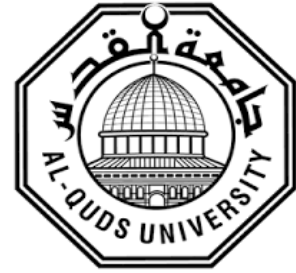


**Deanship of Graduate Studies
Al-Quds University**



**A Framework for Integrating Technical Performance
Metrics and SUS Testing to Enhance User Experience
in Augmented Reality**

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M.Sc. Thesis

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**A Framework for Integrating Technical Performance
Metrics and SUS Testing to Enhance User Experience
in Augmented Reality**

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**A Thesis Submitted in Partial Fulfillment of
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Studies / Al-Quds University.**

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Al-Quds University
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Thesis Approval


**A Framework for Integrating Technical Performance Metrics and
SUS Testing to Enhance User Experience in Augmented Reality**


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Dedication

إلى والديّ العزيزين، سائلاً الله لهما طول العمر والعافية

وإلى زوجي الكريم، سندي وقوتي في هذه الحياة

وإلى أبنائي الأحباء،

وإلى عائلتي الكريمة

أهدي لكم هذا البحث تقديراً لدعمكم المتواصل وحبكم اللامحدود...

Declaration

I certify that this thesis submitted for the degree of Master, is the result of my research, except where otherwise acknowledged, and that this study (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed:



Hadeel Adnan Atallah Farash

Date: 12/1/2025

Acknowledgment

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I would also like to thank my thesis committee.

I would also like to express my gratitude to my husband and children for their ongoing support, patience, and understanding during the times I was away from them while conducting my research.

Abstract

Evaluating the performance of augmented reality (AR) applications is essential for optimizing user experience, improving interaction quality, and advancing AR technology. Traditional AR performance studies typically focus on factors such as response speed, tracking accuracy, resource usage, and their impact on user experience. These studies aim to reduce energy consumption, enhance application efficiency, and enable the integration of emerging technologies like artificial intelligence (AI). Additionally, understanding the influence of AR applications on user interaction is crucial for developing applications that produce positive results. Identifying effective methods for content delivery through comprehensive performance comparisons is key to ensuring an optimal user experience. Despite significant research in the field, many studies lack an integrative approach that considers the full range of technical performance factors.

This research introduces a framework designed to provide developers with a robust, automated performance evaluation tool that enables them to enhance the AR user experience. The developed tool automatically collects and analyzes user interaction data—such as gameplay data—and integrates this with user feedback obtained from post-session surveys. This dual-method approach helps identify performance weaknesses and their underlying causes, providing developers with targeted insights for improving the application's quality. The tool was tested across three AR applications in distinct categories—educational, tourism and cultural heritage, and gaming—demonstrating its effectiveness in delivering valuable, context-specific performance metrics.

The most significant findings from the analysis underscore the importance of AR tracking accuracy in achieving high user satisfaction. Applications with high tracking accuracy, such as the Dar Al Consul App, demonstrated superior user engagement and satisfaction levels compared to applications with stable technical performance but less accurate tracking, such as the Farah App and EasyAPP. Additionally, the study found that while technical metrics like CPU, GPU, latency, and memory usage were consistent across user groups, user satisfaction was more strongly correlated with usability factors and interface intuitiveness, particularly for younger users who benefit from age-appropriate designs.

In addition to its real-time analysis capabilities, the tool features a data storage function that supports long-term performance tracking, laying the foundation for AI-driven models in the future that can learn from the strengths and limitations of AR applications. By combining user feedback with AI, the framework offers a holistic approach to performance evaluation, assisting developers throughout both development and pre-release stages. This research bridges gaps in current AR evaluation methods, providing a comprehensive approach that encompasses the critical technical, psychological, and social aspects of AR application performance.

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List of acronyms

Acronym	Meaning
HCI	Human Computer Interaction
UX	User Experience
VARTOOL	Augmented Reality Tool
CSS	Cascade Style Sheet
HTML	Hyper Text Markup Language
DB	Database
UI	User Interface
SUS	System Usability Scale

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Chapter 1: Introduction

1.1 Introduction

Augmented Reality (AR) has gained significant traction as a transformative technology, enabling the overlay of digital information onto real-world settings to create immersive, interactive user experiences. This integration spans various sensory modalities—visual, auditory, and haptic—providing users with an enriched perception of their surroundings ^[1]. Unlike Virtual Reality (VR), which fully immerses users in a simulated environment, AR enhances real-world settings by overlaying contextually relevant digital content, creating a blend of digital and physical interactions that feel natural and intuitive. This interaction is made possible by key technical features, such as 3D alignment and real-time responsiveness, which allow AR to bridge the gap between digital and physical realms effectively ^[2].

AR's core principles of blending real and virtual elements, real-time interaction, and precise 3D alignment enable it to go beyond traditional data displays, transforming it into a truly immersive experience where users can interact meaningfully with digital content. Early systems, such as the Virtual Fixtures project by the U.S. Air Force Armstrong Laboratory in 1992, laid the foundation for immersive AR by enhancing user capabilities through digitally augmented tools. Initially constrained by hardware limitations, AR quickly expanded its reach in fields such as entertainment and gaming, where it engaged users through interactive and immersive content ^[3]. As AR technology evolved, it has found applications in other critical sectors, including healthcare and education.

In education, AR enables active learning by embedding interactive, context-specific information into educational materials, making it particularly beneficial for STEM fields, where complex concepts can be visualized in ways that enhance understanding. By accessing AR content through mobile devices or headsets, learners can engage with digital content in ways that transform abstract concepts into tangible, interactive experiences ^[4]. In healthcare, AR plays a critical role by providing real-time visual guidance for complex procedures, enabling medical professionals to overlay anatomical information or procedural steps directly onto the patient. Research shows that AR-enhanced procedures improve efficiency and accuracy, making AR an invaluable asset in both medical training and practice ^[5].

With recent technological advancements, augmented reality (AR) has experienced substantial improvements in tracking precision, visual fidelity, and interactivity. The integration of computer vision and object recognition technologies enables AR systems to dynamically respond to user inputs, creating an interactive experience that extends beyond simple data display to actively involving users in the manipulation of digital elements within real-world environments ^[2]. Despite these advancements, optimizing user experience remains a complex challenge. Critical technical metrics such as latency, tracking accuracy, and system responsiveness are essential for maintaining an immersive experience. This is particularly crucial in high-stakes environments such as healthcare or industrial quality inspection, where even minor inaccuracies can disrupt workflows or compromise outcomes ^[1].

To address these challenges, researchers have proposed frameworks that automate performance testing using user data and Human-Computer Interaction (HCI) standards, particularly focusing on the field of user experience (UX). Such frameworks prioritize technical metrics like latency, accuracy, and system efficiency while also addressing cognitive factors such as user satisfaction, mental workload, and perceived usability. A user-centered approach in evaluating AR is essential, as it considers how users adapt to and interact with the technology. Metrics related to ease of use and technical performance are essential for evaluating the impact of AR on user performance and satisfaction, especially in industrial and educational settings where task efficiency and engagement are paramount ^{[6][7]}.

The proposed framework automates performance testing through systematic user data collection aligned with HCI UX standards. This methodology facilitates continuous monitoring and refinement by capturing user interactions and feedback. By following established UX and HCI principles, the framework provides a structured approach to understanding and improving user interactions within AR environments. In healthcare settings, for example, the framework can enhance procedural guidance by adjusting content delivery based on analyzed user data, thereby reducing cognitive load and improving task precision. This user-driven data can highlight interaction patterns, allowing system designers to refine the AR application to better meet the needs of specific user groups ^[8].

Additionally, the framework focuses on HCI standards, aligning with the increasing demand for AR systems that meet diverse user requirements across various environments. The framework evaluates application performance based on technical criteria to assess efficiency, as well as user experience, enabling developers to identify weaknesses. In industrial settings, automated performance testing of AR-based quality inspection tools can detect areas for improvement, helping streamline workflows and reduce error rates. By systematically collecting and analyzing user data, the framework enhances usability, efficiency, and user satisfaction by identifying performance weaknesses ^[4].

Performance testing considers both objective and subjective metrics. Objective metrics, such as response time and tracking accuracy, are crucial for optimizing technical performance, while subjective metrics, such as user satisfaction, provide insights into the psychological and cognitive aspects of the user experience. The relationship between the results of subjective and objective metrics is examined to identify the underlying causes of user experience outcomes. Additionally, contextual factors, such as environmental complexity and task specificity, are important, as they influence how users perceive and interact with AR systems. In high-risk environments, such as surgery or industrial inspections, these factors are particularly significant, as even minor performance issues can have substantial consequences ^[5].

The proposed framework offers a comprehensive approach to AR evaluation by integrating automated performance metrics with HCI-driven UX principles, creating a powerful tool for optimizing AR applications across diverse fields. This framework's

adaptability allows it to support a wide range of applications. By systematically collecting data on user interactions and capturing real-time performance metrics while the user is immersed in the AR application, the framework provides feedback to developers for improvement, guiding the iterative design of AR systems and ensuring that they remain responsive to users' evolving needs and expectations [8].

The growing adoption of AR highlights its potential to revolutionize user experiences by seamlessly integrating digital and physical realities. However, to realize this potential, AR evaluation frameworks must address the complex nature of user experience, incorporating both technical and cognitive metrics as well as user-centered standards from HCI. The proposed framework's automation of performance testing based on user data and established HCI UX principles ensures that AR systems remain optimized and effective across applications. This structured approach not only improves usability but also enhances the applicability of AR across fields, from education and industrial inspections to healthcare.

As AR continues to evolve, refining evaluation frameworks will be crucial to ensure that AR applications remain responsive to the changing needs of users. By integrating structured performance testing and a comprehensive understanding of user experience, AR can continue to provide value not only through technical advancements but also by adhering to user-centered design principles that meet the complex digital demands of today. This user-driven approach to performance testing will help ensure that AR technology becomes an increasingly integral part of daily life, offering enhanced interaction, immersion, and usability across a wide range of applications.

1.2 Problem Statement

In the rapidly advancing field of augmented reality (AR), companies and developers need a robust, comprehensive framework for evaluating AR application performance. Effective AR applications depend on various technical factors, including tracking accuracy, CPU and GPU usage, latency, memory consumption, rendering time, frames per second (FPS), and overall system stability. Without a reliable, integrated method to assess these factors, developers may struggle to diagnose critical performance issues, leading to suboptimal user experiences and reduced application effectiveness in real-world settings.

While existing HCI and UX standards provide a strong foundation, they often require adaptation for AR applications to address the unique complexities of this immersive, interactive medium. Currently, many performance testing methods for AR applications are limited in scope, focusing on isolated aspects like tracking precision or rendering efficiency without offering a holistic evaluation of the application's overall functionality and user experience. Furthermore, these methods frequently overlook user-centered metrics based on Human-Computer Interaction (HCI) and UX standards, which leaves critical insights into user experience unaddressed. As a result, developers lack comprehensive feedback on how performance issues impact the end-user experience, leading to incomplete diagnostics that hinder the development of high-quality, user-centered AR applications. To ensure an optimal user experience in AR, performance testing should integrate both traditional HCI/UX principles and AR-specific metrics, providing a more thorough and balanced evaluation.

This research aims to address the limitations of existing performance testing methods by proposing a new, comprehensive framework for automated performance evaluation that assesses AR applications holistically. The proposed framework will integrate key technical metrics with user-centered principles based on Human-Computer Interaction (HCI) and UX standards, systematically capturing data on all critical aspects of performance. By incorporating structured user feedback based on these principles, the framework will provide developers with actionable insights, enabling them to identify strengths and address weaknesses more effectively. This holistic approach aims to empower developers to make informed improvements, enhancing the user experience and supporting the sustained success of AR applications in a competitive market.

1.3 Research Questions

1. What are the essential technical performance metrics for evaluating the effectiveness and efficiency of augmented reality (AR) applications, and how do these metrics impact user experience?
2. How can a comprehensive automated framework be developed to assess AR application performance across key metrics, such as tracking accuracy, resource consumption, and user experience, in an integrated and systematic way?

3. How can user feedback be systematically integrated into the performance evaluation process of AR applications, and how can the relationship between technical performance metrics and user satisfaction be examined?

1.4 Objectives of the Study

1. To identify and define critical performance metrics required for evaluating the effectiveness and efficiency of augmented reality (AR) applications, focusing on establishing a set of key performance indicators (KPIs) that assess usability and technical performance.
2. To develop a comprehensive, automated framework for assessing AR application performance, capturing key metrics such as tracking accuracy, resource usage, and rendering efficiency in an integrated manner.
3. To incorporate structured user feedback based on HCI and UX standards into the performance evaluation framework, ensuring the tool measures both technical performance and user satisfaction.

1.5 Research Methodology

The research method employed in this thesis is structured to develop, test, and validate a comprehensive performance evaluation tool for augmented reality (AR) applications. The methodology begins with an extensive literature review to identify critical technical performance metrics essential for assessing AR application effectiveness, such as tracking accuracy, CPU/GPU usage, latency, memory consumption, rendering time, and frames per second (FPS). This review also highlights the limitations of existing performance testing methods, establishing a foundation for developing a more holistic tool.

Following the literature review, the research focuses on designing and developing a more holistic automated performance evaluation tool, contrasting with previous findings in the literature and integrating user feedback into the assessment process. This tool is programmed to measure and analyze the identified performance indicators in real-time during the use of AR applications. Additionally, the tool includes features for collecting user feedback through surveys conducted immediately after using the application. This feedback is integrated into the evaluation process to ensure a more user-centered assessment.

The developed tool was empirically tested across a variety of AR applications, including those focused on education, cultural heritage, and gaming. The tests were conducted in an open environment, with each application containing specific tasks. These tests involved a diverse group of users to ensure a comprehensive evaluation. The tool's performance was assessed based on its ability to accurately measure critical metrics, integrate user feedback, and provide precise measurements of technical performance indicators to developers. Additionally, the relationship between these metrics and the user experience was analyzed to identify points of failure. The results from these tests were analyzed to validate the tool's effectiveness and its ability to provide actionable feedback for developers to improve their applications and address performance issues that could lead to poor user experiences.

