Survey of Existing Augmented Reality Frameworks

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***Abstract*—This document gives an overview of popular mobile augmented reality frameworks and the comparison between them. The frameworks were found from various articles and were later compared to each other through simple augmentation tests. From the test results a comparison table is created.**

***Index Terms*—augmented reality, mixed reality, software engineering**

I. Introduction

Augmented reality and the idea of cooperating digital information with our real world has been around for a while. Many consider the first augmented reality experiences to date back to the 1960s. One of the most remarkable achievement's was "The Sword of Damocles". It was one of the first head-mounted display's which could render 3D graphics. It was created by Ivan Sutherland in the year 1968 [1]. The first notable "portable" AR experience was a video game called ARQuake. The inputs to the game are provided through a head-mounted display, mobile computer, head tracker, and GPS system [2]. With the introduction of smartphones, the mixed reality experiences have become more accessible then ever before. With built-in IMU sensors and a camera, all of the necessary components for creating a mixed reality experience are available. In a year 2016, a game called Pokemon GO was released, which with over one billion downloads has introduced many people to the wonders of augmented reality [3].

As there are many different frameworks for creating augmented reality experiences, the goal of this study is to find these frameworks and compare them to each other. The main focus will be on mobile AR frameworks as mobile augmented reality is one of the most accessible forms of augmented reality.

II. Method

The augmented reality frameworks were found through different internet sources and by analysing available applications. Additionally, some academical databases were searched and used. The finding of the frameworks and their evaluation consists of these steps:

- Formulating research questions
- Searching the internet and databases for any references or articles about augmented reality frameworks
- Testing the found frameworks by creating test builds
- Summary of the found frameworks and formulating results

A. Research Questions

This survey studies different frameworks, their pros and cons, and how they are comparing to each other. To find these frameworks three research question were formulated:

- RQ1: What are the existing frameworks for executing augmented reality on mobile devices?
- RQ2: How do different frameworks perform compared to each other?
- RQ3: What framework has the widest device support?

These three questions were formulated to capture the basic information needed to choose the optimal framework when considering to build an augmented reality experience.

B. Search

Most of the found information came from different articles comparing the top augmented reality frameworks available. Searching from the different academic databases like Scopus and ACM using the keywords "Augmented Reality Frameworks" did not give sufficient enough information or the found source was too old to be considered as valid information source.

C. Testing of the frameworks

For testing the found frameworks, simple tests were formulated:

1) Tracking test: The tracking accuracy of a framework was tested by placing a virtual 3d object into a world and seeing how much the object had deviated from the original position (Figure 1).

Two basic movements were used for testing all of the frameworks:

1) Facing the trackable object - how does the framework behave while the placed object is visible to the device
2) Facing the movement direction - how does the framework estimate the position of the placed object without seeing it

In order to evaluate the accuracy of the movement and the tracked object, the grid of the floor tiles was used as reference to align the final results up. From this, a picture with the initial and the final position of the object was generated (Figure 2). The accuracy of the framework was scored in the range of 0 - 5:

- 0 - the framework did not track anything
- 5 - the object tracking was perfect with no deviations.

Fig. 1. Placing of the object onto a control point

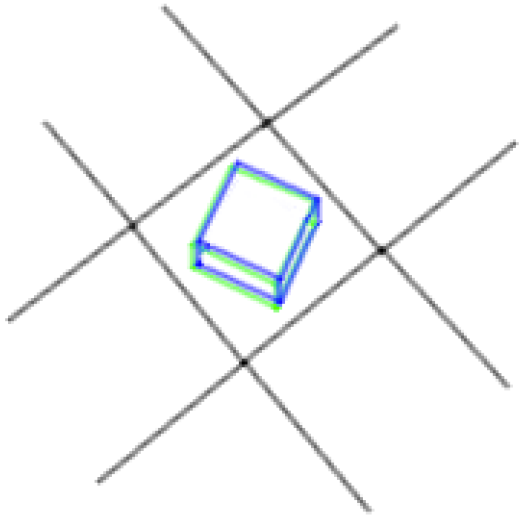

Fig. 2. Results of the tracking test - Green: initial position; Blue: final position

2) Rendering test: The rendering capabilities of a framework were tested by placing multiple 3d objects into the virtual world. The more the framework could render and track at the same time, the better (Figure 3). The final object count was marked down and used to rank the framework.

The rendering test was terminated once the frame rate of the testing framework dropped below 20 frames per second and would not increase again. 20 frames per second was chosen as the termination point, since below 20, everything that is rendered gets quite jittery. Additionally, it has been a standard for movies to use a minimum of 24 frames per second because that is the frame rate at which our eyes still see movement smoothly [9].

