the widespread use of MAR in the real world. However, the mobile nature of AR applications limits users' interactive capabilities. Bermejo Carlos analyzed the current research issues in the field of human-computer interaction and introduced human perception ability and its applicability and challenges in AR applications [2]. With the continuous development of mobile media research, people are paying attention to new developments and trends in mobile technology. One area of interest is MAR. Liao Tony identified some early media, communication, and social science research on MAR, and suggested that researchers adopt new methods to explore the interrelationships between different fields [3]. Some technologies are easily adopted in museum exhibitions, such as audio, video, and touch screen interaction, while others are not easily adopted, such as holography and AR. Marques Diana studied the issues and challenges typically involved in using AR technology in exhibitions, and applied case studies from the Natural History Museum to evaluate the authenticity of this particular technology. The results suggested that AR can deliver a high return on user experience, but as with any technology, there are a number of associated challenges that should be considered before employing AR as a user experience [4]. AR technology increases human perception of the world by combining real environments with virtual spaces, but relying on AR alone cannot provide a better user experience.

MAR is growing in popularity with the explosion of powerful, affordable mobile devices and the emergence of complex communications infrastructures. The emerging 5G communication technology is a key driving factor for future MAR applications to achieve ultra-low latency and extremely high data rates. Siriwardhana Yushan discussed MAR's requirements for 5G communication, mobility management, business offloading and migration, security, and privacy through 5G mobile devices and complementary technologies [5]. Traditional two-dimensional e-commerce websites aim to provide a simple browser based interface, allowing users to access available products and services. However, most virtual presentation websites have shortcomings in imitating human representations in real life. Billewar Satish Rupraoji aimed to introduce three-dimensional e-commerce technology, which demonstrated how VR and AR can help handle restrictions and improve e-commerce operations, and used on various computing platforms, including desktops and mobile devices. It was found that the experience of virtual stores was also enhanced by AR assistants, who provided users with all the information they need through audio or using their virtual images [6]. Hardware based MAR and application based MAR are the two main platforms for MAR applications. However, the implementation cost of hardware based MAR is high and lacks flexibility, while application based MAR requires additional download and installation, and is not convenient for cross platform deployment. Qiao Xiuquan proposed to improve the communication efficiency of network based AR intensive computing on mobile devices through 5G mobile communication networks, enriching the way users interact with the surrounding world [7]. MAR allows users to run AR applications on mobile devices, with higher mobility and lower costs.

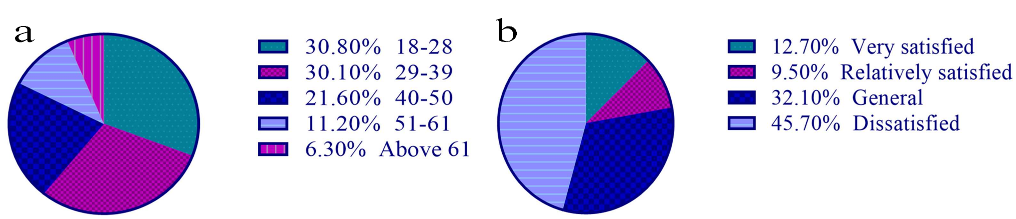
The fast growth of mobile computing and network technologies has led to the increasing research and application of VR and AR technologies on the network and various mobile devices. This article integrated VR into MAR and utilized mobile cameras and sensors to obtain real-time data of the user's current environment. The real-time detection and animation rendering of 3D registration algorithms were utilized to achieve an organic combination of real and virtual images, and were presented in a fusion world where users can interact, thereby improving the user experience. By detecting and drawing real-time images in the cloud, and adding virtual elements such as special effects to these realistic images, these virtual images were combined with real scenes and broadcasted to other participating users, bringing better user experience. MAR technology is increasingly receiving attention from academia and industry, with the aim of seamlessly integrating computer-generated virtual information with the real world observed by users to enhance their visual experience, making their interactions with the real world more intuitive and realistic.