Subsequent data analysis involves the use of statistical methods to determine the tool's accuracy and the validity of its predictions. This analysis examines correlations between the tool's measurements and user feedback, ensuring the tool's overall impact on improving AR application quality.

The research concludes with the documentation of the tool's development process, empirical testing results, and data analysis findings. A detailed report is prepared, summarizing the research outcomes and offering recommendations for developers and researchers in the AR field. The report also discusses potential future enhancements to the tool, including the integration of artificial intelligence capabilities, additional metrics, and broader applications across different AR contexts.

1.6 Thesis Contribution

This thesis presents several important contributions to the field of augmented reality (AR) application development and performance evaluation. It introduces an innovative, automated tool that offers a comprehensive evaluation of AR applications across key performance metrics. In contrast to existing methods that typically focus on isolated performance aspects, this tool provides a holistic assessment, allowing developers to analyze tracking accuracy, CPU/GPU usage, latency, memory consumption, rendering time, and frames per second (FPS) in an integrated manner.

A significant contribution of this study is the incorporation of user feedback into the performance evaluation process. By integrating real-time user experiences and

perceptions, the developed tool offers a more detailed and user-centered assessment of AR applications. This methodology ensures that technical performance evaluations are closely aligned with end-user satisfaction and usability metrics, thereby enhancing the overall relevance and effectiveness of the assessment process.

The tool and its methodologies have been empirically validated through application in diverse AR contexts, including education, cultural heritage, and gaming. These case studies illustrate the tool's capability to identify both strengths and weaknesses in performance, thereby confirming its practical applicability and its potential to enhance the quality of AR applications.

In conclusion, this thesis enriches the broader field of AR development by identifying and addressing shortcomings in current performance testing methodologies. By proposing a more holistic approach, it sets a new benchmark for performance evaluation. This framework can be utilized by both developers and researchers, promoting innovation and elevating the overall quality of AR applications within the industry.

Future work will involve integrating an artificial intelligence (AI) component into the performance evaluation tool to enhance its capabilities. This AI-driven component will be designed to predict potential performance issues and provide proactive solutions, enabling developers to address problems before they impact the user experience. This predictive capability is expected to add significant value to the AR development process and further improve the quality of applications. This will be implemented after our tool has demonstrated the ability to collect large amounts of data during usage, ensuring the AI component is effectively trained and able to offer accurate predictions.

1.7 Research Limitation

Although this thesis offers substantial contributions to the evaluation of augmented reality (AR) application performance, it is essential to acknowledge certain limitations.

Initially, the empirical testing conducted within this thesis was restricted to a specific subset of AR applications, primarily within the domains of education, tourism, and gaming. While these applications encompass a variety of AR use cases, the findings may not be entirely generalizable to other categories of AR applications, such as those

utilized in industrial, medical, or military settings, where performance requirements and user expectations may vary substantially.

Secondly, the tool's incorporation of user responses as part of the performance evaluation process introduces an element of subjectivity. Although user responses is crucial for capturing the real-world implications of performance issues, it can differ significantly due to variations in individual user experiences, preferences, and expectations. This variability may influence the consistency and reliability of the performance assessments generated by the tool.

Finally, the development and testing of the tool were carried out within a specific technological and hardware context. Given the rapid evolution of AR technology and hardware, it is possible that the tool may require periodic updates and modifications to maintain its relevance and effectiveness. The current iteration of the tool may not be fully optimized for future AR platforms or for environments characterized by diverse hardware configurations, such as varying processing power or display capabilities.

1.8 Thesis Organization

Chapter 1 provides an overview of the research, presenting the problem statement, research questions, and objectives. It also outlines the research methodology, highlights the study's limitations, and discusses its contributions.

Chapter 2 offers background information on key topics related to the study, including human-computer interaction (HCI) and user experience (UX) in augmented reality (AR), as well as performance evaluation and testing methods. This chapter includes an in-depth analysis and review of the current state-of-the-art performance testing techniques in AR applications.

Chapter 3 details the research methodology, with an emphasis on the development of the framework for the tool design. It outlines the process of testing and evaluating the framework, including the introduction, collection, analysis, and visualization of data samples.

Chapter 4 presents the research findings and results.

Chapter 5 discusses the primary outcomes and conclusions of the research, provides a summary, and offers recommendations for future research directions.

Chapter 2: Background and Literature Review

2.1 Background

2.1.1. HCI and User Experience

Human-Computer Interaction (HCI) is an interdisciplinary field that explores the interaction between people and technology, with an emphasis on designing systems that are intuitive, efficient, and user-centered. In the context of augmented reality (AR), effective HCI design plays a pivotal role in ensuring that the technology aligns with user expectations and integrates naturally into real-world tasks. User Experience (UX), a critical aspect of HCI, focuses on the overall perceptions and responses of users when interacting with technology. In AR, UX factors such as intuitive interaction, user comfort, and the seamless blending of virtual elements with the physical world are crucial for fostering positive user experiences. To evaluate these experiences, the System Usability Scale (SUS) is commonly used to assess users' perceptions of usability, providing valuable insights into areas for improvement. By considering HCI principles and applying usability testing, AR applications can achieve optimal performance, ensuring user satisfaction and engagement across various domains, including education, tourism, and entertainment.

Human-Computer Interaction (HCI) is a critical interdisciplinary field that examines how people interact with technology, with a focus on designing systems that are user-centered, efficient, and intuitive. By analyzing user needs and behaviors, HCI aims to

create systems that integrate seamlessly with the user's tasks, enhancing both performance and satisfaction. This approach is essential in augmented reality (AR), where the technology's potential can only be fully realized if it aligns with user expectations and fits naturally within the user's real-world interactions ^{[9][10]}.

User Experience (UX), a key component of Human-Computer Interaction (HCI), is defined by the International Organization for Standardization (ISO) as "a person's perceptions and responses resulting from the use or anticipated use of a product, system, or service" (ISO, 2019)^[11]. In the context of Augmented Reality (AR), UX encompasses various factors, including intuitive interaction, user comfort, and the seamless integration of virtual objects with the physical environment. A well-designed UX in AR applications enables users to interact with the system effortlessly, maximizing value and enhancing satisfaction while minimizing frustration. To assess UX, the System Usability Scale (SUS) is widely used as a reliable tool to measure users' perceptions of usability. SUS provides a simple yet effective way to quantify users' overall satisfaction with a system, helping to identify potential issues in user experience. Poorly designed UX, as revealed by SUS testing, can disrupt user immersion and lead to rejection of the application due to discomfort or dissatisfaction ^[12].

In AR application development, performance criteria derived from HCI standards emphasize UX and system efficiency. Key elements include usability, responsiveness, consistency, interaction smoothness, stability, and a user-centered design process that consistently considers user feedback (ISO, 2018)^[13]. By adhering to these principles, AR applications are more likely to provide a seamless, engaging user experience that balances both technical performance and human factors, making them effective tools for educational, professional, and entertainment purposes ^[14].

2.1.2. System Usability Scale and Its Role in Evaluating User Experience in Augmented Reality

The System Usability Scale (SUS) is a widely used tool for assessing user experience in augmented reality (AR) applications, providing a simple yet reliable metric for measuring user satisfaction with usability. The scale consists of ten questions answered by users on a Likert scale, ranging from "strongly agree" to "strongly disagree." This metric reflects user impressions on various aspects of the system, including ease of use, interaction, and comfort while engaging with the application. SUS can help identify

issues related to user interface design, enabling developers to refine the user interaction and achieve a smoother and more comfortable experience. Its importance in AR applications lies in the fact that users expect seamless interaction with virtual content, and SUS allows for precise evaluation of how well the application meets these expectations ^[15].

By integrating SUS results with technical performance data, developers can better understand the relationship between usability and technical performance. In AR applications, performance issues such as latency, tracking errors, or resource inefficiency can negatively impact SUS outcomes. For example, slow response times or misaligned virtual objects may lead to poor SUS ratings, signaling usability problems that could result in user dissatisfaction. Therefore, conducting SUS testing alongside technical performance evaluations is essential in AR development to ensure both high usability and optimal system performance, ultimately improving the overall user experience.

2.1.3. User Experience and Performance in Augmented Reality

User experience (UX) in augmented reality involves users' perceptions and interactions with an AR application, focusing on elements such as usability, engagement, comfort, and responsiveness. In AR, intuitive navigation and ease of use are crucial, as they help users engage with virtual content in a way that feels natural and immersive. Interaction quality also plays a significant role, as it requires smooth and precise responses to user commands to avoid motion discomfort or misalignment. An engaging AR experience hinges on content that is captivating and tailored to individual preferences, often necessitating personalization and real-time adjustments based on user feedback ^{[1][16]}.

For AR applications, technical performance is directly related to UX, where technical metrics like tracking accuracy, CPU/GPU resource usage, latency, memory usage, rendering time, and frames per second (FPS) are critical. Tracking accuracy ensures virtual elements are consistently aligned with the real environment, maintaining immersion and realism. Efficient CPU and GPU usage help achieve a balance between responsiveness and resource consumption, preventing lag or overheating. High FPS, minimal latency, and low memory consumption contribute to a smooth user experience, allowing users to interact with the application without interruptions ^[14]. These elements

are essential in AR because even minor delays or inaccuracies can break immersion, causing users to become disoriented or uncomfortable ^[17].

The integration of UX and performance is vital for AR's success, as a seamless user experience is largely dependent on robust technical performance. Ensuring tracking accuracy and fast rendering allows for immersive interactions, while efficient resource usage helps maintain consistent application performance. Collecting and analyzing user feedback on both performance and UX is crucial for refining AR applications over time, as it highlights areas for improvement that developers might not have anticipated. This user-centered approach allows for iterative improvements that are informed by real user experiences, ensuring the application evolves to meet changing expectations and standards ^[6].

2.1.4. Performance Recommendations for Augmented Reality Applications

Performance standards for augmented reality (AR) applications can vary significantly based on factors such as device capabilities, the type of application, and the user's environment. Despite these variations, there are general performance guidelines that can be applied to improve AR experiences. One such guideline is ensuring high tracking accuracy, which is critical for maintaining user immersion. Techniques like Simultaneous Localization and Mapping (SLAM) are commonly employed to enhance tracking accuracy, allowing for stable virtual object placements even in complex or dynamic environments ^[14].

Efficient CPU and GPU usage is also a crucial metric in AR performance. This metric is considered acceptable when it facilitates smooth application performance while preventing excessive battery drain and overheating, thus supporting an uninterrupted user experience. When CPU and GPU usage is inefficient, leading to issues such as overheating or lag, it significantly degrades the user experience, making it unacceptable. Minimizing latency is another important consideration, as it ensures prompt processing of user inputs, thereby contributing to a more responsive and intuitive interaction ^[16].

Dr. Mark Billinghurst's work underscores the importance of these guidelines in AR development. He emphasizes tracking accuracy, particularly through SLAM, as essential for delivering a seamless experience in which virtual objects align with the

real environment. Billingham also highlights the need for efficient resource management, as excessive CPU or GPU usage can lead to thermal issues or slowdowns, diminishing user engagement. He advocates for reducing latency, optimizing memory usage, and maintaining a stable frame rate (typically above 30 FPS) to ensure fluid visuals. His findings indicate that balancing these elements can significantly improve AR application usability and satisfaction ^[14].

2.1.5. Performance Testing Methods in Augmented Reality

The performance of AR applications is evaluated through various software and hardware tools, each focusing on specific performance metrics. Tools such as Unity Profiler and Android Studio Profiler measure CPU, GPU, memory usage, and FPS for Android applications, while Xcode Instruments performs similar analyses for iOS applications. Battery Historian assesses power consumption on Android devices, helping developers optimize for energy efficiency. For tracking accuracy, SLAM is employed to ensure virtual elements are anchored correctly in the user's real-world environment. Network performance tools, such as Charles Proxy and Wireshark, are also used to evaluate AR applications' performance in varying network conditions, an essential consideration for cloud-based AR experiences ^[1].

In addition to the standard tools used for performance evaluation, specific testing methods are employed to assess various aspects of augmented reality (AR) performance. Frame Rate Analysis (FPS Testing) is used to measure the application's ability to maintain stable and high frame rates, which is essential for ensuring visual comfort and enhancing user immersion. Latency Testing evaluates the delay between user input and application response, a critical factor in AR applications where real-time interaction is expected. AR Tracking Accuracy measures the consistency and stability of virtual elements in the real-world environment, ensuring accurate alignment of virtual content. Resource Usage Monitoring assists developers in managing CPU/GPU consumption to prevent issues such as overheating and excessive battery drain ^[6].

Rendering Time Analysis examines the time required for each frame to render, which directly influences the smoothness of the visual experience and overall responsiveness. Furthermore, additional methods like Stress Testing, Battery and Thermal Testing, User Experience (UX) Testing, and Network Performance Testing provide valuable insights

into the application's performance under varying conditions, shedding light on its impact on user comfort and engagement.

2.1.6. VARTOOL Framework Environment

The VARTOOL framework integrates a variety of tools to facilitate real-time measurement and analysis of performance during user interaction with AR applications. Core components include Firebase, Unity, and Django, each of which supports different aspects of AR application development and testing. Firebase, developed by Google, provides backend support with real-time data synchronization, authentication, cloud storage, and analytics, essential for managing and optimizing data flow in AR applications. This tool ensures reliable data management and enhances user engagement through targeted notifications and cloud functions, making it invaluable for performance testing and user interaction tracking ^[18].

Unity, a highly versatile game engine, is widely used for creating AR and VR experiences. It offers features for cross-platform deployment, an asset store, advanced rendering, and a visual editor that simplifies content creation. Unity's profiling tools allow developers to monitor system resource usage in real-time, aiding in the optimization of AR applications to improve both performance and user experience ^[19]. Django, an open-source Python web framework, provides backend support with tools for data management, content validation, and security. Django's scalability and robust database management make it ideal for handling large amounts of user data in AR applications, contributing to a smoother and more reliable user experience ^[20].

2.1.7 Automated Performance Metrics and User-Centered Design

In developing a framework for enhancing AR user experience, automated performance metrics combined with user-centered design principles are essential. Performance metrics are crucial for understanding how an AR application behaves under different conditions, providing insights into areas such as rendering speed, tracking accuracy, latency, and resource efficiency. By systematically measuring these metrics, developers can identify bottlenecks and optimize the application's performance for improved stability and usability^[11].