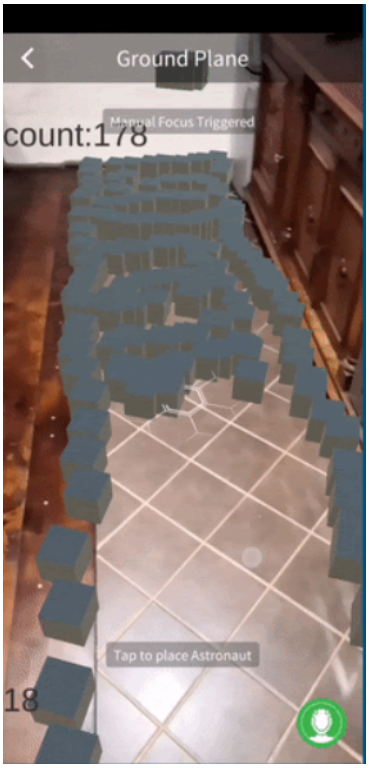

Fig. 3. Rendering capability test

III. Findings

A. RQ1 - Existing mobile augmented reality frameworks

Found mobile augmented reality frameworks can be seen on Table I.

TABLE I
MOST POPULAR AR FRAMEWORKS USED IN 2021

Framework	*Platform*	*Free?*	*Framework link*	*Mentions in literature*
Vuforia	Android/iOS	No	link	[4], [5], [6], [7], [8]
ARCore	Android/iOS	Yes	link	[4], [5], [6], [7], [8]
ARKit	iOS	Yes	link	[4], [5], [6], [7], [8]
Wikitude	Android/iOS	No	link	[4], [5], [6], [7], [8]
ARToolKit	Android/iOS	Yes	link	[5], [6], [7]
Kudan SDK	Android/iOS	No	link	[4], [5], [6]
EasyAR	Android/iOS	No	link	[4], [5]
MAXST	Android/iOS	No	link	[4], [8]
Ar.js	Android/iOS	Yes	link	[6]
WebXR	Android/iOS	Yes	link	[6]
8th Wall	Android/iOS	No	link	[6]

B. RQ2 - Framework comparison

For evaluating the goodness of the framework, all of the frameworks were tested using the Unity Game Engine [10]. Unity was chosen because of the author's past experience using the engine. However,this puts a rather harsh restriction on the testability of the frameworks, since not all of the frameworks are supported by Unity, and in order to have the results as accurate as possible, the underlying rendering system

should be the same. Additionally, due to the freedom of the Android system the testing was done on Android frameworks - meaning the ARKit was excluded from the tests and it isn't compared to the other frameworks. Thus only 6 from the found frameworks were tested fully and compared to each other.

The frameworks were ranked by the achieved scores on the individual tests. The sum of the rankings from each test was taken and compared between each of the frameworks. The framework with the least amount of points - meaning receiving the highest scores in each of the tests, would be ranked as the number 1. The results can be seen in Table II.

TABLE II
TEST RESULTS

Framework	*Tracking - Ranking*	*Objects Rendered - Ranking*	*Android version support - Ranking*	*Final ranking (points)*
8th Wall	3.5/5 - 5	1600+ - 1	7 >= - 1	1-2(7)
Wikitude	4.5/5 - 1	360 - 5	7 >= - 1	1-2(7)
ARCore	3.75/5 - 4	970 - 2	10 >= - 2	3(8)
Vuforia	4/5 - 3	180 - 6	10 >= - 2	4(11)
MAXST	3.25/5 - 5	450 - 3	7 >= - 1	5(10)
Easy AR	2/5 - 6	400 - 4	10 >= - 2	612)

C. RQ3 - Device support

The supporting of the devices can be categorised into two: 1) supporting the markerless AR and 2) supporting the marker-based AR. While markerless AR does not require any physical prerequisites for the augmentation, it is more performance heavy and utilises more sensors from the device. Marker-based AR is creating the AR experience using the marker, allowing to create augmentation even on lower-end devices [11]. Using this information, the Table III was created.