II. Optimization Based on 5G Network

II. A. Current Situation of MAR Experience

MAR is a new technology developed on the basis of VR technology. The purpose of MAR is to integrate computer-generated virtual information into real scenes, increase people's visual experience, and make people's interaction with the real world more intuitive and realistic [8], [9].

Smartphones are a highly promising AR application platform. The opening and operation of the network has greatly increased the number of smartphone users and promoted the development of smartphones. AR applications based on smartphones have broad application prospects [10], [11]. This article conducts a survey and analysis on 500 users of different age groups who have used MAR related applications. The current usage and satisfaction of MAR are shown in Figure 1.



(a): Usage (b): Satisfaction situation

Figure 1: Usage and satisfaction of MAR

As shown in Figure 1: Figure 1 (a) reflects the user base of MAR. The user base of MAR is mainly young users aged 18-28, followed by users aged 29-39. As age increases, the number of people using new technologies decreases. Figure 1 (b) reflects users' satisfaction with using MAR, with the highest proportion of dissatisfaction being 45.7%.

The survey of user experience status is shown in Table 1.

Table 1: Experience status survey (multiple choice)

Reason	Proportion (%)	Reason	Proportion (%)
Poor visual effect	43.30	Energy consumption and heating problems	58.49
Run slowly	51.17	Unstable data connection	51.76
Low interactivity	46.08	User privacy	43.14
Low positioning accuracy	48.82	Low participation	59.59

As shown in Table 1, the proportion of issues such as poor visual effects, slow running speed, and low interactivity in the user experience is over 40%, indicating that these are all factors that affect the user experience.

MAR is an important direction in the development of AR technology, which effectively applies AR technology to mobile device terminals, in order to apply AR technology to a wider range of fields [12], [13]. As computer software and hardware technologies have developed rapidly in recent years, some small mobile devices have become more and more rich in functions, with touch screen, positioning, Bluetooth communication, gravity sensing, acceleration sensing, video camera and other functions, as well as high computing power and processing capacity, and integrates a variety of related technologies and modules needed for mobile augmented reality, which lays the foundation for the development of MAR based on mobile terminals [14], [15].

II. B.5G Network Support

The frequent operation of MAR results in a large amount of data being transmitted end-to-end, especially downloading high-quality AR images from the server generates a large amount of data [16]. By utilizing the high-speed and low latency characteristics of 5G networks, real-time data transmission and processing can be achieved, ensuring smooth operation of AR applications and high-quality user experience.

The traffic in the network changes with the changes in business requirements, and static routing allocation methods can no longer meet the specific needs of network services. Different network users have different network requirements, including ultra large bandwidth, ultra-low latency, low packet loss rate, etc. It is necessary to ensure the quality of network service, improve the balance ability of network transmission links, and dynamically route and allocate transmission flow paths to the network. In a network topology, there are many different transmission paths, with each path having different bandwidth, latency, and packet loss rate for transmitted data.

II. C.MAB Based Dynamic Routing Algorithm

The MAB based dynamic routing algorithm (MAB algorithm) is an algorithm used to optimize network traffic allocation. It draws on the ideas of multi-armed bandit problems and dynamically adjusts routing choices by continuously exploring and utilizing different paths or strategies to maximize mobile performance. The algorithm can achieve reasonable routing selection and resource allocation based on network resources, achieving good network performance.

When personalized network requests arrive, the behavior of multi-armed bandit continuously detects different connected routes, ultimately obtaining the optimal route, which is then sent to the switch for routing decisions. The software-defined networking (SDN) routing framework based on multi-armed bandit is shown in Figure 2.