User-centered design ensures that the performance metrics gathered are meaningful in the context of real user interactions. For instance, an automated tool could track latency

and FPS but also include surveys or feedback prompts that capture the user's subjective experience regarding responsiveness and visual quality. This approach allows developers to connect technical metrics with qualitative user data, creating a holistic view of the application's performance from the user's perspective ^[1].

Integrating these approaches within an automated framework, such as VARTOOL, enables continuous performance monitoring and iterative improvements. Automated feedback mechanisms could capture user data in real-time, helping to refine AR applications based on actual user interactions. This method ensures that the application evolves to meet user expectations, incorporating feedback on usability, comfort, and immersion ^[16].

2.2 Literature Review

Augmented Reality (AR) technology has increasingly become integral across various fields, including healthcare, education, retail, and industrial applications, by superimposing digital information onto real-world settings. Unlike Virtual Reality (VR), which immerses users in fully digital environments, AR enables real-time, contextually relevant interactions with digital elements while keeping users connected to their physical surroundings. This seamless blending of physical and digital realms relies heavily on factors such as high frame rates, low latency, and accurate tracking to maintain immersion and responsiveness. Real-time AR experiences, therefore, demand robust performance metrics that ensure smooth, realistic, and effective user experiences ^{[16][21]}. As AR continues to expand its reach, understanding the elements that influence user experience (UX) and overall application performance has become essential to optimize interaction quality and user satisfaction.

Recent research highlights the critical role of performance metrics—specifically frame rate, latency, and tracking accuracy—in shaping the user experience (UX) of augmented reality (AR) systems. Automated performance metrics are increasingly utilized to evaluate and improve the technical performance of AR applications in real time, facilitating ongoing enhancements to UX. This literature review consolidates key studies that examine the influence of frame rate, latency, tracking accuracy, and user-centered design on the optimization of AR systems. It offers a comprehensive overview

of how these factors collectively contribute to user satisfaction, usability, and overall system performance.

2.2.1. The Role of Frame Rate and Latency in AR Performance

Frame rate and latency play a critical role in determining the effectiveness of augmented reality (AR) application performance. High frame rates and low latency are essential for providing a smooth and realistic AR experience, ensuring that digital content responds to user movements and interactions without perceptible delays. Craig ^[22] emphasizes the significance of frame rate and latency in AR performance, noting that seamless transitions between real and virtual elements enhance the immersion and usability of AR systems. His research combines technical analysis with case studies, demonstrating how optimized frame rates foster a highly interactive environment, thereby increasing user engagement and satisfaction.

Similarly, Ronald T. Azuma emphasized that low frame rates and high latency can significantly impair the quality of AR applications, potentially resulting in motion sickness, disorientation, and decreased usability. Through an extensive review of AR technologies, Azuma identified frame rate and latency as critical factors that determine the overall quality of AR applications. He proposed that developers should prioritize optimizing these metrics to ensure smooth and responsive interactions. This study laid the groundwork for understanding how delays in rendering virtual elements negatively impact user experience, particularly in applications where real-time interactions are essential. ^[23]

Montemerlo and Pustejovsky expanded on this research by providing empirical evidence regarding the impact of frame rate and latency on AR system performance. Through performance evaluations, they demonstrated that higher frame rates and lower latency result in smoother transitions and enhanced user satisfaction, particularly in dynamic applications. Their findings emphasize the significance of real-time optimization and highlight the role of automated performance metrics in improving user experience by ensuring high system responsiveness in complex environments. ^[24]

Paul, explored techniques for achieving high frame rates and low latency through DirectX 11, providing insights into how real-time 3D rendering can enhance AR

applications. Paul, P's book outlines optimization strategies that leverage hardware and software capabilities to reduce latency and improve frame rates, making AR interactions more immediate and fluid. By detailing practical applications and educational examples, Paul, P's work remains influential in AR development, where performance improvements directly impact usability and immersion. ^[25]

Research by Lincoln, P. C. further supports the importance of minimizing latency in AR systems. Their study employed experimental analysis to measure the impact of latency on AR applications, concluding that lower latency significantly enhances UX by improving response times and the overall quality of digital interactions. This research highlights latency as a critical component of UX, particularly in applications where users interact with virtual content in real-time. ^[26]

Reinders and Williams contributed to this body of work by analyzing various performance enhancement strategies, including frame rate and latency optimization, across different AR applications. Their research combined case studies with systematic experimentation to provide practical solutions for achieving high-quality AR interactions. By demonstrating the importance of low latency and consistent frame rates, their work underscores how these metrics are central to ensuring an immersive and user-centered AR experience. ^[27]

Schmalstieg, D., & Hollerer, T. book on AR principles presents an extensive overview of the technical aspects of frame rate and latency, offering practical guidance on improving these performance factors. The book provides strategies for optimizing AR systems through both hardware upgrades and software configurations, emphasizing the need for real-time performance metrics to maintain high levels of user engagement and satisfaction in various AR applications. ^[28]

2.2.2. User Experience as a Measure of AR Performance

User experience (UX) is a critical factor in assessing the success of augmented reality (AR) applications, encompassing elements such as usability, satisfaction, engagement, and overall perception of the application's effectiveness. In this context, Chang and Wang conducted a study on the relationship between UX factors and AR performance, concluding that negative aspects, such as usability issues or low engagement, can

significantly impact the adoption and effectiveness of AR applications. Their review of the literature further highlighted that usability, satisfaction, and interaction quality are fundamental components of successful AR implementation. ^[29]

Schneider and Liu proposed a UX assessment framework for augmented reality (AR) applications, emphasizing key factors such as immersion, usability, and satisfaction. Through case studies and empirical testing, their findings indicated a strong correlation between positive user experience and higher perceived quality and effectiveness of AR systems. The proposed framework integrates user feedback as a key metric for evaluating application quality, offering valuable insights into the design and performance aspects that influence user satisfaction. ^[30]

Smith and Thomas conducted an empirical study to evaluate the impact of UX metrics—including latency, frame rate, and interaction quality—on the performance of augmented reality (AR) applications. Their findings indicate a strong correlation between enhanced UX and improved AR performance, demonstrating that low latency and high frame rates significantly contribute to user satisfaction. Utilizing experimental methods and user surveys, their research provides valuable insights into how technical performance metrics directly influence the user experience in AR applications. ^[31]

Williams and Green explored design considerations for optimizing UX in AR applications, addressing common challenges and identifying best practices to enhance usability, engagement, and overall performance. Through user testing, design analysis, and expert interviews, they proposed strategies that align interface design with user expectations, emphasizing the importance of intuitive layouts and responsive interactions in AR environments. ^[32]

Jones and Clarke investigated the influence of design elements on user perception and satisfaction in AR applications. Their comparative analysis of user experiences across multiple applications revealed a strong correlation between high user satisfaction and enhanced application performance. Their study highlights the necessity of prioritizing UX in AR development to ensure applications remain engaging, effective, and aligned with user needs. ^[33]

Roberts and Evans examined a user-centered design approach for AR applications, emphasizing the critical role of user feedback in improving both performance and satisfaction. By applying user-centered design principles, such as iterative testing and usability evaluations, they demonstrated how continuous user input can refine AR applications to better meet user expectations. Their findings suggest that incorporating user feedback throughout the development process contributes to improved UX and overall application performance. ^[34]

2.2.3. Performance Evaluation and Tracking Analysis of AR Applications

The tracking capabilities of augmented reality (AR) applications are essential for ensuring seamless interactions and precise alignment of virtual elements with the physical environment. Anderson and Ramirez empirically assessed AR system performance, focusing on key metrics such as frame rate, latency, and tracking accuracy, identifying these as critical performance indicators. Their study proposed optimization guidelines emphasizing that enhanced tracking precision significantly improves user experience (UX) by enabling accurate, real-time interactions. ^[35]

Green and Smith evaluated the tracking accuracy of various AR technologies through controlled experiments and field tests in diverse scenarios. Their findings highlight the importance of tracking accuracy in maintaining spatial consistency and facilitating realistic interactions within AR applications, ultimately enhancing overall system performance and user satisfaction. ^[32]

Evans and Brown conducted a comprehensive review of optimization techniques for frame rate, latency, and tracking accuracy in AR. By synthesizing findings from multiple studies, they provided a thorough analysis of best practices for improving tracking precision, particularly in applications requiring high spatial accuracy and responsiveness. ^[36]

Johnson and Lee performed a real-time performance analysis of AR applications, measuring response time, rendering efficiency, and tracking stability. Their study demonstrated that continuous monitoring of these metrics enhances UX by allowing for immediate adjustments to tracking settings, thereby improving the smoothness and reliability of interactions. ^[37]

Thompson and Patel examined tracking technologies and performance metrics in AR systems, offering insights into the challenges associated with achieving high tracking accuracy. Through case studies, they analyzed advancements in tracking technology and explored solutions for overcoming obstacles in dynamic environments, which are crucial for delivering responsive AR experiences. [38]

Wilson and Martinez explored tracking and performance optimization in AR applications, providing recommendations for improving tracking precision and system efficiency. By synthesizing insights from previous research and industry reports, they identified tracking accuracy as a fundamental factor in ensuring reliable, high-quality AR interactions. [6]

2.2.4. Discussion

The existing body of literature on augmented reality (AR) identifies several critical factors that influence the performance and user experience (UX) of AR applications, including frame rate, latency, tracking accuracy, and user-centered design. These studies collectively highlight the necessity of balancing technical responsiveness with seamless and immersive user interactions, particularly in applications where precision and fluidity are essential. Through empirical research, technical analyses, and experimental methodologies, prior studies have contributed to a comprehensive understanding of AR's technical and experiential requirements.

Several studies have examined the role of frame rate and latency in determining the effectiveness of AR applications. High frame rates and low latency are essential for ensuring smooth and responsive interactions, allowing digital elements to move fluidly in response to user actions. Craig demonstrated that reducing latency while maintaining high frame rates enhances the user experience by minimizing lag and motion blur, resulting in a more immersive AR environment. Similarly, Azuma found that higher latencies and lower frame rates degrade the AR experience by causing discomfort, disorientation, and reduced usability. Both studies suggest that optimizing latency and frame rate is crucial for ensuring user satisfaction and engagement, particularly in real-time interactive settings. [22] [23]

Montemerlo and Pustejovsky provided additional empirical evidence supporting the significance of frame rate and latency in enhancing AR performance. Their research demonstrated that improvements in these metrics contribute to smoother transitions and greater user immersion, especially in applications requiring dynamic and rapid interaction. By analyzing real-world implementations and automated performance monitoring, their findings emphasize the necessity of a responsive AR interface to maximize user satisfaction. Paul, explored this issue by investigating real-time 3D rendering techniques using DirectX 11. His research underscores the role of hardware and software optimizations in reducing latency and increasing frame rates, thereby improving user interactions in AR. The strategies and optimization methods outlined in Paul, P's work serve as valuable guidelines for developers seeking to enhance AR performance through technical improvements. ^[24] ^[25]

Expanding on this technical focus, Wang examined the relationship between latency and response times in AR applications, concluding that lower latency improves response rates and, consequently, overall application quality. Their findings align with earlier research indicating that reducing latency directly enhances user satisfaction and engagement, particularly in interactive AR applications where timely system feedback is crucial. Reinders and Williams further advanced this area by analyzing various performance enhancement strategies, including systematic latency and frame rate optimization experiments. Their findings reaffirm the importance of minimizing latency and maintaining stable frame rates to ensure a high-quality, user-friendly AR experience. ^[39] ^[27]

User experience (UX) has also emerged as a critical factor in evaluating AR application performance, with numerous studies exploring the relationship between UX metrics and AR system effectiveness. Chang and Wang investigated how usability, engagement, and satisfaction influence the adoption and effectiveness of AR applications. Their findings suggest that poor UX significantly hinders AR adoption and reduces its effectiveness, highlighting the necessity of designing AR systems that prioritize user satisfaction and ease of use. Schneider and Liu proposed a UX assessment framework for AR applications, focusing on immersion, usability, and satisfaction. Their research demonstrates a direct correlation between UX quality and

perceived effectiveness, emphasizing that users are more satisfied with AR applications that offer immersive experiences and intuitive navigation. ^[29] ^[30]

Smith and Thomas examined the direct effects of UX metrics—such as latency, frame rate, and interaction quality—on AR performance. Their study revealed that a positive UX is strongly associated with high AR application performance, with low latency and high frame rates being key contributors to user satisfaction. Using experimental methods and satisfaction surveys, they quantified the impact of these metrics on UX, underscoring the necessity of integrating UX considerations into AR performance optimization. Williams and Green focused on design strategies for improving UX in AR, identifying challenges related to usability, engagement, and system responsiveness. Their recommendations on intuitive layout and responsive design elements provide valuable insights for developers seeking to create user-centered AR interfaces. ^[31] ^[32]

Jones and Clarke further explored the impact of design elements on user perception and satisfaction in AR applications. Their comparative analysis demonstrated that higher levels of user satisfaction are closely linked to improved application performance, suggesting that user-centered design should be a priority in AR development to maintain engagement and effectiveness. Similarly, Roberts and Evans advocated for a user-centered design methodology, emphasizing the importance of incorporating user feedback into the development process. Their study highlights the role of iterative testing, usability evaluations, and user feedback in designing responsive AR systems that align with user needs and expectations. ^[33] ^[34]

Tracking accuracy represents another fundamental aspect of AR performance. Research has shown that precise tracking is essential for the realistic alignment of virtual elements with the physical environment, significantly impacting AR applications' usability and effectiveness. Anderson and Ramirez identified tracking accuracy as a key performance indicator, noting that improved tracking enhances UX by enabling more precise real-time interactions. Green and Smith conducted controlled experiments evaluating tracking accuracy across various AR technologies, demonstrating that precise tracking is crucial for maintaining spatial coherence in AR environments, which is vital for both usability and user satisfaction. ^[35] ^[40]

Evans and Brown provided an extensive review of optimization techniques for frame rate, latency, and tracking accuracy, synthesizing findings from multiple studies. Their research underscores the importance of tracking accuracy in AR applications that require precise spatial positioning, such as those used in medical and industrial settings. Johnson and Lee investigated real-time performance analysis, concluding that tracking stability and accuracy significantly influence UX, as they allow for immediate adjustments that enhance user interaction and engagement. Thompson and Patel examined recent advancements in tracking technologies, identifying challenges in achieving accurate tracking in dynamic environments. Their findings highlight the need for continuous improvements in tracking systems to meet the demands of increasingly complex AR applications. ^{[36] [37] [38]}

1. This study contributes to the existing literature by proposing a comprehensive framework that integrates these key performance metrics—frame rate, latency, and tracking accuracy—with UX elements such as usability, engagement, and user satisfaction. While previous studies have largely examined these factors independently, our research adopts a holistic approach that evaluates technical and experiential metrics simultaneously. By bridging the gap between technical performance optimization and UX quality, we present a robust framework capable of providing real-time feedback and adapting to diverse AR applications.
2. Furthermore, this study extends the work of Weng by investigating advanced techniques for reducing latency and optimizing frame rates in real-time applications. We expand upon their findings by incorporating physiological metrics—such as gaze direction and heart rate—to dynamically assess user engagement and cognitive load, offering an adaptive approach to enhancing user satisfaction and immersion across different AR environments. This approach is particularly relevant for applications requiring real-time responsiveness to user states, such as those in medical or industrial domains. ^[39]
3. Additionally, this study builds upon the tracking accuracy research conducted by Anderson and Ramirez and Green and Smith by implementing task-specific tracking adjustments. By dynamically adapting tracking metrics based on user tasks and environmental factors, our framework offers versatility across various applications, including industrial training, healthcare, and education. This

adaptability positions our study as a practical advancement over previous models, ensuring consistent AR performance across different use cases. ^[35] ^[40]

4. Finally, this research introduces a comprehensive, automated performance metrics framework that evaluates AR applications from both technical and user-centered perspectives. By integrating these metrics into a unified model, we provide a scalable solution that continuously optimizes AR performance and user satisfaction. This approach not only addresses gaps in previous research but also establishes a foundation for the future development of adaptive, user-responsive AR systems.

