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A Framework for Adopting Enhanced Augmented Reality Technology through Edge Computing: A Case Study of Yemen

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Abstract

As technological advancements accelerate globally, it is crucial for emerging markets like Yemen to keep up with these changes to make the most of modern technology. In particular, Augmented Reality (AR) technology offers significant potential to improve operations across sectors such as education, healthcare, trade, and tourism. Yemen, despite its developing position in the telecommunications and information technology sectors, is experiencing a recovery in computing services, driven largely by policies that promote local data centers to ensure information security. This proximity to data storage and processing facilities provides a unique opportunity to implement AR more efficiently and effectively. This paper proposes a framework for adopting AR technology using Edge Computing (EC) in Yemen. EC technology allows data to be processed and stored closer to end users, reducing the need to rely on remote data centers and ensuring unique interactive immersive experiences. The proposed framework was built using two established models: The Technology Acceptance Model (TAM) and The Unified Theory of Acceptance and Use of Technology (UTAUT2), informed by on-the-ground insights from key technology and telecom entities in Yemen. The research results showed that Perceived Usefulness and Facilitating Conditions received the highest scores (5/5), indicating their critical role in the adoption of edge computing, while Ease of Use and Social Influence scored lower (3.5/5) due to existing technical and societal limitations.

Article Info

Keywords:
Augmented Reality, Edge Computing, Cloud Computing, TAM Model, UTAUT2 Model, Mixed-Methods Approach.

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1. INTRODUCTION

1.1. Background

With the rapid technological development, driven by advanced technologies that have reshaped the way people interact with the world around them, Augmented Reality AR has emerged as a promising technology, providing immersive experiences that blend digital information with the real world [1]. Similar to what robots has done, where robots are able to impact on many applications such as industrial manufacturing, healthcare transportation, and so on [2]. However, for AR applications to perform optimally, they require low latency and fast data processing capabilities, which are essential for smooth interaction and real-time updates [3]. This is where EC comes in to provide innovative solutions that contribute to enhancing the user experience and expanding the scope of AR applications [4, 5]. It offers a potential solution to these challenges by processing data closer to the end user, reducing dependence on remote cloud servers, thus improving response time and reducing latency, enabling smoother and more immersive AR experiences [6]. However, in Yemen, the adoption of AR has been considered limited despite its potential [7].

This is largely due to the emerging nature of the local technological environment. This is normal because the financial and business environment in Yemen, despite its persistent attempts to keep pace with technical

progress and raise the level of reliance on technology to improve performance and benefit from the advantages of technology, these attempts are still insufficient due to the weakness of internet services and the difficulty of providing technical equipment due to the political and economic conditions imposed on Yemen at the present time [8].

1.2. Problem Statement

Despite the global momentum towards AR adoption, Yemen, due to its unique circumstances, has yet to embrace this immersive technology [5]. Nevertheless, Yemen's technological system presents both opportunities and obstacles, so this paper aims to address the current problem: How can Yemen embrace AR technology given its unique circumstances? However, many sectors in Yemen, such as education, healthcare, and tourism, can significantly benefit from enhanced AR solutions, especially when integrated with edge computing to improve service delivery and develop the digital economy [6].

The main question this paper seeks to address is: What are the key factors that influence the adoption of enhanced AR technology in Yemen, and how can edge computing be leveraged to improve its performance?

1.3. Research Objectives

This paper aims to:

- D Develop a framework that integrates TAM and UTAUT2 to facilitate the adoption of AR technology through edge computing.
- Assess Yemen's readiness to adopt AR and identify the steps needed to implement it successfully.
- Provide recommendations for policymakers, businesses, and technology providers for the implementation of AR using edge computing in Yemen.

1.4. Research Significance

This paper is significant because it addresses the gap between AR's potential and its actual adoption in an emerging market, like Yemen. By focusing on both the technical and regulatory challenges, this paper offers a holistic view of what is needed to facilitate AR adoption. The framework developed in this paper will serve as a blueprint for organizations in both public and private sectors looking to adopt AR technologies in environments where edge computing infrastructure is still developing.