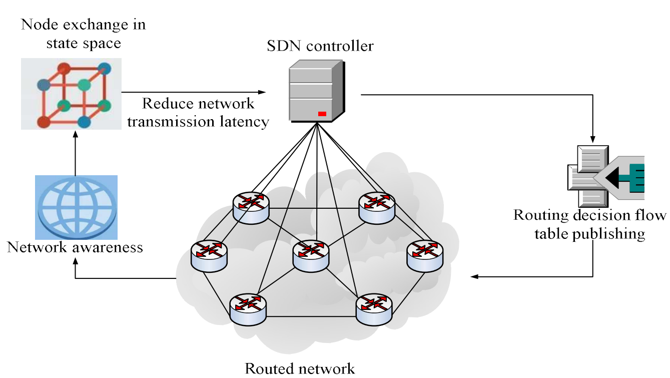


Figure 2: SDN routing framework based on multi-arm bandit

As shown in Figure 2, the SDN controller publishes the routing decision flow table, perceives the network through the routing network, and exchanges nodes in the state space, effectively reducing the network transmission delay.

According to the network business attributes required by users, the SDN controller can dynamically and intelligently allocate appropriate routing paths for each data flow. In the SDN network environment, a network routing model is constructed to provide high-performance transmission paths for different network requirements. While meeting the quality of network service, it is necessary to ensure the utilization of the lowest load link in the network and reduce latency. The MAB algorithm can monitor the distribution of network topology resources and the status of selectable paths for network service forwarding by introducing an SDN controller.

On the basis of implementing network business functions, it is necessary to improve link load balancing as much as possible while reducing network routing transmission delay, as shown in Formula (1):

$$\lambda \max load_{ij} = (1-\lambda) \sum_{(ij)\in E} a_{ij}^{k} \cdot d_{ij} \tag{1}$$

In Formula (1), $load_{ij}$ represents the bandwidth utilization of the link; $\sum_{(ij)\in E} a_{ij}^{k} \cdot d_{ij}$ represents the product of path delay accumulation; adjusting parameter λ can indirectly adjust the link routing selection to focus on link load. The main constraints are:

$$\sum_{(ij)\in E} a_{ij}^{k} \cdot d_{ij} \le D^{K}, \forall k \in K \tag{2}$$

The set of finite state networks is represented by T, and the set of finite state actions is represented by S. State, action, and reward functions can be independently learned and constructed based on strategies to construct functional relationships:

$$T \times S \to T(S) \tag{3}$$

$T(S)$ is used to express the probabilities of S being in their respective states. After applying actions to the network environment, the network environment returns the reward function value based on the actions, and a relationship can be constructed as shown in Formula (4):

$$T \times S \to R \tag{4}$$

The mapping function between state and action values represents the value between state and action pairs, and represents the difference between the current reward state and the stable state, as shown in Formula (5):

$$Q(s_t, a_t) = \alpha * R(s_t, a_t) + (1-\alpha) * \sum_{k=1}^{t-1} R(s_k, a_k) \tag{5}$$

The learning factor is represented by α, and $R(s_t, a_t)$ is used to express the reward function at time point t. The action by which the agent may obtain the maximum Q value based on the action. At time t, the agent obtains the current state. After making a decision to execute action a_t, the agent can receive new rewards and update the state to s_t. After taking action, the feedback loop uploads the reward function $R(s_t, a_t)$ at time t and updates the action value function $Q(s_t, a_t)$ based on the reward function $R(s_t, a_t)$ mentioned above.

After the above cycle, the intelligent agent selects the optimal strategy $Q^{*}(s_t, a_t)$ based on the optimal return among each strategy. The solution formula for the optimal strategy can be expressed by Formula (6):

$$Q^{*}(s_t, a_t) = \max_{a\in A} Q(s_t, a) \tag{6}$$

The MAB routing algorithm is compared in terms of network transmission delay under different data volumes with and without link rewards. The comparison results are shown in Figure 3 (where the horizontal axis represents the amount of data and the vertical axis represents the time delay, in milliseconds (ms)).

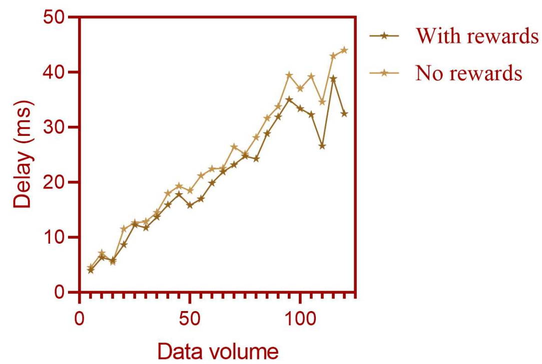


Figure 3: Network transmission delay under different data volumes

As shown in Figure 3, as the amount of network transmission data increases, the network transmission delay of the MAB routing algorithm also increases, but overall it remains within 50ms, and the delay changes little with and without rewards.