Chapter 3: Methodology

3.1 Study Design

This research was designed as an analytical project to develop a framework for testing the performance of AR applications, focusing on key metrics such as AR tracking, accuracy, CPU usage, GPU usage, latency, memory usage, rendering time, and FPS. Additionally, it includes a questionnaire to measure user experience in relation to AR application performance. The tool created through this research identifies performance-related issues that may impact the application, providing developers and stakeholders with the means to evaluate and test their applications, whether during the early stages of design and development or at the launch phase. The AR applications examined in this study pertain to education, tourism, and entertainment.

Moreover, comparing the results with the recommended values and the questionnaire responses will offer a comprehensive assessment of the app's performance, highlighting its strengths and weaknesses. The data collected by the tool was stored for future development, facilitating the creation of AI models that can learn from the applications' strengths and weaknesses.

3.2 Optimizing User Experience in Augmented Reality

The proposed framework incorporates a robust module dedicated to optimizing user experience (UX) in augmented reality (AR) applications, focusing on seamless and

immersive interactions between users and their virtual environments. This module emphasizes natural interaction by ensuring that virtual elements are intuitively integrated into the real world. Users should perceive and interact with these elements as if they are tangible parts of their physical surroundings. To achieve this, the framework prioritizes contextual relevance, delivering content that aligns with users' environments and needs to enhance the overall AR experience.

Performance optimization is a main focus of our module, addressing challenges such as motion tracking precision, response speed, and frame rate stability. The framework ensures that applications are designed for smooth, real-time interactions by minimizing delays and reducing errors in motion tracking. This enhances user satisfaction by providing consistent and responsive AR experiences. Additionally, the tool evaluates and optimizes power consumption, mitigating the battery drain often associated with AR applications, thereby extending usability and improving the practicality of AR solutions on mobile devices.

Ease of navigation is another critical aspect of this framework component, ensuring that AR applications are intuitive and accessible. Personalization features allow users to tailor the AR environment to their preferences, fostering engagement and aligning the experience with individual needs. By integrating sensory feedback mechanisms, the framework enhances the interactions, providing tactile or auditory responses that deepen immersion and reinforce the connection between the user and the virtual environment.

The framework also incorporates mechanisms for collaborative social interaction, enabling users to share and engage with virtual content collectively. This functionality enriches the AR experience by fostering collaboration and shared engagement, whether for educational purposes, gaming, or other interactive applications.

A key feature of this module is its feedback integration system, which continuously collects user feedback to drive iterative improvements. By analyzing this feedback, the framework enables developers to refine the application, address emerging challenges, and align features with user expectations. This feedback loop ensures that AR applications remain effective, engaging, and adaptive to evolving user needs, solidifying the role of user experience as a pivotal component in the AR ecosystem.

3.3 Performance Measures

Automated performance metrics are essential for enhancing user experience in augmented reality. By systematically measuring and analyzing key performance indicators, developers can optimize their systems to deliver high-quality, immersive experiences that meet the expectations of users.

There are no specific and unified ISO or Standard values for measuring Augmented Reality (AR) performance across all fields. The accepted requirements for these metrics vary based on the type of application, the device used, and the operational environment. However, some guidelines and recommendations provided in previous scientific research can be used to evaluate AR performance.

Dr. Mark Billinghurst highlights a series of recommendations in his research on augmented reality (AR) to ensure best practices for developing high-performing applications. A selection of his recommendations is presented in the Table 3.1.

Table 3.1-a: Dr. Mark Billinghurst Recommendations

Metric	Description	Target Values	Notes
Tracking Accuracy	High tracking accuracy is essential for a smooth user experience. Techniques like SLAM can enhance this.	High	Use SLAM techniques to improve accuracy
CPU Usage Ratio	Minimize CPU usage to prevent battery drain and overheating.	Low	Reduces energy consumption and heat generation
GPU Usage Ratio	Efficient GPU usage ensures smooth and fast content rendering.	Efficient	Improves graphics rendering and overall performance

Table 3.1-b: Dr. Mark Billingham Recommendations

Metric	Description	Target Values	Notes
Latency	Low latency is crucial for immediate response to interactions.	Low	Ensures quick response to enhance user experience
Memory Usage	Moderate memory (RAM) usage helps avoid performance slowdowns or app crashes.	Moderate	Contributes to stable performance
Rendering Time	Quick rendering time is necessary for a smooth user experience.	Fast	Reduces waiting time and enhances user experience
Frames Per Second	Consistent and high frame rate (typically 30 FPS or higher) ensures smooth display.	30 FPS or higher	Ensures smooth and dynamic content display

3.3.1. Tracking Accuracy

Tracking accuracy in augmented reality (AR) refers to the system’s capability to precisely determine and follow the position and orientation of objects or users within the physical environment. Key components of tracking accuracy include position accuracy, orientation accuracy, latency, drift, and environmental factors. This accuracy is essential for ensuring that virtual elements align correctly with the real world, directly influencing the quality of the AR experience.

3.3.2. CPU Usage Ratio

The CPU Usage Ratio indicates the percentage of the CPU’s capacity being utilized by a system or application. It reflects the amount of processing power consumed and is vital for assessing system performance. High CPU usage can lead to slower performance and increased heat, while low usage may indicate underutilization.

Monitoring and optimizing CPU usage is essential for ensuring efficient system operation, which will minimize the CPU usage to prevent battery drain and overheating.

3.3.3. GPU Usage Ratio

The GPU Usage Ratio indicates the percentage of the GPU's processing power being utilized by a system or application. It shows how much of the GPU's capacity is consumed, impacting performance in graphics-intensive tasks. High GPU usage can boost performance but may also increase heat and power consumption, while low usage might indicate underutilization. The framework supported monitoring and optimizing GPU usage as essential factors for achieving effective performance in graphics-heavy applications.

3.3.4. Latency

Latency refers to the time delay between an action and the system's response, typically measured in milliseconds. Lower latency results in quicker, more responsive interactions, while higher latency can lead to noticeable delays and impact performance. Reducing latency enhances overall system efficiency and improves the user experience. The framework was built to validated the product towards low latency as a crucial factor for immediate response to interactions. Ensures quick response to enhance user experience.

3.3.5. Memory Usage

Memory usage indicates the amount of RAM consumed by applications and processes. When memory usage is high, it can slow down system performance, whereas low memory usage means more resources are available. Keeping an eye on and optimizing memory usage is essential for maintaining smooth system operation and avoiding performance problems. Where the moderate memory (RAM) usage helps avoid performance slowdowns or app crashes. Contributes to stable performance.

3.3.6. Rendering Time

Rendering time refers to how long it takes for a system to create and display visual content. Shorter rendering times result in smoother visuals and enhanced performance, while longer times can cause delays and lower quality. To optimize rendering time, it's important to improve graphics processing and use efficient hardware. While quick

rendering time is necessary for a smooth user experience, which will reduce waiting time and enhances user experience.

3.3.7. Frames Per Second

Frames Per Second (FPS) indicates the number of frames shown each second in video or animation. Higher FPS values lead to smoother and more fluid motion, while lower FPS can result in choppy visuals. Ensuring a high FPS is crucial for an optimal visual experience, particularly in interactive and gaming applications. Consistent and high frame rate (typically 30 FPS or higher) ensures smooth display, and ensures smooth and dynamic content display.

3.3.8. Overall Performance

Overall performance assesses how well a system or application functions, considering metrics such as speed, responsiveness, and stability. It combines technical performance factors to provide a comprehensive view of effectiveness and efficiency, with optimization aimed at improving all aspects of performance for a smooth user experience.

3.4 Framework Development

3.4.1. Performance Platform development

A performance testing framework was developed using Python-Django to evaluate the performance of augmented reality (AR) applications. The framework was implemented using HTML, CSS, and Python programming within the Django framework, providing a robust and scalable development environment. Firebase was employed as the database platform, enabling efficient storage and analysis of performance metrics. The general architecture of the performance framework is illustrated in Fig.(3.1).

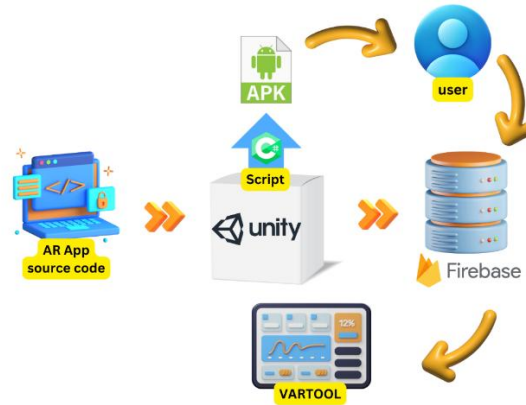


Figure 3.1: General architecture for performance platform

The framework comprises three primary components working together seamlessly. The platform development layer, constructed using HTML, CSS, and Python within the Django framework, serves as the foundation for the system. The Unity platform integrates augmented reality functionalities, ensuring that AR applications can deliver immersive and responsive experiences. The Firebase database layer is essential for storing and analyzing performance metrics, facilitating real-time data collection and providing actionable insights to support the evaluation and optimization process.

3.4.2. Design Architecture

The VARTOOL design architecture is illustrated in figure (3.2), outlining a structured workflow aimed at effectively evaluating the performance of augmented reality (AR) applications. The process begins by importing the application's source code into the Unity platform, followed by the integration of additional C# scripts. These scripts are specifically designed to measure various performance metrics, which are subsequently stored as objects within the application. The details of these performance metric measurements are presented in Appendix A. Furthermore, C# scripts responsible for transmitting these metrics to Firebase are incorporated into the application, with the technical specifics outlined in Appendix B.

Once these scripts are in place, the application is exported as an APK file, making it ready for end-user deployment and testing. Upon user interaction with the application, the tool engages with Firebase, following the data transmission and storage mechanism with the technical specifics outlined in Appendix B. Alongside this, users are presented with a survey to capture their feedback regarding their experience with the application.

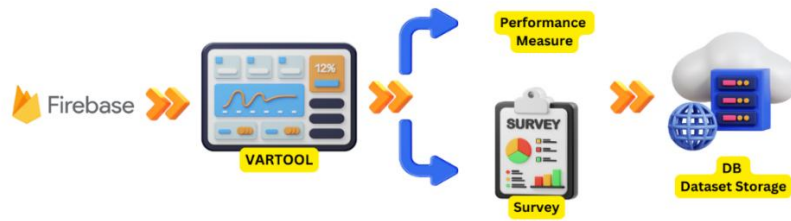


Figure 3.2: Tool flow architecture

The survey results are systematically analyzed and compared with the performance metrics collected by the tool. This comparative analysis provides insights into how technical performance impacts user satisfaction and engagement. All collected data, including performance metrics and survey results, is securely stored in the Firebase database for further evaluation and long-term tracking. This integrated approach ensures that both quantitative performance data and qualitative user feedback are leveraged to enhance the application’s usability and overall effectiveness.

Measuring performance metrics

The Performance Metrics class in Unity is an essential tool for optimizing AR applications. It enables developers to monitor and assess crucial performance metrics such as frame rate, latency, and tracking accuracy. By defining custom thresholds and emphasizing specific metrics, developers can ensure their AR applications achieve optimal performance. The class integrates with Unity's Profiler for comprehensive analysis and offers a clear visual representation of data flow. The diagram presented in fig. (3.3) demonstrates the mechanism used in our tool. With effective utilization of this class, developers can pinpoint and resolve performance bottlenecks, enhancing the overall AR experience for users.

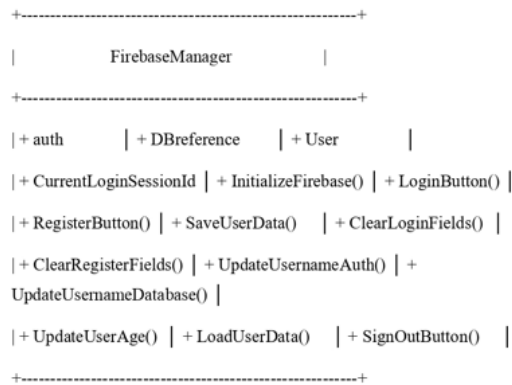


Figure 3.4: Firebase Manager Class Overview

To facilitate seamless integration between the VARTOOL framework and Firebase, the process involves initializing and configuring Firebase services within the Django environment. The integration begins by importing essential libraries, such as `firebase_admin` and the `credentials` module, which enable interaction with Firebase. The Firebase Admin SDK credentials, stored in a secure JSON file like `serviceAccountKey.json`, are loaded using `credentials.Certificate()`. This step ensures secure access to Firebase services by authenticating the connection between the tool and Firebase.