TABLE III
DEVICE SUPPORT

Framework	*Android version support - plane detection*	*Android version support - marker based AR*	*iOS support*
8th Wall	Android 7 or newer	Android 4.4 or newer	iOS 7 or newer
ARCore	Android 10 or newer	10 Android 10 or newer	iOS 11 or newer
Wikitude	Android 7 or newer	Android 6 or newer	iOS 12 or newer
Easy AR	Android 10 or newer	Android 4.2 or newer	iOS 8 or newer
MAXST	Android 7 or higher	Android 4.3 or newer	iOS 8 or newer
Vuforia	Android 10 or higher	Android 6 or newer	iOS 12 or newer
ARKit	Not supported	Not supported	iOS 11 or newer
WebXR	Android 10 or newer	Android 10 or newer	iOS 11 or newer(needs special browser)
AR.js	Not supported	Android 5 or newer	iOS 11 or newer
Kudan SDK	Unknown	Android 4.0.2 or newer	iOS 9 or newer

IV. DISCUSSION

A. RQ1 - Existing mobile augmented reality frameworks

From the results, we can conclude that there are many different frameworks to choose from, each with their own pros and cons. Most of them were found through internet articles and not from academic papers, which is to be expected as the topic has started to gain popularity in recent years. The most recent similar type of survey was done in the year 2014 [12].

B. RQ2 - Framework comparison

The results of the testing of different frameworks are not accurate enough to declare one framework as the "best". In the tracking tests, the clear winner was Wikitude. The responsiveness and the smoothness of the placed objects were surprisingly good, and even the tests in a dim light were handled with ease. But its good tracking abilities are not without flaws. Although it does a good job at rendering over a hundred objects, other frameworks with similar performance (i.e. Vuforia and ARCore) can handle even more objects. 8th Wall was on the other end of the spectrum - the framework was great at rendering many 3d objects at once, but overall tracking of the objects was rather average. Considering that both of the frameworks had quite a wide device support, it is not a surprise that they will be sharing the 1-2 place. The worst performing framework,according to the made tests, was EasyAR. The Tracking recieved such low points, since it only was able to the track the position of the cube correctly when facing the object. Moving away from the object while facing the direction of movement didn't perform at all, meaning the tracking of the object was completely lost. On the Figure 4 is the side-by-side comparison of the tracking performance of the Wikitude and EasyAR.

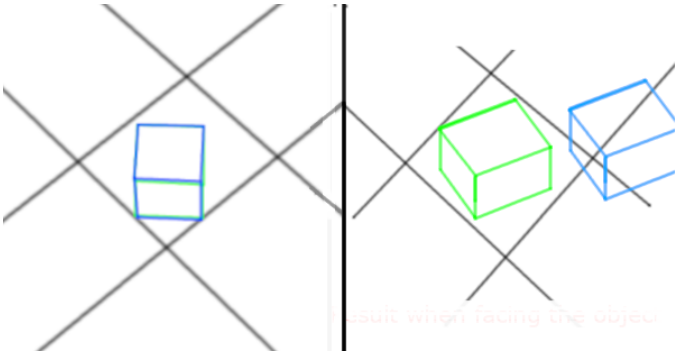

Fig. 4. Comparison of the tracking: left - Wikitude, right - EasyAR

C. RQ3 - Device support

Many of the frameworks had the restriction of supporting only Android 10 or higher. This is because markerless augmented reality requires far more sensors and computing power than most of the older phones have. ARCore has even a specific page with all of their supported devices [13]. However the list of the supported devices has grown alot and the overall availability of Android 10's has grown. According to

Globalstats, the market share of Android devices with the version 10 or higher is 61.89% as of Oct 2021.

TABLE IV
ANDROID VERSION MARKET SHARE [14]

Android 11	*Android 10*	*Android 9*	*Android 8.1*	*<= Android 8*
33.32%	28.57%	14.27%	7.71%	16.13%

Last year there were only 36.7% devices with Android 10. Meaning if the rise of the android devices continues, most people will have a device capable enough to handle augmented reality experiences in the upcoming year. As of now it might be a good idea to still consider the device support range when choosing a framework, depending on the application and the target group of the AR application. About 38.11% of the devices will not be supported if choosing the framework that only supports Android 10's.

V. CONCLUSION

In the paper, a study of existing mobile augmented reality frameworks was conducted in order to find different frameworks and evaluate their goodness against each other. For this study, 3 research questions were formulated and answered. Most of the frameworks were found through internet articles since a survey like this has not been done in recent years, and most of the academic papers have not specified their framework of choice.

During the study a total of 6 frameworks were tested to determine the tracking and rendering capabilities of the chosen frameworks. Only 6 out of the total of 11 frameworks were chosen because of their compatibility with Unity. Unity was chosen to have all the frameworks use the same underlying rendering system, thus making the rendering test more equal.

From this study it was concluded that there is not a singular best framework for creating an augmented reality solution. The choice must be based on the focus of the desired application: is it more important that the tracked object would be as accurate as possible or that there will be multiple 3d object on the screen at once. The problem might be a device support as well since there is quite a considerable market share on older devices that don't have the necessary computing power and sensors needed to create augmented reality experiences.

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