In the process of finding the optimal route, MAB are an efficient algorithm that can efficiently complete ultra-low latency, high throughput, and dynamic routing. The network controller of the software defined network makes routing decisions over a discrete period of time, determining whether to allow or reject access requests for routing based on existing network conditions.

III. Optimization Based on VR

III. A. 3D Registration Algorithm

In MAR, due to the relative position between the camera and virtual information, it is necessary to calculate the camera's pose in real-time to determine the correct registration position of the generated virtual information in the real scene. This is a function implemented by tracking and registration technology in MAR [17], [18]. In MAR, display technology is the foundation for achieving AR, and tracking and registration technology is the key to achieve AR. The quality of registration technology directly affects the success of AR. Therefore, studying 3D registration algorithms is of great significance [19], [20].

Markup based 3D registration technology is a tracking registration technology based on computer vision, which is built on the foundation of computer technology and graphics and image processing technology.

The improvement of the 3D registration algorithm aims to improve the performance of the 3D registration system and reduce its registration error rate. The pixel coordinate (u,v) of any point on the coordinate of the marker on the two-dimensional imaging plane, as shown in Formula (7):

$$u = \frac{f\left(Z_r r_{11} + Y_r r_{12} + Z_r r_{13} + u_{11}\right)}{u_0} \tag{7}$$

Feature matching refers to evaluating the similarity of two feature point neighborhoods through correlation functions (usually multiple distance functions), in order to determine the corresponding points. The feature vector is the nearest neighbor of the feature point. Therefore, by comparing the similarity of feature vectors, possible matching points can be obtained.

In practical applications, Euclidean distance is used as a similarity measure for feature vectors. For two frame images, feature points and feature vectors are calculated separately, and priority search is performed to find the two closest feature points for each feature point. The Euclidean distance from this feature point to two adjacent feature points is calculated:

$$D = \sqrt{\sum_{i=1}^{N} \left(V_{1i} - V_{2i}\right)^2} \tag{8}$$

Among them, D is the Euclidean distance between feature vectors V_{1i} and V_{2i} with a length of V. If the ratio of the closest distance to the next closest distance is less than the set threshold, the matched feature points are accepted, and finally the incorrect matching is eliminated to obtain a correct and stable feature point matching.

By using the homography matrix and the camera intrinsic parameter matrix, the translation vector T can be obtained:

$$T = \lambda C h_i \tag{9}$$

h_i is the column vector of the homography matrix.

Gaussian filtering is the most time-consuming operational step in constructing Gaussian scale spaces. According to the separability of Gaussian convolution, Gaussian filtering is also divided into two stages. The one-dimensional filtering in the horizontal and vertical directions is used to replace the two-dimensional Gaussian filtering. For images $I(x,y)$ and $Gx,y(t)$, the convolution operation is performed, and the next layer of images is obtained. The horizontal filtering is performed first, and then the vertical filtering is performed:

$$L(x,y) = I(x,y) * Gx,y(t) \tag{10}$$

After secondary filtering of the image, the next layer of Gaussian grayscale image is obtained and stored in the texture unit channel, thereby saving time for accessing textures.

The main problem solved by AR and VR technology is how to accurately integrate computer-generated 3D models with the actual scene captured by the camera, thereby achieving effective fusion of real scenes [21], [22]. From the 3D model library, the virtual enhanced model corresponding to the target object is found, and then mapped onto the camera's projection surface according to the camera's projection matrix. This image is combined with images in actual space to obtain the final virtual real fusion scene and output [23], [24].