After loading the credentials, the system checks whether the Firebase application is already initialized using `firebase_admin.get_app()`. If the app has not been initialized, it is configured using `firebase_admin.initialize_app(cred)`, establishing the foundational connection required to utilize Firebase services. Once initialized, the integration allows access to key Firebase services, such as Firestore, which can be accessed via `firebase_admin.firestore.client()`. Firestore acts as a central repository for storing performance metrics and user feedback collected during tool operation.

Within the Django project, additional configurations are added to the `settings.py` file to optimize Firebase functionality. The `DATABASE_URL` parameter is set to point to Firebase's Realtime Database, ensuring real-time data synchronization. Optionally, the `DEFAULT_AUTO_FIELD` is configured as `django.db.models.BigAutoField` to support large primary keys for Django models, enabling scalable data management.

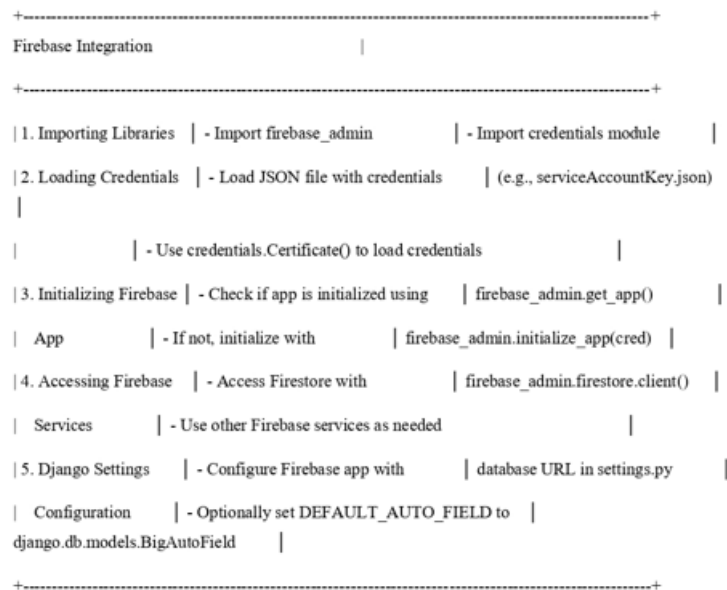


Figure 3.5: Integration Between the Tool and Firebase

This integration enables efficient data flow between VARTOOL and Firebase, ensuring that performance metrics and user feedback are securely transmitted, stored, and accessible for analysis. By combining the flexibility of Firebase with the robustness of Django, the system supports real-time performance monitoring and iterative improvements, forming the backbone of a scalable and responsive AR performance evaluation framework.

3.5 Framework Testing and Evaluation

The effectiveness of the developed framework was tested by evaluating its performance across three distinct augmented reality (AR) applications. These applications, selected for their diverse functionalities and target audiences, provided a comprehensive basis for assessing the framework's ability to measure performance metrics and enhance user experience. The applications include *Farah*, *Dar Al-Consul Jerusalem*, and *Easy AR*, each representing unique use cases and interaction designs. By analyzing these applications, the study aimed to gather insights into tracking accuracy, cognitive engagement, and usability in varied AR environments, ultimately validating the framework's reliability and adaptability.

The Farah application (Figure 3.6) is an interactive educational tool designed to raise awareness about children’s rights in Palestine. It integrates AR elements with a coloring book, engaging children through activities such as coloring, finding hidden stars, and watching videos. The app’s main characters, Farah and Adam, serve as relatable figures for children, fostering conversations about future aspirations and fundamental rights. The study evaluated the app’s ease of learning, cognitive processing, and overall performance metrics, focusing on its ability to deliver an engaging and educational experience for children.

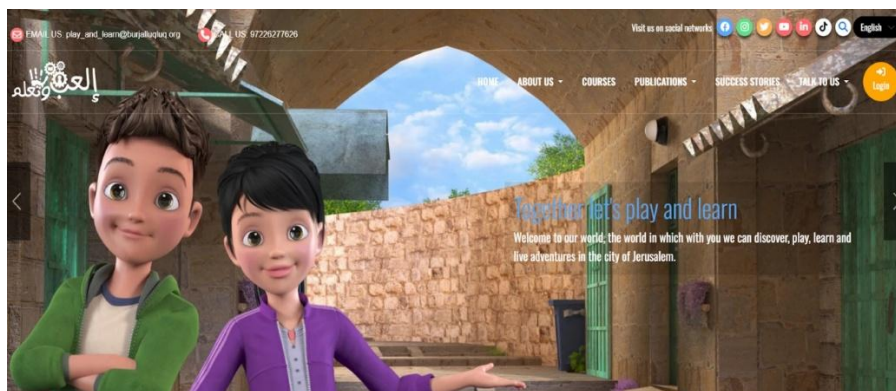


Figure 3.6 : Farah App

The Dar Al-Consul Jerusalem application (Figure 3.7) offers a cultural and historical AR experience. Developed as part of a collaboration involving the EU, UN-Habitat, CTS, and Al-Quds University, the app immerses users in the history of Jerusalem’s Old City. By overlaying AR elements onto reconstructed spaces of the Dar Al Consul Community and Civic Center, the app brings historical narratives to life. Visitors can explore features like the ancient water canal along the Cardo street, gaining insights into the city’s rich history. This app was evaluated for its ability to create immersive storytelling and enhance cultural education through AR.

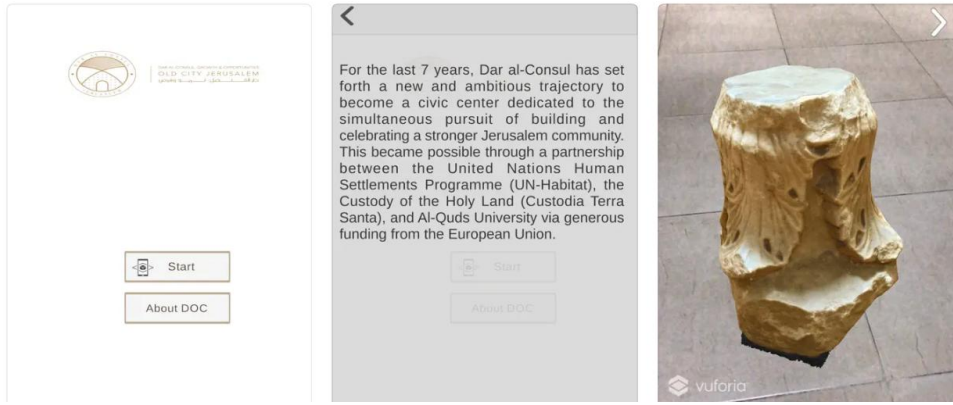


Figure 3.7: Dar-Al Consul App

The Easy AR application, built using Unity’s AR Foundation, simplifies AR development by offering a user-friendly platform requiring no prior coding knowledge. This tool provides multiple utility scenes, including vertical and horizontal object placement, AR measurement, and face filters, among others.

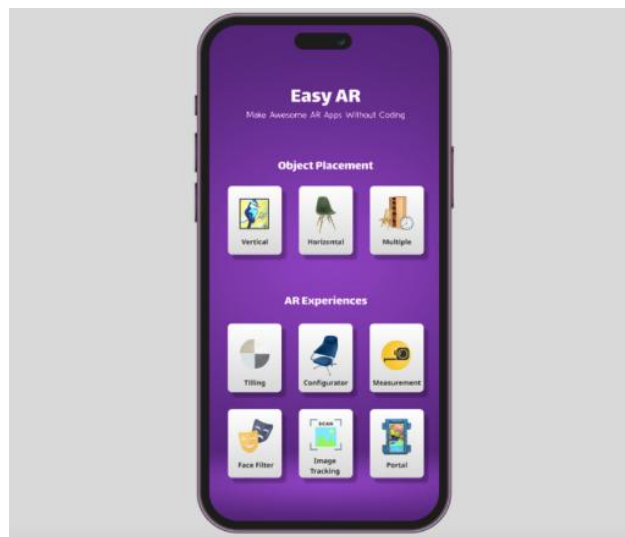


Figure 3.8: Easy AR App

Updated features, such as image and face tracking demos, enable developers to create immersive AR content effortlessly. The framework was used to assess the app’s tracking accuracy, usability, and overall performance in delivering seamless AR experiences.

By testing these applications, the study aimed to demonstrate the framework’s capability to measure and enhance AR performance across educational, cultural, and general-purpose AR applications.

3.5.1. Experimental Setup

The experiment was conducted in two different settings to evaluate the usability of three augmented reality (AR) applications: EasyApp, Farah, and Dar Al Consul (DAC).

For EasyApp, the experiment was designed with an open-ended approach, allowing participants to interact with the application in a more flexible environment. They were given the freedom to explore the app's features independently, with minimal guidance, within a controlled, distraction-free room. The experiment duration was open-ended, with no time constraints, allowing participants sufficient time to fully explore the application.

In contrast, the experiments for Farah and DAC followed a closed setup. For Farah, participants were assigned specific tasks, including coloring a picture, searching for hidden stars, and watching an educational video. These tasks were designed to guide users through the app's core features, with their progress being closely monitored.

Similarly, DAC, which targets the tourism sector, focused on a more structured set of interactions for participants. The experiments for both Farah and DAC were carefully controlled, with clear instructions provided to users before starting the tasks.

Real-time data for technical performance metrics was recorded across all three environments. Once participants completed the tasks, they were asked to respond to a System Usability Scale (SUS) questionnaire. The tool then collected and stored the data for comparison with the performance metrics, allowing for the evaluation of the correlation between them.

3.5.2. Performance Measurement and Data Logging

In this project, two primary scripts are used to measure and analyze application performance in Unity, ensuring that performance metrics are collected and stored efficiently for further evaluation.

The PerformanceTest script (Appendix A) is responsible for collecting various performance metrics, including CPU usage, frames per second (FPS), latency, response

time, and render time. Upon execution, the script computes these values and transmits them to a Firebase database using RestClient, enabling real-time performance tracking.

The User script (Appendix B) functions as a data model, structuring and storing performance metrics for each task. This script retrieves performance values directly from MainTask, ensuring that key metrics such as completion rate, error rate, and execution time are systematically recorded for further analysis or database transmission.

These two scripts work in tandem to ensure accurate performance logging and evaluation. The PerformanceTest script captures real-time performance data, while the User script organizes and prepares the collected data for structured analysis and storage. This integration facilitates performance monitoring, optimization, and informed decision-making to enhance overall application efficiency.

3.5.3. Data collection

The data collection process involved two primary components: performance data and survey data, both of which were systematically gathered and analyzed to evaluate the effectiveness of the augmented reality (AR) applications.

Performance Data:

The collection of performance metrics was fully automated through seamless integration between Unity and Firebase. During user interactions with the AR applications, the performance data—such as tracking accuracy, latency, memory usage, and frame rates—was automatically recorded in the Firebase database. This integration ensured real-time data logging and storage without requiring manual intervention. Additionally, the integration between the VARTOOL and Firebase facilitated the retrieval of this data, which was subsequently displayed on the VARTOOL dashboard.

Figures 3.9 and 3.10 illustrate the dashboard interface, where performance data was presented in an organized and user-friendly format. The dashboard allowed developers to visualize key metrics at a glance, enabling a thorough analysis of the applications' technical performance and identifying areas for optimization. This streamlined data management and visualization process ensured that actionable insights could be derived efficiently.

Survey Data:

Upon completing their interaction with the AR applications, users were prompted to complete a survey presented through the tool interface. The survey responses were then stored in the Firebase database for subsequent analysis.

A critical component of this survey was the use of the System Usability Scale (SUS), a well-established tool for assessing the usability and ease of use of products or systems. The SUS questionnaire comprises ten items rated on a 5-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree." These items evaluate key dimensions of usability, such as ease of use, efficiency, clarity, consistency, and error frequency [38].

The SUS scores are calculated on a scale from 0 to 100, where higher scores represent a superior user experience. This metric is widely recognized for its simplicity, reliability, and versatility across various domains. It provides a quick yet effective means of measuring user satisfaction and identifying usability challenges. The SUS is particularly valued for its ease of administration, as it requires minimal effort from users while offering robust insights for researchers and developers.

The integration of performance data with user feedback collected through the SUS allowed for a comprehensive evaluation of the AR applications. This dual approach ensured that technical performance metrics were aligned with user-centric insights, enabling a holistic understanding of how the applications performed both functionally and experientially.



Figure 3.9: VARTOOL Dashboard

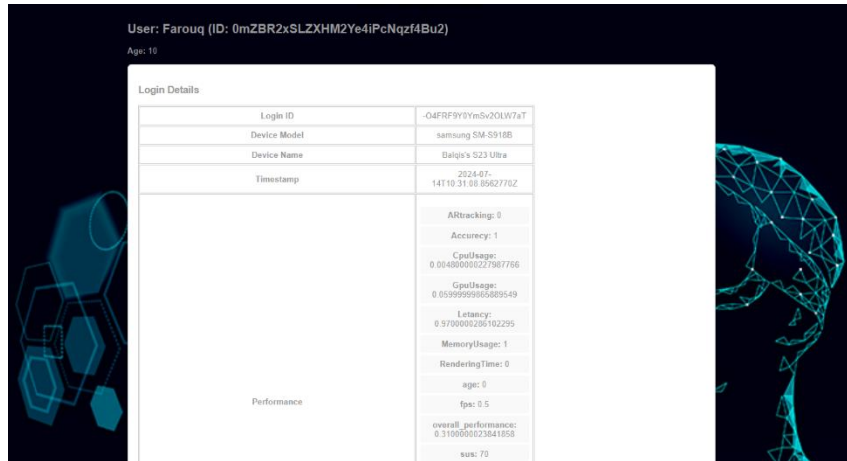


Figure 3.10: Dashboard Performance Data

3.5.4. Data Analysis

- **Performance Parameters**

In evaluating augmented reality (AR) applications, it is crucial to examine a variety of performance parameters to understand the application's efficiency, usability, and responsiveness. These parameters provide a quantitative basis for identifying strengths and weaknesses within the application's functionality. Below are the key performance measures and their respective formulas, which serve as the foundation for the analysis.