1.5. Research Scope

This paper focuses on assessing Yemen's readiness to adopt AR technology by integrating EC to enhance performance. The study is centered around evaluating the technological infrastructure and readiness of the country through a detailed analysis based on field visits and interviews with key institutions, including technology companies, Internet service providers, cloud computing providers, and the Yemen Telecommunications Corporation. To define and analyze the scope of the research, the mixed exploratory approach was adopted, combining qualitative expert interviews with quantitative sectoral analysis. This approach combines utilizing both qualitative insights (e.g., interviews, expert opinions) and quantitative data (e.g., percentages for sectoral involvement) and exploratory nature, which aim at discovering and understanding new or under-researched areas [9], such as assessing Yemen's readiness for adopting AR with EC.

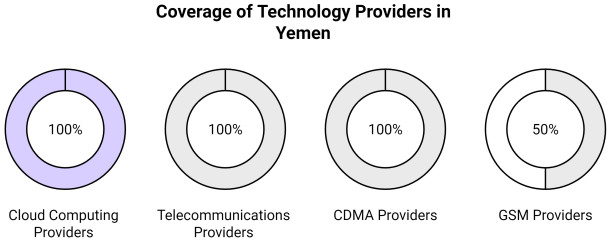

Figure 1. Research Scope

The paper covers the following entities, classified with sectoral involvement percentages and company names:

Cloud Computing Providers (fully covered):
100%
YemenNet
Sohobcom

Telecommunications Providers (fully covered):
100%
TeleYemen

CDMA Providers (fully covered):
100%
Yemen Mobile

GSM Providers (partially covered):
50%
YOU (covered)
Sabafon (not covered)

Internet Service Providers (ISPs) (Fully covered):
100%
YemenNet
Yemen Telecommunications Corporation

These percentages and company names reflect the comprehensive coverage and expert input from representatives in each sector, ensuring the research encompasses diverse perspectives from Yemen's key technology providers. The following figure, figure 1, describes the research's scope.

A key driver of this research is Yemen's information security policies, which limit the reliance on foreign data

centers. This regulation has accelerated the growth of local data centers, creating a unique opportunity for AR applications to thrive by leveraging the proximity of servers to end users [7]. This infrastructure could provide the foundation for a widespread AR ecosystem, offering significant benefits to sectors such as education, healthcare, commerce, and tourism, whose smooth and systematic implementation is ensured by the proposed framework.

2. LITERATURE REVIEW

2.1. Emerging Markets Potential of Augmented Reality

Augmented reality presents itself as a growing technology holding an enormous application base across diverse sectors, including education, medicine, trade, and tourism. AR involves the projection of digital information directly onto the physical, actual world, which provides a living, breathing experience. This generally improves value-oriented decision-making and operational effectiveness. Recent studies discuss AR's impact in developing economies. Research in [10] emphasized that introducing AR into education and healthcare within developing countries can significantly enhance their service provision [7]. The key challenges identified in the way forward involve the technological gap of infrastructure in AR adoption. Similarly, many researches pointed out that the adoption of AR in emerging markets, including the ability for low-latency data processing, which is very important in real-time applications such as AR, still faces limiting factors [11, 12]. In Yemen, even though its telecommunications and IT sectors are growing, there is still substantial potential to implement AR in order to enhance essential sectors. Recovery of computing services, especially establishment of local data centers, is going on presently and forms a very good base for the adoption of AR [13].

2.2. Edge Computing as a Solution for AR Latency Issues

Latency issues are one of the biggest technical setbacks that most AR applications face in operation. AR indeed requires fast data processing with minimal delay between the interaction of a user and the system response to offer a smooth and pretty seamless experience [5]. Traditional cloud computing, however powerful, often suffers from latency due to distances between data centers and end-users [14]. This has been particularly challenging in underdeveloped regions around the world with inadequate internet infrastructure. MEC was one such proposal that aimed at handling the latency problem by providing data processing closer to end-users. Recently, researchers in [15] showed that MEC can greatly reduce AR response times by bringing computation and storage closer to the edge of the network. Their results clearly showed that reducing the number of hops between the user and one of their data centers improves overall AR quality. Similarly, the outcomes in [16] confirmed that MEC allows for real-time processing of data, which is fundamental for AR applications in hostile connectivity, whereas Yemen has within it plenty of potential because of efforts lately to increase the localizing data centers and computing facilities. This proximity to users can sometimes enable AR applications to overlook latency issues and provide a smoother user experience.