III. B. Environmental Perception Improvement

After identifying the video images of the actual scene, the external parameters of the camera are obtained by calculating the posture of the phone. In terms of tracking and registration, mobile devices are detected through tracking, positioning, and calibration methods, and transmitted to AR devices to unify their coordinates with the real environment, thereby seamlessly integrating virtual information with the real environment [25], [26].

How to detect the position and direction angle of the mobile phone relative to the real scene in real-time, so as to determine the correct position of the virtual information to be added in the real world and conduct human-machine interaction based on this information, is the task that MAR registration needs to complete [27], [28].

The coordinate conversion between camera coordinate system $\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix}$ and marker coordinate system $\begin{bmatrix} X_r \\ Y_r \\ Z_r \end{bmatrix}$ reflects the position and direction of the camera relative to the marker in the real scene, determining the camera's posture. The mapping relationship between a point in the camera coordinate system and its mapping point in the marker coordinate system is shown in Formula (11):

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & u_{11} \\ r_{21} & r_{22} & r_{23} & u_{21} \\ r_{31} & r_{32} & r_{33} & u_{31} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_r \\ Y_r \\ Z_r \end{bmatrix} \tag{11}$$

In order to reduce the measurement angle error and other unexpected errors, an effective rotation matrix is obtained to generate the best approximation of the transformation, and it is necessary to ensure the orthogonal standardization of the rotation matrix. According to the characteristics of orthogonal matrices, the matrix must satisfy Formula (12):

$$r_{11}^2 + r_{21}^2 + r_{31}^2 = 1 \tag{12}$$

Both matrix r_{11}^2 and matrix r_{31}^2 are determined by the direction and position of the camera relative to the marker coordinate system. Therefore, the matrix is the external parameter of the camera, that is, the camera's attitude. The tracking result is matrix r_{21}^2.

When the images captured by the camera are input to the computer for image processing, they are measured in pixels. Therefore, it is necessary to obtain the conversion relationship between the position coordinates of points on the two-dimensional imaging plane and the pixel coordinates.

Assuming that the pixel coordinates of a point on a two-dimensional imaging plane are (u, v); the pixel coordinates of the origin are (u_0, v_0); each pixel has a size of dx on the horizontal axis and dy on the vertical axis, the relationships between its position coordinates and pixel coordinates are:

$$u = \frac{x}{dx} u_0 \tag{13}$$

$$v = \frac{y}{dy} v_0 \tag{14}$$

When a user moves inside a building, the Bluetooth positioning module on the mobile end allows the user to locate their current position for human-computer interaction, regardless of their location inside the building, and record their movement trajectory inside the building [29], [30]. When the user moves on this trajectory again, the mobile end compares the previously recorded trajectory information with the current information and analyzes the position coordinates in the same trajectory. New position coordinates are added, and incorrect position coordinates are modified. The modified trajectory information is saved in the mobile terminal for future use.

When a user moves within a certain floor, the mobile phone camera is aimed at the floor passage. If there are markers in the scene information captured by the mobile phone camera, the mobile end generates corresponding enhanced information and overlays it in the real scene for interaction [31], [32]. The staircase guide information is shown in Figure 4.

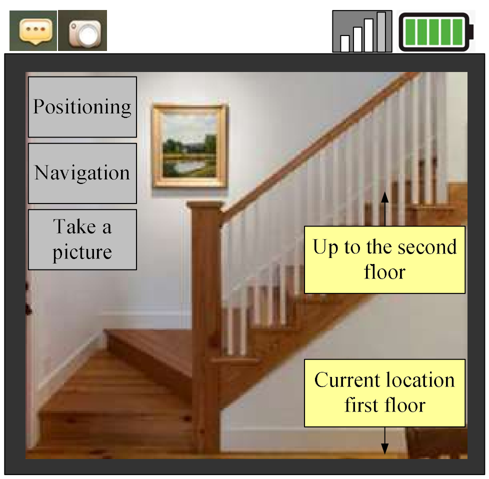


Figure 4: Stairway guide information

When the user passes through intersections, steps, and other intersections, the mobile camera is aimed at the intersection or steps, and the actual scene image information obtained by the camera is used for detection. Figure 4 shows the second floor upwards.