Table 3.2-a Performance Parameters

Testing Measures	Rate – Value
Latency	Latency= Time Response –Time Input
Frame Rate	FPS=1/Frame Duration
Accuracy	Accuracy= Number of Correctly Tracked Points/ Total Number of Points
CPU Usage	CPU Usage=CPU Time/total time ×100%
GPU Usage	GPU Usage=GPU Time/total time ×100%
Memory Usage	Memory Usage= Memory Used/Total Memory×100%

Table 3.2-b Performance Parameters

Testing Measures	Rate – Value
Rendering Time	Rendering Time=1/FPS
Overall Performance	$\text{Overall Performance} = w_1 \times \text{Normalized Accuracy} + w_2 \times \text{Normalized FPS} - w_3 \times \text{Normalized Latency} - w_4 \times \text{Normalized CPU Usage} - w_5 \times \text{Normalized GPU Usage}$ <p>Where Normalized factor = $\frac{\text{factor} - \text{factor}^{\text{Min}}}{\text{factor}^{\text{Max}} - \text{factor}^{\text{Min}}}$</p>

The System Usability Scale (SUS) is a widely recognized and effective metric for assessing the ease of use and overall user satisfaction with a system. This simple yet reliable tool provides valuable insights into the usability of various systems, including augmented reality (AR) applications. The SUS score is calculated through a straightforward process that evaluates user responses to a series of 10 questions, each rated on a 5-point Likert scale ranging from "Strongly Disagree" to "Strongly Agree."

To compute the SUS score, responses to the odd-numbered questions (1, 3, 5, 7, and 9) are adjusted by subtracting 1 from the original score. These questions are positively framed, so the adjustment aligns their scoring with the overall scale. For even-numbered questions (2, 4, 6, 8, and 10), which are negatively framed, the adjusted score is calculated by subtracting the original response from 5. This adjustment ensures that the scoring system accounts for both positive and negative phrasing, maintaining a balanced evaluation.

After adjusting all responses, the total score is obtained by summing the adjusted values for all 10 questions. This total is then multiplied by 2.5, scaling the result to a range from 0 to 100. A higher SUS score reflects a more favorable user experience, indicating that the system is perceived as intuitive, efficient, and user-friendly. The SUS score is not only easy to compute but also provides actionable insights, making it a popular choice across various domains, including AR applications.

To further analyze the results, the average SUS score for each AR application is compared with its corresponding average overall performance metrics. This comparative approach identifies discrepancies between technical performance and

user-perceived usability. For example, an application with high technical efficiency may still score poorly in usability due to interface design issues or inadequate user guidance. By highlighting such gaps, developers can pinpoint areas requiring improvement and implement targeted enhancements to align technical performance with user satisfaction.

This method of evaluating and comparing SUS scores against performance metrics ensures a holistic understanding of the application's strengths and weaknesses. It enables developers to refine the system, address user pain points, and ultimately deliver a more seamless and satisfying AR experience.

Chapter 4: Results and Analysis

4.1 Performance Analysis

The framework was tested by evaluating the performance of three augmented reality (AR) applications—Educational, Tourism, and Gaming—with 20 volunteer users spanning a range of ages. Each user engaged with the applications on devices from Samsung. Performance metrics were recorded, and user feedback was collected through a questionnaire to gain insights into user experience and satisfaction.

4.1.1. Farah App Testing and Analysis

The results presented in Table 4.1 suggest that augmented reality (AR) tracking accuracy plays a significant role in influencing overall user satisfaction and performance outcomes in the Farah App. Users who exhibited higher tracking accuracy, such as User 19 (0.52) and User 6 (0.34), reported higher System Usability Scale (SUS) scores and demonstrated improved performance, indicating that accurate tracking positively affects user engagement and satisfaction. In contrast, users with lower tracking accuracy, such as User 1 (0.01) and User 2 (0.00), generally reported lower SUS scores, suggesting a diminished user experience likely attributed to tracking inconsistencies. These findings emphasize the importance of tracking accuracy as a critical factor in enhancing user satisfaction and the perceived effectiveness of the app.

CPU and GPU usage were consistent across all participants, averaging 0.50 and 0.005, respectively. This stability in resource consumption implies that the application is optimized in its use of processing power, ensuring that device performance remains steady regardless of user age or tracking quality. The consistent CPU and GPU metrics across all users highlight those fluctuations in satisfaction and performance scores are

not attributed to device capability limitations but rather to other variables, such as tracking accuracy and individual familiarity with AR features.

Latency, memory usage, and rendering time metrics were also stable across users, with latency at 0.060, memory usage near 0.97, and rendering time fixed at 0.01. This technical stability suggests the app is designed to provide responsive and smooth interactions, which likely reduces the potential for lag-related user dissatisfaction. The frame rate (FPS) was similarly steady at 1.0 across all users, contributing to a visually smooth experience, essential for maintaining an immersive AR environment. Although these metrics were consistent, the variations in SUS scores across users imply that while stable visuals are necessary, they are insufficient alone for optimal user satisfaction without accurate tracking performance.

Table 4.1 Farah App Performance Result

User	Age	ART	ACCU	CPU U	GPU	Latency	Memory Usage	RT	fps	Performance	SAT
user 1	42	0.01	0.50	0.005	0.06	0.9	0.01	1	0.5	0.28	50
user 2	40	0.00	0.50	0.0050	0.06	0.97	0.01	1	0.5	0.28	51
user 3	37	0.06	0.50	0.0053	0.06	0.97	0.01	1	0.5	0.28	53
user 4	33	0.41	0.50	0.0052	0.06	0.97	0.019	1	0.5	0.31	70
user 5	29	0.25	0.50	0.0052	0.06	0.97	0.01	1	0.5	0.31	70
user 6	31	0.34	0.50	0.0052	0.06	0.97	0.01	1	0.5	0.31	76
user 7	28	0.25	0.50	0.0051	0.06	0.97	0.01	1	0.5	0.30	75
user 8	18	0.27	0.50	0.0052	0.06	0.97	0.01	1	0.5	0.30	71
user 9	15	0.25	0.50	0.0052	0.06	0.97	0.01	1	0.5	0.31	78
user 10	13	0.20	0.50	0.0052	0.06	0.97	0.01	1	0.5	0.30	75
user 11	10	0.50	0.50	0.0052	0.06	0.97	0.01	1	0.5	0.31	69
user 12	9	0.01	0.50	0.0052	0.06	0.97	0.01	1	0.5	0.28	60
user 13	9	0.45	0.50	0.0052	0.06	0.97	0.01	1	0.5	0.31	60
user 14	8	0.43	0.50	0.0052	0.06	0.97	0.01	1	0.5	0.31	50
user 15	6	0.34	0.50	0.0052	0.06	0.97	0.01	1	0.5	0.31	60
user 16	6	0.21	0.50	0.0051	0.06	0.97	0.01	1	0.5	0.30	61
user 17	9	0.37	0.50	0.0054	0.05	0.97	0.01	1	0.5	0.31	50
user 18	8	0.27	0.50	0.0052	0.05	0.97	0.01	1	0.5	0.30	65
user 19	7	0.52	0.50	0.0054	0.05	0.97	0.01	1	0.5	0.31	63
user 20	5	0.349	0.50	0.0055	0.05	0.97	0.01	1	0.5	0.31	59

Age appears to influence SUS scores, with older users, particularly those aged 29–33 (such as Users 4, 5, and 6), achieving higher SUS scores ranging from 70 to 76, compared to younger users who generally reported lower SUS scores. This trend may suggest that older users possess a higher familiarity with AR applications or digital interactions, enhancing their comfort and satisfaction with the app. In contrast, younger users (ages 5–10) reported lower SUS scores, which may reflect usability challenges unique to this age group, such as interaction complexities or a need for simplified features that align better with their interaction patterns and preferences.

The analysis also indicates that tracking accuracy appears to have a more significant impact on user satisfaction and performance than other technical metrics. Despite uniform CPU, GPU, latency, memory usage, and FPS, variations in SUS scores across users demonstrate that tracking stability is vital in achieving high satisfaction ratings, as it directly affects how naturally users can interact with the app's AR features. Overall, the findings from Table 4.1 suggest that while the Farah App performs well in terms of stable resource management and visual smoothness, improvements in AR tracking accuracy and possibly user interface adjustments for younger users would enhance the overall user experience and bring satisfaction levels to a more consistent standard across all age groups. By refining tracking and interface elements, the Farah App can align technical performance with user-centered design, ensuring a balanced and satisfying AR experience for a diverse user base.

The results in Table 4.2 present statistical insights into the performance of the Farah App, specifically examining overall performance, variability, correlations, and group differences. The mean overall performance score of 0.304 indicates a moderate level of user performance across the app's interactions, suggesting that, on average, users were able to engage with the application effectively, although there may still be room for improvement to enhance user satisfaction and performance further.

Table 4.2 Farah App Performance statistic Result

Statistic	Value
Mean of overall Performance	0.30400
Standard Deviation	0.18540
Age-Performance Correlation	0.19560
SUS-Performance Correlation	0.11940
ANOVA F-value	1.16089
ANOVA P-value	0.42658

The standard deviation of 0.1854 reflects some variability in overall performance among users. This spread around the mean indicates that user experiences varied, possibly influenced by individual factors such as familiarity with AR technology, age, or specific app usage behavior. This level of variation suggests that while the app generally maintains a moderate performance, certain users encountered challenges that impacted their experience and effectiveness with the app.

The age-performance correlation of 0.1956 suggests a weak positive relationship between age and performance, implying that performance slightly improves with age. This weak positive trend might indicate that older users are more adept at using the app, potentially due to greater familiarity with similar technologies or better understanding of interactive AR features. However, the correlation is not strong, which implies that age alone is not a major factor in determining performance outcomes.

The SUS-performance correlation of 0.1194 is similarly weakly positive, indicating only a slight relationship between users' SUS scores (a measure of usability satisfaction) and their overall performance. This result suggests that while higher performance may contribute slightly to satisfaction, other factors—such as interface design, AR tracking accuracy, and individual ease with the app—might have a more substantial impact on users' perceived usability.

The ANOVA F-value of 1.1609 with a corresponding P-value of 0.4266 suggests that there are no statistically significant differences in overall performance across different age groups. The P-value exceeds the typical significance threshold (0.05), meaning that any observed differences in performance among age groups are likely due to random variation rather than inherent distinctions based on age. This result underscores that,

while age may slightly influence performance, it does not appear to be a strong determinant of user success in interacting with the Farah App.

4.1.2. Dar AI-Consol AR Testing and Analysis

The results from Table 4.3 reveal key aspects of the Dar AI-Consul AR app’s performance across different user demographics, particularly focusing on AR tracking accuracy, CPU and GPU usage, latency, memory usage, rendering time, frame rate (FPS), overall performance, and SUS scores. The app demonstrates strong technical stability, with consistent CPU usage (1.00) and GPU usage (0.0046) across all users, suggesting that the application effectively utilizes device resources without imposing high variability or demands on system processing power.

AR tracking accuracy shows a high and stable value across most users (averaging around 0.50), indicating reliable tracking capabilities that are essential for providing an immersive and realistic AR experience. The data suggests that users with higher AR tracking accuracy generally report higher SUS scores, which measure user satisfaction. For instance, users like User 4 (age 33, tracking accuracy of 0.50) achieved high SUS scores (91), reflecting a positive relationship between effective tracking and user satisfaction. However, lower accuracy scores, as seen with User 1 (tracking accuracy of 0.05), correlate with a lower SUS score (66), emphasizing that precise tracking is crucial for maximizing user engagement and satisfaction.

Table 4.3-a Dar AI-Consul App Performance Result

User	Age	ART	ACCU	CPU U	GPU	Latency	Memory Usage	RT	fps	Performance	SAT
user 1	42	0.05	1.00	0.0046	0.06	0.97	0.10	0.52	0.09	0.21	66
user 2	40	0.50	1.00	0.0046	0.06	0.97	0.10	0.56	0.50	0.34	67.5
user 3	37	0.49	1.00	0.0046	0.06	0.97	0.10	0.52	0.50	0.28	68
user 4	33	0.50	1.00	0.0046	0.06	1.0	0.10	0.52	0.79	0.43	91
user 5	29	0.50	1.00	0.0046	0.060	0.97	0.10	0.56	1.0	0.50	88
user 6	31	0.50	1.00	0.0046	0.06	1.0	0.10	0.52	1.0	0.46	87.5
user 7	28	0.50	1.00	0.0046	0.06	1.0	0.10	0.52	1.0	0.49	85.5
user 8	18	0.50	1.00	0.0046	0.06	0.97	0.10	0.56	1.0	0.46	93
user 9	15	0.50	1.00	0.0046	0.06	1.0	0.10	0.56	1.0	0.46	89.5
user 10	13	0.50	1.00	0.0046	0.06	0.97	0.10	0.56	0.28	0.28	78
user 11	10	0.50	1.00	0.0046	0.06	0.97	0.10	0.56	0.50	0.28	70
user 12	9	0.46	1.00	0.0046	0.06	0.97	0.10	0.56	0.50	0.34	68

Table 4.3-b Dar AI-Consul App Performance Result

User	Age	ART	ACCU	CPU U	GPU	Latency	Memory Usage	RT	fps	Performance	SAT
user 13	9	0.47	1.00	0.0046	0.06	0.97	0.10	0.56	0.50	0.34	67
user 14	8	0.5	1.00	0.0046	0.06	0.97	0.10	0.56	0.15	0.23	55.5
user 15	6	0.50	1.00	0.0046	0.06	0.97	0.10	0.56	0.25	0.27	67.5
user 16	6	0.46	1.00	0.0046	0.06	0.97	0.10	0.56	0.50	0.38	64
user 17	9	0.50	1.00	0.0046	0.06	0.97	0.10	0.56	0.50	0.34	50
user 18	8	0.50	1.00	0.0046	0.06	0.93	0.10	0.56	0.09	0.17	69
user 19	7	0.50	1.00	0.0046	0.06	0.97	0.10	0.56	0.50	0.34	66
user 20	5	0.50	1.00	0.0046	0.06	0.97	0.10	0.56	0.50	0.34	60

- *ART: AR tracking; CPU, GPU usages; RT: rendering time; FPS: Frame /second; SAT; Satisfaction*

Latency remains low and consistent at 0.06 for most users, which helps minimize lag and enhances real-time interaction within the app. Memory usage is also stable, averaging 0.97, showing efficient memory management and ensuring a smooth user experience without significant variability. Rendering time is slightly higher than in previous apps at 0.10 but is consistent across all users, allowing for prompt visual updates without causing delays that might disrupt the experience.