2.3. Technology Acceptance Models: TAM and UTAUT2

In the domain of technology adoption, there are two theoretically recognized models: TAM and UTAUT2. Both of the models set a framework for analyzing major factors that determine the adoption and use of new technologies [17]. TAM, developed by Davis in 1989, argues that there are two key factors governing the acceptance of technology among users. These consist of perceived usefulness and perceived ease of use [18]. In [19] researchers have concluded through numerous studies that these two factors are referred to as the two continually effective factors that explain technology adoption through various contexts, including mobile and cloud-based services. [20] is a study on the adoption of Metaverse Technologies in the Middle East, report that perceived usefulness is a critical factor in ensuring that new technologies are going to be adopted in this region. On the other hand, UTAUT2, which stands as a super-set over the original UTAUT model by considering social influence, facilitating conditions, and hedonic motivation, makes it more useful for the explanation of consumer-oriented technologies like AR. Researchers in [21] reported that UTAUT2 could report up to 70% variance in users' intentions toward the adoption of new technologies.

In summary, the literature finds that latency is one of the most fast-growing concerns for AR. By using EC to bring the processing closer to customers, this would be able to guarantee improving real-time performance. Furthermore, through TAM and UTAUT2, an established environment has been determined that knows the factors affecting the adoption of any new technology. If Yemen follows the same path as these countries, it can expect analogous results.

3. METHODOLOGY

3.1. Research Design

The paper adopts a mixed exploratory approach, using qualitative and quantitative methods to assess Yemen's readiness to adopt AR technology via EC. It focuses on understanding technological and human issues, drawing

on lessons from TAM and UTAUT2 [22, 23]. This paper is based on data obtained from visits and interviews with key stakeholders in Yemen's technological sectors, with an emphasis on cloud computing, telecommunications, and internet services.

3.2. Data Collection

The data collecting strategy consisted of two core activities: field visits and expert interviews.

Field visits were done at significant institutions in Yemen's telecommunications and technology industries. These visits were intended to evaluate the technical infrastructure and capabilities available for AR adoption through EC. However, in expert interviews, formal discussions were held with stakeholders from diverse entities. The interviews aimed to gather expert insights into Yemen's technological readiness for AR and EC, with a focus on critical variables like as infrastructure, policy, and AR deployment challenges. So, the interviews with technical specialists offered a thorough understanding of the practical issues of AR adoption in Yemen.

3.3. Limitations

Due to regulatory constraints and the emerging status of Yemen's technology sectors, the research relied on field visits and interviews rather than large-scale surveys or simulations.

4. RESULTS AND DISCUSSION

A simple five-point scale (5-1) was used to evaluate each factor, a scale ranging from 1 to 5 is commonly referred to as a Likert scale. The Likert scale is a popular method for measuring attitudes, opinions, or perceptions by asking respondents to rate statements on a scale, typically from 1 (strongly disagree) to 5 (strongly agree) making it widely used in surveys and research studies [24].

In this case, the factors were divided and the response was classified as shown in the table:

- **5 - Very High Impact**: The factor plays a crucial role and is expected to significantly influence the success or failure of edge computing adoption.
- **4 - High Impact**: The factor has a notable positive influence, though it may face some challenges.
- **3 - Moderate Impact**: The factor has a clear influence, but it is conditional on the presence of other supporting factors.
- **2 - Low Impact**: The factor may not play a major role in success or failure unless surrounding conditions are improved.
- **1 - No Impact**: The factor does not have a significant influence or is currently unattainable in the local environment. The following table describes the evaluation mechanism used in the research.