When a sign is detected, the mobile terminal detects and calculates the current pose of the sign, determining the registration location of the virtual information. The virtual information is registered and output to the user's mobile screen for easy browsing.

Users follow the floor guidance information displayed on their mobile phone screen to take action. Before arriving at a specific room, they only need to point their phone camera towards the room to obtain information about the room. The actual scene in the indoor environment obtained through the mobile terminal is used to detect whether there are labels in the indoor environment through the mobile terminal. If there is a logo, the mobile end would output an enhanced image combining virtual and real to the user's mobile screen. Users can learn the current room number and personnel information in the room by following the wizard information on their mobile phone screen. They can also press the location key to obtain the current location information.

IV. Optimization Effect Experiment

IV. A. Real-time Performance

With the popularization and development of MAR, users have also put forward higher requirements for MAR, such as faster response and better user experience [33], [34]. This further increases the energy consumption of mobile devices for computationally intensive tasks such as target recognition and animation rendering in MAR, and the unstable network environment still cannot guarantee the real-time performance of MAR applications [35]. This article conducted comparative experimental analysis between mobile devices that have not integrated VR and 5G networks (MAR before optimization) and those that have integrated VR and 5G networks (MAR after optimization).

The time delay between user interaction and mobile response was measured. Low latency is crucial for AR applications to ensure that users feel immersive. The time delay for downloading videos of different sizes (30MB, 60MB, 90MB, 120MB, 150MB) on 4G and 5G networks is shown in Table 2.

Table 2: The time delay for downloading videos of different sizes on 4G and 5G networks (ms)

Video size and average	4G	5G	Difference value
30	20.89	14.94	5.95
60	19.59	11.00	8.59
90	22.29	11.54	10.75
120	21.35	10.20	11.15
150	17.47	12.12	5.35
Average	20.32	11.96	8.36

As shown in Table 2, the average latency of MAR downloading videos of different sizes under 4G was 20.32ms, while the average latency of MAR transmitting videos of different sizes under 5G was 11.96 ms. The average latency of MAR downloading videos of different sizes under 5G has increased by -41.1% ($\frac{11.96\text{-}20.32}{20.32} = \text{-}41.1\%$) compared to the average latency of MAR downloading videos of different sizes under 4G, which was 41.1% less.

IV. B. Smoothness

The smoothness scores of MAR before and after 50 optimizations by the same user are shown in Figure 5 (the horizontal axis represents the number of operations, and the vertical axis represents the score).

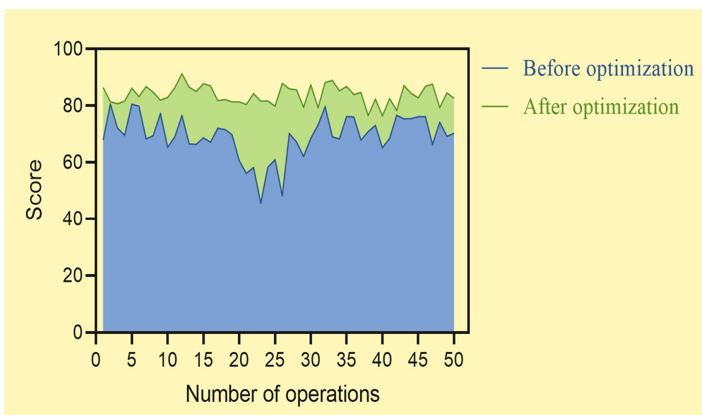


Figure 5: Smoothness rating of MAR before and after optimization

As shown in Figure 5, the fluency score of the optimized MAR operation was mostly above 80 points, while the fluency score of the pre optimized MAR operation was mostly below 80 points.

The optimized MAR can ensure image quality, ensuring user experience during the corresponding data transmission process while reducing the amount of data transmitted, thereby reducing response latency and improving smoothness. Due to differences in user experience, the optimized MAR not only reduces costs for each user, but also provides personalized services for users.