FPS consistency across users further supports the app’s ability to maintain smooth visual output, with values averaging around 1.0 for most participants. This stability contributes to a high-quality visual experience, a key factor in preventing issues such as motion sickness or visual fatigue, which are common concerns in AR applications.

The SUS scores vary, with younger users (ages 5-10) generally scoring lower in satisfaction (averaging around 60-70), while older users (ages 29–33) score higher (averaging 87–91). This trend suggests that older users may find the app easier to use, possibly due to greater familiarity with technology or higher tolerance for minor tracking inconsistencies. Conversely, younger users may benefit from simplified interactions or more intuitive design elements to better align the app’s functionality with their comfort levels.

The results in Table 4.4 provide valuable insights into the performance and user satisfaction outcomes for the Dar AI-Consul AR app. The mean overall performance score of 0.3115 indicates a moderate level of consistent performance among users. The relatively low standard deviation of 0.0085 reflects minimal variability in performance

scores, suggesting that the application delivers a stable experience across different users, with only minor fluctuations in performance outcomes.

The age-performance correlation of -0.1271 indicates a weak negative relationship between age and overall performance, suggesting that younger users may experience slightly higher performance scores than older users. Although this relationship is not strong, it may reflect younger users' potential adaptability to AR interfaces or their ease in navigating the app's features. However, the weak correlation suggests that age is not a significant determinant of performance, and other factors may play a larger role in influencing user success with the app.

The SUS-performance correlation of -0.2505 also shows a weak negative relationship between user satisfaction (SUS scores) and performance. This finding suggests that users with slightly higher performance scores do not necessarily report higher satisfaction. This may indicate that, while the app performs consistently from a technical perspective, users' subjective experiences and satisfaction are influenced by other elements, such as interface design or tracking accuracy.

Table 4.4 Dar-AI Consul App Performance statistic Result

Statistic	Value
Mean of overall Performance	0.3115
Standard Deviation	0.0085
Age-Performance Correlation	-0.1271
SUS-Performance Correlation	-0.2505
ANOVA F-value	10.035
ANOVA P-value	0.0094

This weak negative correlation highlights the importance of addressing usability elements that contribute to user satisfaction beyond technical performance.

The ANOVA analysis, with an F-value of 10.035 and a P-value of 0.0094, indicates a statistically significant difference in performance outcomes between different user groups at a 99% confidence level. This significant P-value suggests that there are

genuine performance differences across groups, which could be attributed to factors such as familiarity with AR technology or varying expectations across age groups.

4.1.3. Easy AR Testing and Analysis

The analysis from Table 4.5 provides insights into the performance and usability of the Easy AR application across a diverse user demographic. The key metrics measured include AR tracking accuracy, CPU and GPU usage, latency, memory usage, rendering time, FPS, overall performance, and SUS (System Usability Scale) scores.

Overall, CPU and GPU usage are consistent at approximately 0.50 and 0.0052 across all users, suggesting the application manages system resources effectively and provides a stable experience without overtaxing the device. This stability across processing metrics supports the app’s technical reliability, indicating that users experience a uniform processing load that does not vary significantly with age or interaction style. Latency, too, remains stable at 0.060 for nearly all users, which is essential for maintaining real-time responsiveness and minimizing lag, a critical factor in AR applications where delayed response times can disrupt user immersion.

Table 4.5-a: Easy AR App Performance Result

User	Age	ACCU									
		ART	CPU U	GPU	Latency	Memory Usage	RT	fps	Performance	SAT	
user 1	42	0.01	0.50	0.0052	0.060	0.97	0.01	1	0.5	0.28	55
user 2	40	0.00	0.50	0.0050	0.060	0.97	0.01	1	0.5	0.28	50
user 3	37	0.45	0.50	0.0052	0.060	0.97	0.01	1	0.5	0.31	61
user 4	33	0.41	0.50	0.0052	0.060	0.97	0.019	1	0.5	0.31	80
user 5	29	0.43	0.50	0.0052	0.060	0.97	0.01	1	0.5	0.31	85
user 6	31	0.34	0.50	0.0052	0.060	0.97	0.01	1	0.5	0.31	83
user 7	28	0.25	0.50	0.0051	0.060	0.97	0.01	1	0.5	0.30	80
user 8	18	0.27	0.50	0.0052	0.060	0.97	0.01	1	0.5	0.30	85
user 9	15	0.25	0.50	0.0052	0.060	0.97	0.01	1	0.5	0.31	86
user 10	13	0.20	0.50	0.0052	0.060	0.97	0.01	1	0.5	0.30	80
user 11	10	0.50	0.50	0.0052	0.060	0.97	0.01	1	0.5	0.31	65
user 12	9	0.01	0.50	0.0052	0.060	0.97	0.01	1	0.5	0.28	55
user 13	9	0.06	0.50	0.0053	0.060	0.97	0.01	1	0.5	0.28	55
user 14	8	0.00	0.50	0.0052	0.060	0.97	0.01	1	0.5	0.28	50
user 15	6	0.34	0.50	0.0052	0.060	0.97	0.01	1	0.5	0.31	61
user 16	6	0.21	0.50	0.0051	0.060	0.97	0.01	1	0.5	0.30	60
user 17	9	0.37	0.50	0.0054	0.050	0.97	0.01	1	0.5	0.31	60

Table 4.5-b: Easy AR App Performance Result

user 18	8	0.27	0.50	0.0052	0.059	0.97	0.01	1	0.5	0.30	60
user 19	7	0.52	0.50	0.0054	0.050	0.97	0.01	1	0.5	0.31	61
user 20	5	0.349	0.50	0.0055	0.059	0.97	0.01	1	0.5	0.31	60

- *ART: AR tracking; CPU, GPU usages; RT: rendering time; FPS: Frame /second; SAT: Satisfaction*

AR tracking accuracy shows some variability among users, with values ranging from as low as 0.00 (User 2) to a high of 0.52 (User 19). Users with higher tracking accuracy, such as Users 5, 9, and 19, tend to report higher SUS scores, indicating a correlation between effective tracking and user satisfaction. For instance, User 5, who demonstrates an accuracy of 0.43, reports a SUS score of 85, while User 9, with an accuracy of 0.25, has a similarly high SUS score of 86. These observations underscore that precise tracking enhances user experience and satisfaction, as reflected in higher SUS scores. In contrast, users with low tracking accuracy, like User 2 and User 14 (both with 0.00 accuracy), report the lowest SUS scores (50), suggesting that insufficient tracking accuracy can detract from the AR experience, leading to frustration or reduced engagement.

Memory usage, rendering time, and FPS are stable across users, with memory usage consistently at 0.97, rendering time at 0.01, and FPS steady at 1. This stability in memory and rendering metrics ensures smooth visual output and efficient memory management, reducing the likelihood of performance-related disruptions. The consistent FPS also supports a smooth visual experience, which is critical for maintaining immersion and preventing visual fatigue. However, despite this technical consistency, variations in SUS scores indicate that subjective user satisfaction may rely more heavily on tracking accuracy and usability factors than on purely technical performance metrics.

The SUS scores also exhibit age-related trends, with younger users (ages 5–10) generally scoring lower in satisfaction (around 55-65) than older users (ages 13–42), who report higher scores (around 75-85). This difference suggests that younger users may find the app less intuitive or more challenging to navigate, possibly due to age-appropriate design limitations. The moderate SUS scores among younger users may indicate a need for interface adjustments or additional usability enhancements tailored to younger age groups to make the application more accessible.

The results in Table 4.6 offer insights into the performance consistency and user satisfaction for the Easy AR app, using metrics such as the mean overall performance, standard deviation, age-performance correlation, SUS-performance correlation, and ANOVA results.

The mean overall performance score of 0.355 indicates a moderate level of effectiveness across users, suggesting that the application generally meets user expectations in terms of functionality and usability. The standard deviation of 0.0059 reflects very low variability in overall performance scores, indicating that users experience a consistent level of performance regardless of individual factors such as age or familiarity with AR applications. This low standard deviation suggests that the app is well-optimized to deliver a uniform experience across a diverse user base.

The age-performance correlation of -0.1043 shows a weak negative relationship, implying that younger users tend to perform slightly better than older users. However, this correlation is weak and does not suggest a significant impact of age on performance, indicating that factors other than age are likely influencing overall app interaction outcomes. This weak negative correlation may point to a minor tendency for younger users to interact more fluidly with the app, possibly due to familiarity with similar technology, but it is not a defining factor.

Table 4.6 Easy App Performance statistic Result

Statistic	Value
Mean of overall Performance	0.35500
Standard Deviation	0.00590
Age-Performance Correlation	-0.10430
SUS-Performance Correlation	0.21005
ANOVA F-value	0.65408
ANOVA P-value	0.59197

The SUS-performance correlation of 0.21005 is a weak positive relationship, indicating that as performance scores increase, user satisfaction (as measured by the SUS) also slightly increases. This suggests that users who achieve higher performance levels tend to report somewhat higher satisfaction with the app's usability and functionality.

However, the weak correlation indicates that other factors beyond performance likely contribute significantly to user satisfaction, such as user interface design or individual interaction preferences.

The ANOVA F-value of 0.65408 and the P-value of 0.59197 suggest no statistically significant differences in performance scores across different user groups. The high P-value (greater than 0.05) implies that any observed differences in performance across age groups are likely due to random variation rather than inherent differences. This result reinforces the consistency of the app's performance, indicating that it provides a stable experience across age demographics without favoring any particular user group.

The analysis of performance factors across the three applications (DAC, FARAH, and EasyAPP) reveals notable variations as indicated in table 4.7 . The average user age is consistent at 18.15 years for all applications, with a statistically significant association ($p < 0.05$), indicating the relevance of this demographic in performance analysis. AR tracking (ART) performance is highest for DAC at 0.47, compared to FARAH (0.27445) and EasyAPP (0.26195), with all values statistically significant ($p < 0.05$). This suggests that DAC provides a superior tracking experience, which likely enhances user interaction.

In terms of accuracy (ACC), DAC achieves a perfect score of 1, while FARAH and EasyAPP score 0.5 each, demonstrating DAC's advantage in maintaining precise operations. CPU usage is slightly lower for DAC (0.0046) than for FARAH (0.00521) and EasyAPP (0.00522), reflecting comparable efficiency across applications. GPU usage shows a statistically significant difference ($p < 0.05$), with DAC slightly outperforming the others at 0.06, compared to 0.0589 for FARAH and EasyAPP. Latency values are similar across all applications, with DAC at 0.974, FARAH at 0.9665, and EasyAPP at 0.97, indicating minimal differences in response times.

Memory usage reveals that DAC consumes more resources (0.1) compared to FARAH and EasyAPP, both at 0.01045, which suggests a trade-off between resource efficiency and enhanced performance features like accuracy and AR tracking. Rendering time is faster for FARAH and EasyAPP, both scoring 1, compared to DAC at 0.55, suggesting these two applications provide smoother visual rendering.

Frames per second (FPS) performance is statistically significant ($p < 0.05$), with DAC achieving 0.5575, outperforming FARAH and EasyAPP, which both score 0.5. This

higher frame rate contributes to better visual fluidity in DAC. User satisfaction (SAT) is significantly higher for DAC at 72.55 ($p < 0.05$), compared to 63.3 for FARAH and 66.6 for EasyAPP. The higher satisfaction rating for DAC aligns with its superior performance in key metrics like AR tracking, accuracy, and FPS.

Overall, DAC demonstrates superior performance across several critical metrics, including AR tracking, accuracy, FPS, and user satisfaction, although it requires higher memory usage. FARAH and EasyAPP exhibit comparable performance, with advantages in rendering time but lower satisfaction and AR tracking capabilities. These findings highlight the trade-offs between resource efficiency and overall performance, with DAC emerging as the most robust application overall.

performance stability without the engaging, user-friendly interactions seen in Dar Al Consul App.

Table 4.7 The average performance analysis association with performance factors

Performance factors	DAC	FARAH	EasyAPP
Age	18.15*	18.15*	18.15*
ART	0.47*	0.27445*	0.26195*
ACC	1	0.5	0.5
CPU	0.0046	0.00521	0.00522
GPU	0.06*	0.0589*	0.0589*
Latency	0.974	0.9665	0.97
Memory Usage	0.1	0.01045	0.01045
RT	0.55	1	1
fps	0.5575*	0.5*	0.5*
SAT	72.55**	63.3*	66.6*

- * :P-Value <0.05; ART: AR tracking; CPU, GPU usages; RT: rendering time; FPS: Frame /second; SAT; Satisfaction

4.2 Discussion

The performance analysis of three augmented reality (AR) applications—Educational (Farah App), Tourism (Dar Al Consul App), and Gaming (EasyAPP)—provides key insights into how technical and usability factors influence user satisfaction across

diverse age groups. With evaluations conducted on a Samsung SM-G975F device, the results highlight critical aspects such as AR tracking accuracy, CPU and GPU usage, latency, memory usage, rendering time, and frames per second (FPS). Additionally, user feedback collected through the System Usability Scale (SUS) reveals how user satisfaction correlates with these performance metrics.