As shown in Table 1, we find that the axes that were relied upon in the interview questions reflect one of the factors of the models that were relied upon in developing the framework. To understand the nature of the response of the research targets and how to give points, the responses were summarized in the following points, Table 2:

1. Perceived Usefulness:
   This factor received 5 points based on full agreement among experts that edge computing will play a crucial role in improving the performance of augmented reality applications by reducing response time and increasing interaction speed.
2. Ease of Use:
   This factor received 3.5 points due to the division of opinions. Some see that the emerging environment represents an opportunity to apply edge computing easily, while others see that economic and security challenges and the lack of experts make integrating edge computing a complex matter.
3. Behavioral Intention:
   This factor was given 4 points due to the differences in opinions. Experts agreed that the market and user needs will be the main influential factor in pushing service providers to adopt edge computing.
4. Social Influence:
   This factor received 3.5 points due to the limited impact of technology currently on the local community. Experts believe that the lack of reliance on technology at the present time may represent an obstacle or an opportunity for smooth adoption in the future, but the lack of previous experiences makes this factor risky.
5. Facilitating Conditions:
   This factor received 5 points based on the consensus of experts that the government policy that requires companies to use local data centers provides great opportunities to improve response time and data security. However, the high cost of expanding the infrastructure is a major challenge.
6. Technology Hedonism:
   This factor received 4.5 points, as there is great interest from the state and experts in adopting modern technologies and moving towards developing the infrastructure, but some individual challenges may affect the speed of implementation. The following table summarizes the key factors evaluated based on the interviews.

Based on the above findings in table 2, it can be said that edge computing has the potential to boost the adoption of AR technology in Yemen, but there are some factors that need to be taken into consideration to achieve this goal. That is shown in the coming points and figure 2:

o Importance of technical factors:

Table 1. Evaluation Mechanism

Factor	Description	TAM or UTAUT2	Score (from interviews)
Perceived Usefulness	Expected benefit from using the technology	TAM	1-5
Ease of Use	Ease of integrating edge computing into systems	TAM	1-5
Behavioral Intention	Intention to adopt edge computing	UTAUT2	1-5
Social Influence	Impact of technology adoption on the technical community	UTAUT2	1-5
Facilitating Conditions	Infrastructure required to enable edge computing	UTAUT2	1-5
Technology Hedonism	Interest of specialists in adopting modern technologies	UTAUT2	1-5

- Perceived usefulness and ease of use are the two main factors that can encourage technology companies to adopt edge computing. Reducing latency and improving performance are the focal points here. In addition, edge computing is easy to integrate with existing cloud systems, especially with the availability of modern networks.
- Behavioral intention plays an important role in determining the readiness of companies to adopt this technology. Interviews show that large technology companies see promising potential in adopting this technology, but they need government support and more advanced infrastructure.

o Technical challenges and opportunities:

- Facilitating conditions represent a major challenge, as the lack of sufficient infrastructure such as edge servers and fast networks such as 5G is considered a barrier to the widespread adoption of edge computing.

However, this aspect can be improved through government investments and strategic plans to develop local networks. The following figure, figure 2, illustrates the results of enhancement of the models to find new framework for AR technology adoption in Yemen

After presenting the results, it became easy to reach

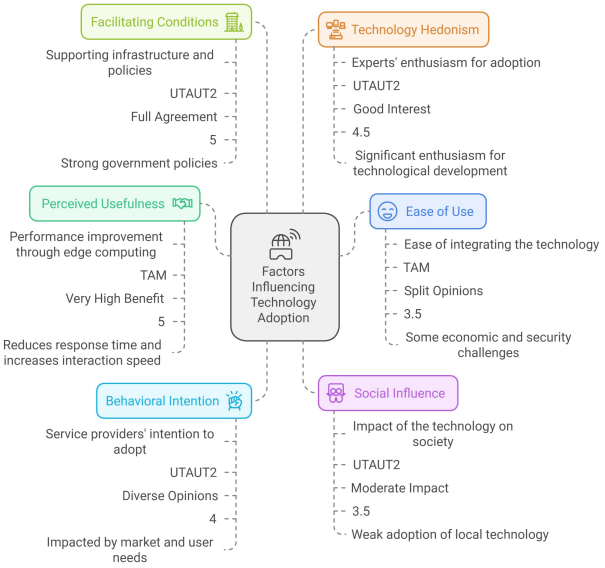

Figure 2. The results of enhancement of the models to find new framework for AR technology adoption in Yemen.

the general form of the new framework by analyzing the results that were previously reached. The following figure, figure 3, shows the proposed framework for adopting enhanced AR technology through EC.