IV. C. User Experience

The basic experience is mainly related to the devices and tools used by users, such as the availability of devices or tools, product performance, support for user activities, etc., including usefulness, efficiency, and significance. Cognitive experience is related to human thoughts, information processing, and reasoning abilities, which originate from the semantic features of AR on mobile devices and the ability to arouse users' curiosity and satisfaction with knowledge. Sensory experience is related to instinctive and non sensory related experiences, such as the pleasure of touch, which mainly refers to the ability of products or services to mobilize sensory and physical pleasure, immersion, confusion, visual, tactile, auditory, and aesthetic abilities. Emotional experience is related to the subjective emotional reactions of users when using mobile devices to enhance reality, such as pleasure, entertainment, and memory arousal.

The user experience scores of MAR before and after optimization are shown in Figure 6 (the horizontal axis in Figure 6 represents basic experience, cognitive experience, sensory experience, and emotional experience, while the vertical axis represents scores).

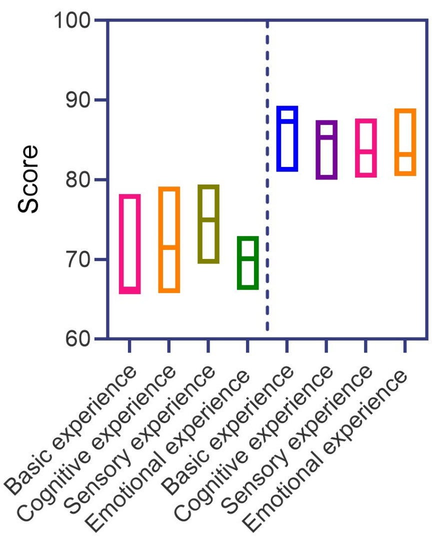


Figure 6: User experience rating of MAR before and after optimization

As shown in Figure 6: the left side of Figure 6 showed the user experience rating of MAR before optimization, with the overall rating of basic experience, cognitive experience, sensory experience, and emotional experience being within 80 points; the right side of Figure 6 was the user experience rating of optimized MAR, with an overall rating of over 80 for basic experience, cognitive experience, sensory experience, and emotional experience.

AR technology presents not a single scene, but a fusion of specific scenes and feelings, which minimizes the unnecessary mental labor required for users to switch between computer screens and the real world. In other words, AR technology integrates computer interfaces with the real world as a whole.

IV. D. User Engagement

In a large area of unknown scenes, mobile AR allows users to determine their orientation and perspective through the sensors they wear, and overlay them with the surrounding environment images captured by the camera. Mobile AR should have the following characteristics: AR is placed in the physical world; the user's line of sight only depends on the position and orientation of the user's head, and can display information related to the user; mobile devices can be used both indoors and outdoors.

The frequency of user interaction with AR content was measured, including touch, gesture, and voice input. The user participation situation is shown in Table 3.

Table 3: User participation (multiple choice)

Classification		Touch	Gesture	Voice input
Before optimization	Number of interactions	35	29	31
	Number of Voluntary withdrawal people	8	5	9
After optimization	Number of interactions	56	68	64
	Number of Voluntary withdrawal people	2	1	3

As shown in Table 3: before optimization, the interaction times of user touch, gesture, and voice input in the MAR experience were all within 40 times, while after optimization, the interaction times of user touch, gesture, and voice input in the MAR experience were all above 50 times.

Mobile applications that integrate VR and 5G networks can meet user needs and are no longer limited to specific hardware devices or spatial environments. Whether outdoors or indoors, high-quality services can be enjoyed.

IV. E. User Satisfaction

In order to understand user satisfaction in the actual use of MAR, surveys were conducted on user satisfaction in the fields of advertising, information browsing, museums, navigation, and gaming. User satisfaction in different fields is shown in Figure 7 (the horizontal axis represents satisfaction level, and the vertical axis represents percentage).