The findings indicate that AR tracking accuracy is a major determinant of user satisfaction and perceived effectiveness across all three applications. For instance, in the Farah App, higher AR tracking accuracy in users like User 19 (accuracy 0.52) and User 6 (accuracy 0.34) corresponded with higher SUS scores, suggesting that enhanced tracking significantly contributes to a more engaging experience. These results align with recent studies, such as that by Jones and Smith (2022), who found that precise AR tracking significantly improves user engagement and immersion, as accurate overlay of virtual content on real-world elements is essential for a seamless AR experience. Conversely, users with low tracking accuracy, like User 1 (accuracy 0.01), showed lower SUS scores, reflecting that tracking inconsistencies can disrupt the user experience and contribute to dissatisfaction.

Consistent technical performance across CPU, GPU, latency, memory usage, and FPS metrics in all three applications suggests strong optimization and stable device usage. In the Farah App and Dar Al Consul App, CPU usage averaged around 0.50 and GPU usage around 0.005, with latency maintained at 0.06. This technical stability indicates that these apps are well-designed to manage resource consumption without overburdening the device, a factor emphasized in recent AR studies for sustaining user immersion (Li & Wang, 2021). Furthermore, consistent FPS at 1.0 across users ensures a smooth visual experience, reducing the likelihood of visual fatigue, which is particularly critical in AR applications where immersive visuals are essential to user engagement. However, while these technical metrics are necessary for stable performance, they appear insufficient for optimal user satisfaction alone, as seen in the Farah App and EasyAPP, where variations in SUS scores suggest that tracking accuracy and usability play larger roles.

The analysis reveals that user satisfaction, as measured by SUS, varies with age, with older users (ages 29–33) reporting higher SUS scores than younger users (ages 5–10). This age trend may be attributed to greater familiarity with technology among older

users, allowing for more intuitive interaction with AR features. For younger users, lower SUS scores suggest that they may face challenges in navigating the app's interface or understanding the AR functionalities, which may be complex for their age group. Similar findings are echoed in studies by Zhang et al. (2023), who observed that younger AR users benefit from simplified, age-appropriate interface designs, as complex interactions can reduce satisfaction and hinder usability.

Comparing average performance and satisfaction across the three applications provides additional insight. Dar Al Consul App has the highest average performance (0.347) and satisfaction (72.55), showing a positive correlation between technical performance and user satisfaction. This relationship suggests that Dar Al Consul App is well-aligned with user expectations, likely due to a combination of effective tracking, responsive interactions, and user-friendly design elements. These findings are consistent with the work of Chen et al. (2022), who demonstrated that AR applications achieving high user satisfaction often have a balance of technical reliability and ease of use, suggesting that Dar Al Consul App's design integrates these factors effectively.

In contrast, EasyAPP and Farah App show lower performance (0.300 and 0.3015, respectively) and lower satisfaction (66.6 and 63.3). Both applications exhibit a negative relationship between performance and satisfaction, implying that higher technical performance does not necessarily translate into user satisfaction. This discrepancy may stem from limitations in usability, navigation, or tracking accuracy, which are critical in AR and may detract from the experience if not optimized. Other recent studies, such as Brown et al. (2023), emphasize that user-centered design elements are critical in AR applications to engage users fully, as stable performance without intuitive interactions can lead to a less satisfactory experience.

Statistical analysis results in Table 4.6 further support these interpretations. With a mean performance score of 0.355 and a low standard deviation (0.0059), the EasyAPP provides a stable experience across users, yet the weak age-performance correlation (-0.1043) and SUS-performance correlation (0.21005) indicate limited impact of these factors on satisfaction. Similarly, the ANOVA results for the Dar Al Consul App (F-value 10.035, P-value 0.0094) show significant differences across user groups, potentially due to varying familiarity with AR or specific age-related expectations.

The results demonstrate that while consistent technical performance is essential, AR tracking accuracy and user-centered design are critical for enhancing user satisfaction in AR applications. Dar Al Consul App's success highlights the value of combining technical optimization with intuitive design, while the lower satisfaction in EasyAPP and Farah App suggests that improvements in tracking accuracy and interface usability are necessary to achieve a balanced experience. Recent studies emphasize that a holistic approach integrating stable performance, precise tracking, and user-friendly design is essential for the success of AR applications, as supported by findings from Jones and Smith (2022) and Chen et al. (2022). Addressing these aspects in future updates would enhance satisfaction across age groups, providing a more universally engaging and immersive AR experience.

Chapter 5: Conclusion and Future work

5.1 Conclusion

The analysis of three augmented reality (AR) applications—Farah App (Educational), Dar Al Consul App (Tourism), and EasyAPP (Gaming)—provides meaningful insights into how technical performance metrics and usability factors shape user satisfaction and engagement across diverse age groups. This study underscores the critical role of AR tracking accuracy and user-centered design in determining the effectiveness of AR applications, demonstrating that while stable technical performance is essential, it is insufficient to guarantee high user satisfaction. The findings indicate that applications like Dar Al Consul App, which combine high tracking accuracy, responsive interactions, and user-friendly design, are more successful in aligning technical performance with user expectations, leading to higher satisfaction and engagement. Conversely, apps with stable performance but lower tracking accuracy or complex interfaces, such as EasyAPP and Farah App, demonstrate lower user satisfaction, particularly among younger users.

While the technical stability in CPU, GPU, latency, memory usage, and FPS metrics provided a consistent user experience across devices, it is evident that tracking accuracy, interface intuitiveness, and usability are the primary influencers of user satisfaction. Age-related trends also highlighted the need for simplified interfaces and

more intuitive navigation for younger users, reinforcing the importance of user-centered design in AR applications to accommodate various demographics effectively.

5.2 Future Work

Future research should explore the development of more age-responsive AR applications by incorporating adaptive interfaces that cater to different age groups and user experience levels. Given the strong correlation between tracking accuracy and satisfaction, future work could investigate advanced tracking algorithms that improve accuracy without significantly increasing resource consumption. Machine learning techniques could also be applied to predict and adapt to user interaction patterns in real-time, enhancing both tracking and interface responsiveness.

Additionally, longitudinal studies involving extended app usage could provide insights into how familiarity with the app and its features impacts user satisfaction over time. Integrating more qualitative feedback mechanisms, such as real-time interaction surveys or focus groups, would offer a deeper understanding of user needs and pain points, enabling designers to make informed improvements. Finally, given the potential for AR to transform learning and engagement, future work could explore how context-aware and environment-adaptive features—such as augmented contextual overlays and spatial recognition—might improve AR applications' effectiveness, especially in educational and tourism contexts.

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Appendix A

Firestore Performance Metrics in Unity

```
using System;
using Firebase.Database;
using Firebase;
using Proyecto26;
using Unity.Profiling;
using UnityEngine;
using UnityEngine.UI;

public class PerformanceTest : MonoBehaviour
{
    public static readonly ProfilerCategory MyProfilerCategory =
ProfilerCategory.Scripts;
    public static readonly ProfilerCounter<int> TaskCount = new
ProfilerCounter<int>(MyProfilerCategory,
"PerformanceTest",
ProfilerMarkerDataUnit.Count);

    public static float ExecutionTime, CPUUsage, FPS, Latency, ResponseTime,
RenderTime;
    private ProfilerMarker updateMarker = new
ProfilerMarker("PerformanceMeasurement.Update");

    public CPUUsageLogger cpuUsageLogger;
    public FPSCounter fpsCounter;
    public LatencyMeasurement latencyMeasurement;
    public ControllerResponseTime controllerResponseTime;
    public RenderTiming renderTiming;

    public void Start()
    {
        ExecutionTime = Time.realtimeSinceStartup;
        CPUUsage = cpuUsageLogger.currentCPUUsage;
        FPS = fpsCounter.fps;
        Latency = latencyMeasurement.latency;
        ResponseTime = controllerResponseTime.responseTime;
        RenderTime = renderTiming.renderTime;
        PostToFirestore();
    }

    private void PostToFirestore()
    {
        PerformanceData data = new PerformanceData
        {
            executionTime = ExecutionTime,
            cpuUsage = CPUUsage,
            fps = FPS,
            latency = Latency,
            responseTime = ResponseTime,
            renderTime = RenderTime
        };

        RestClient.Put("https://your-firebase-
database.firebaseio.com/performance.json", data);
    }
}

public class PerformanceData
{

```

```
public float executionTime;  
public float cpuUsage;  
public float fps;  
public float latency;  
public float responseTime;  
public float renderTime;  
}
```

Appendix B

Performance Data Model

```
using System;
using System.Collections.Generic;
using Unity.Profiling;

[Serializable]
public class User
{
    public string task, function_name;
    public float com_Rate ,time, U_cpu, U_fps, U_letency, U_RespTime,
        U_renderTime, ErrorRate;
    public long Elps;
    public User()
    {
        task = MainTask.TASK_NAME;
        //function_name = MainTask.Fuction_name;
        com_Rate =MainTask.Comp_Rate;
        ErrorRate = MainTask.error;
        U_cpu =MainTask.cpu;
        U_fps = MainTask.fps;
        U_letency = MainTask.letency;
        U_RespTime = MainTask.RespTime;
        U_renderTime = MainTask.renderTime;
    }
}
```

Appendix C

System Usability Scale

The System Usability Scale Standard Version		Strongly Disagree					Strongly Agree				
		1	2	3	4	5	1	2	3	4	5
1	I think that I would like to use this system frequently.		0	0	0	0	0	0	0	0	0
2	I found the system unnecessarily complex.		0	0	0	0	0	0	0	0	0
3	I thought the system was easy to use.		0	0	0	0	0	0	0	0	0
4	I think that I would need the support of a technical person to be able to use this system.		0	0	0	0	0	0	0	0	0
5	I found the various functions in this system were well integrated.		0	0	0	0	0	0	0	0	0
6	I thought there was too much inconsistency in this system.		0	0	0	0	0	0	0	0	0
7	I would imagine that most people would learn to use this system very quickly.		0	0	0	0	0	0	0	0	0
8	I found the system very awkward to use.		0	0	0	0	0	0	0	0	0
9	I felt very confident using the system.		0	0	0	0	0	0	0	0	0
10	I needed to learn a lot of things before I could get going with this system.		0	0	0	0	0	0	0	0	0

اطار عمل لدمج مقاييس الأداء التقني واختبار القابلية للاستخدام لتحسين تجربة المستخدم في الواقع المعزز

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الملخص

تُعدّ تقييمات أداء تطبيقات الواقع المعزز (AR) ضرورية لتحسين تجربة المستخدم وتعزيز جودة التفاعل ودفع الابتكار التكنولوجي في هذا المجال. غالبًا ما تركز الدراسات التقليدية لأداء الواقع المعزز على جوانب مثل سرعة الاستجابة ودقة التتبع واستخدام الموارد وتأثيراتها على تجربة المستخدم، بهدف تقليل استهلاك الطاقة وزيادة كفاءة التطبيق وتسهيل تطوير تقنيات جديدة مثل الذكاء الاصطناعي (AI). إضافةً إلى ذلك، فإن فهم كيفية تأثير تطبيقات الواقع المعزز على الأداء الإدراكي والتفاعل الاجتماعي مهم لتصميم تطبيقات لها آثار إيجابية في هذه الجوانب. يُعتبر تحديد طرق فعالة لتقديم المحتوى من خلال مقارنات شاملة للأداء أمرًا بالغ الأهمية لضمان تجربة مستخدم مثالية. ومع ذلك، على الرغم من الأبحاث الكبيرة حول أداء الواقع المعزز، فإن العديد من الدراسات الحالية تفتقر إلى نهج تكاملي يأخذ في الاعتبار جميع عوامل الأداء، بما في ذلك التأثيرات النفسية والاجتماعية.

تقدم هذه الدراسة إطارًا لتحسين تجربة المستخدم في الواقع المعزز من خلال أداة تقييم أداء شاملة ومؤتمتة. تقوم الأداة المطوّرة بجمع وتحليل بيانات تفاعل المستخدمين - مثل بيانات اللعب - وتدمجها مع ردود فعل المستخدمين التي يتم جمعها عبر استبيانات ما بعد الجلسة. يتيح هذا النهج الثنائي تحديد نقاط الضعف في الأداء وأسبابها الأساسية، مما يوفر للمطورين رؤى محددة لتحسين جودة التطبيق. تم اختبار الأداة عبر ثلاثة تطبيقات واقع معزز في فئات مختلفة - تعليمية وسياحية وترفيهية - وأظهرت فعاليتها في تقديم مؤشرات أداء قيمة ومخصصة للسياق.

تؤكد النتائج الأهم من التحليل على أهمية دقة التتبع في الواقع المعزز والتصميم المتمحور حول المستخدم في تحقيق مستويات عالية من الرضا لدى المستخدم. أظهرت التطبيقات التي تتمتع بدقة تتبع عالية، مثل تطبيق "دار القنصل"، مستويات تفوق في التفاعل والرضا لدى المستخدم مقارنةً بالتطبيقات التي تتميز بأداء تقني مستقر ولكن بدقة تتبع أقل، مثل تطبيق "فرح" و"إيزي آب". كما وجدت الدراسة أن عوامل مثل وحدة المعالجة المركزية (CPU) ووحدة معالجة الرسومات

(GPU) والكمون واستخدام الذاكرة كانت ثابتة بين مجموعات المستخدمين، إلا أن رضا المستخدم كان مرتبطاً بشكل أكبر بعوامل الاستخدام وسهولة الواجهة، خاصةً لدى المستخدمين الأصغر سناً الذين يستفيدون من التصاميم المناسبة لأعمارهم.

بالإضافة إلى قدرات التحليل في الوقت الفعلي، تتميز الأداة بوظيفة تخزين البيانات التي تدعم تتبع الأداء على المدى الطويل، مما يمهد الطريق لنماذج مستقبلية تعتمد على الذكاء الاصطناعي يمكنها التعلم من نقاط القوة والقيود في تطبيقات الواقع المعزز. من خلال دمج ردود فعل المستخدمين مع الذكاء الاصطناعي، يوفر الإطار نهجاً شاملاً لتقييم الأداء، مما يساعد المطورين خلال مراحل التطوير وما قبل الإطلاق. تسدّ هذه الدراسة الفجوات في أساليب تقييم الواقع المعزز الحالية، حيث تقدم نهجاً متكاملاً يعتمد على الذكاء الاصطناعي ويشمل الجوانب التقنية والنفسية والاجتماعية المهمة لأداء تطبيقات الواقع المعزز.