The figure above illustrates the proposed framework inclouding the integrated relationship between the different factors in the framework, showing how each factor

Table 2. Summary of Key Factors Evaluated Based on Expert Interviews.

Factor	Description	Result Obtained	Points	Notes	Type
Perceived Usefulness	Performance improvement through edge computing	Very High Benefit	5	Reduces response time and increases interaction speed	Independent
Ease of Use	Ease of integrating the technology	Split Opinions	3.5	Some economic and security challenges	Independent
Behavioral Intention	Service providers' intention to adopt	Diverse Opinions	4	Impacted by market and user needs	Dependent
Social Influence	Impact of the technology on society	Moderate Impact	3.5	Weak adoption of local technology	Independent
Facilitating Conditions	Supporting infrastructure and policies	Full Agreement	5	Strong government policies	Independent
Technology Hedonism	Experts' enthusiasm for adoption	Good Interest	4.5	Significant enthusiasm for technological development	Independent

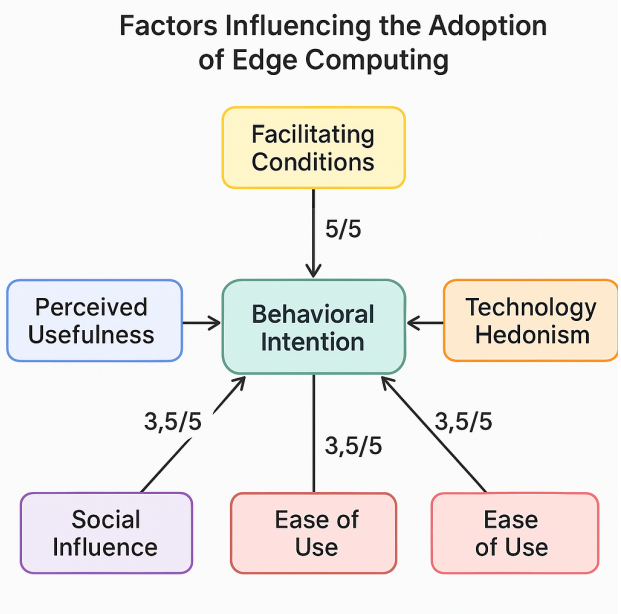

Figure 3. The proposed Framework for Adopting Enhanced Augmented Reality Technology through Edge Computing.

affects the other in a specific order. In this framework, it is clear that:

Perceived Usefulness directly affects behavioral intention and technical motivation, highlighting its importance in the adoption process.

Facilitating Conditions have a dual effect, facilitating perceived usefulness and supporting ease of use.

Behavioral Intention is affected by perceived usefulness and in turn contributes to influencing the social factor.

Technology Hedonism directly affects ease of use, demonstrating the relationship between technical enthusiasm and ease of dealing with technology.

Social Influence plays a role in facilitating conditions, as social opinions can influence the availability of resources and support.

These relationships show how each factor interacts with the other, forming an integrated process that contributes to a framework for adopting edge computing-enhanced AR technology.

5. CONCLUSION

The paper concluded that EC represents a promising solution to improve the adoption of AR technology in Yemen, but its implementation is heavily reliant on strengthening technical infrastructure and providing fast networks like 5G. This was done based on the technical factors extracted from the TAM and UTAUT2 models, and according to the results, it can be said that enhancing the infrastructure and awareness of new technologies will play an important role in the adoption of AR via EC.

Accordingly, the outputs of this paper can be summarized in a set of recommendations that contribute to increasing the potential for adopting AR technology in Yemen by integrating edge computing. This is as follows:

The government should invest in developing 5G networks and increasing the number of edge servers to ensure the availability of a suitable technical environment for edge computing applications. It is also important to encourage cooperation between government institutions and companies providing Internet and cloud computing services to develop joint solutions based on edge computing, which enhances the speed of their adoption. Awareness and training campaigns should be conducted for developers and local technology companies on the benefits of edge computing and how to integrate it into AR applications to improve user experience. In addition, periodic evaluation of technical factors should be conducted through interviews with specialists to ensure that the proposed framework is updated according to the latest technical developments.

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