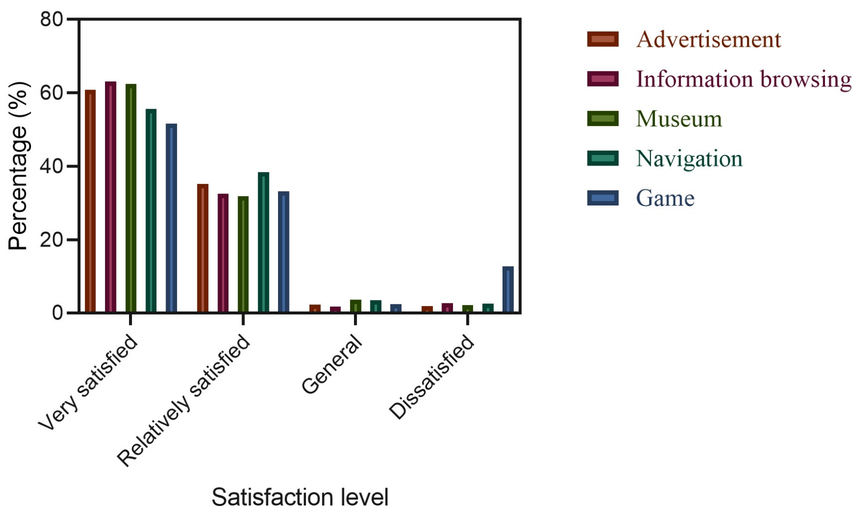


Figure 7: User satisfaction in different fields

As shown in Figure 7: in the fields of advertising, information browsing, museums, navigation, and gaming, most users were very satisfied, exceeding 40%.

V. Discussion

Table 2 shows that the average latency of MAR downloading videos of different sizes is higher under 4G. Massive amounts of data need to be transmitted between the cloud and mobile devices, and the instability of network state prolongs the response time of MAR applications, resulting in high latency and energy consumption from downloading and rendering images from the cloud to the mobile device, seriously affecting the user experience.

The delay on the mobile end is mainly end-to-end delay. The implementation of MAR is the result of multiple processes working together, and each process requires a certain amount of time, which increases the end-to-end latency of the mobile end. For some mobile devices with simple structures and fewer processes, due to the limited end-to-end transmission, the delay time of the mobile device is smaller. In some complex AR mobile devices, due to the large amount of end-to-end transmission and the need to load a large amount of data or information during mobile operation, some even have to work in a network environment, the delay time of the mobile device increases.

Figure 5 illustrates that integrating VR and 5G networks can improve the smoothness and user experience of MAR applications. 5G networks have higher bandwidth and lower latency, enabling faster and more stable data transmission compared to 4G networks, which is crucial for AR applications. The accuracy and real-time nature of data are crucial for user experience. VR applications require a large amount of computation and transmission of high-definition images and videos, while the higher bandwidth and lower latency of 5G networks allow for higher quality image transmission, making the visual effects of AR applications more realistic and clear. In VR applications, a large amount of real-time computing is required, and the higher speed and lower latency of 5G networks can enable mobile devices to respond more quickly to user operations, improving the interactivity and smoothness of AR applications.

Figure 7 shows that most users are very satisfied. MAR has become the backbone of AR applications due to the convenience of mobile devices. Most satisfaction experiences mainly come from the novelty of location-based content and interaction, and the practicality and ease of use of MAR also have a significant impact on user satisfaction experiences.

VI. Conclusions

With the continuous development of mobile devices and network technology, VR and AR technology are becoming important trends in mobile application development. The integration of VR and 5G networks can further improve the smoothness, real-time performance, and user experience of MAR applications, thus having broad prospects and application potential. The dynamic routing algorithm based on multi-armed bandit can effectively optimize network traffic allocation, improve user experience, and reduce congestion. It is very important to combine VR with 5G networks. VR technology can provide users with an immersive experience, while 5G networks can provide higher quality images and faster response times. By integrating VR and 5G networks, more realistic, smooth, and interactive AR applications can be created, which greatly promotes the development and progress of mobile devices and network technology.

Funding

This work was supported by the Education Research and Teaching Reform Project of the Institute of Disaster Prevention (JY2024B22); This work was supported by Innovation Ability Training Program for Master's Students in Hebei Province (CXZZSS2024161).

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