Augmented Reality SDK Overview for General Application Use

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***Abstract*—Augmented Reality Software Development Kits, or as they are commonly called AR SDKs, are useful for developers to build digital objects in AR. This paper presents a comparative study of AR SDKs. This comparison is based on several significant criteria, to select the most suitable SDK. The evaluation used the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method. Based on a comparative analysis of the features and virtual elements available for application development with the AR SDK, researcher suggests that the main functions of the AR SDK were to be able to offer AR application Editing Platform and facilitate software creation without requiring knowledge of algorithms. Besides that, it is possible to establish some general observations regarding the benefits and limitations of the AR SDK. The result of this research is expected to provide with the clear framework for processing the data that has been collected, summarized, and tested from case study so the researcher will be able to reach useful conclusions. From the literature study has been conducted, it was concluded that among many SDK tools, there are 15 of them which were the most employed by AR developers. These 15 tools were selected based on certain main attributes and support platforms. At the end of this research, it also presents the advantages and limitations of these 15 tools.**

Keywords*—Augmented reality; software development kits; AR SDK; platform; framework; AR technology

I. Introduction

Augmented Reality Software Development Kits, or AR SDKs, are useful for developers to build digital objects [1]. By utilizing devices like gadgets or tablets, digital objects can be incorporated into the real world through augmented reality (AR). The advantages of the features provided by the AR SDK are the functions for image recognition, 3D object tracking and other multi-tracking, providing simultaneous visual localization and mapping, and many other additional features. This allows developers to create a wide range of digital experiences. AR engineers can leverage this SDK to develop mobile applications, integrate with various CAD platforms, create marketing experiences, develop educational applications, and explore many other possibilities [2]. The AR SDK can generally be used for hardware with certain frameworks [3]. From the results of the literature review, it is also known that several AR SDKs are very flexible to use, so they can be applied to many systems. This makes it easy for AR developers to build AR applications across platforms.

This study presents a comparative study of several AR SDKs. The aim of the comparison that will be carried out is so that AR developers can choose the SDK that best suits their needs so that it can be adapted easily. There are several important criteria that will be explained in the SDK comparison carried out. This research is expected to add value because it has been collected, summarized, and tested from the case study samples that have been carried out so that it can reach useful conclusions for this research.

As we know, AR and virtual reality (VR) have different ways of working. Therefore, AR SDK and VR SDK are also different. The main benefit in the AR SDK category is the functionality of creating AR experiences that can be integrated with various operating systems and various other hardware [1]. Basically, there are three steps in the AR system: recognition, tracking, and blending. At the recognition stage, visual identification occurs in the form of images, whether images of objects, faces, bodies, other body parts, or space will be recognized as virtual objects [4]. The tracking stage is carried out to get real-time visual results in the form of images, objects, faces, bodies, or places such as space so that videos, 3D images, 2D images, text, and others can be added to the AR application [5]. In marker-based AR systems, symbols are used as reference points for overlaying computer graphics. The camera used in this system will continue to search for and identify the target object and then process the image data, starting from the position, orientation, and movement of the visual display that appears. The marking system has a problem, namely that if the lighting is not good, the focus will decrease, and resulting in the image disappearing from the screen, so AR services will not be optimal when using this system [6].

It is different from the AR system without markers [7]. This system uses a combination of electronic devices, such as accelerometers, location data (GPS), compasses, and others, that can determine position in the physical world. With this marker-less AR system, objects can be identified from the direction where the camera is pointing or on which axis the device used operates to obtain the location [6]. This location data determines what the device sees by comparing it to a database, allowing data or computer graphics to appear on the screen. This technological approach sparked the idea of the emergence of 'mobile 'augmented reality' on smartphones, tablets, gadgets, and other mobile technology devices [8].

II. Literature Reviews

AR technology is applied in many fields, and AR Software Development Kits ("SDK") have been entered into various applications such as gaming, media and entertainment, automotive, retail, health, education, manufacturing, and others. In the gaming industry, the success of AR technology is that it can offer immersive and interactive experiences that will increase the adoption of AR in the gaming industry. With the success of Pokémon Go, the game company has extensively expanded the technology for games and other applications. For example, the game Ingress Prime adapts the idea of Pokémon Go, where players can go out of the house, travel around, and meet face-to-face with other players. Ingress Prime maximizes the rapid development of AR technology, as seen from the presence of a feature that can make players place a 3D map of a location on the dining table or living room table to set a strategy. Previously, the available portal locations were only numbered in the hundreds of thousands, but now Ingress Prime offers millions of locations spread across the globe [9].

For the media and entertainment industries, the advantage of AR technology is that it can provide real-time experiences. For example, in November 2019, Samsung Electronics launched the Samsung TV True Fit. Using smartphones, both Android and iOS, consumers can see exactly what Samsung's widescreen TV will look like on the wall before buying it. This AR application produced by Samsung can combine futuristic technology with the future of retail shopping and virtual product display. Its main goal is to give consumers the opportunity to choose the right TV at the right size and have a pleasant shopping experience [10].

In the retail industry, AR also offers a promising role. Its ability to provide product and service details tailored to customer needs via smartphones with 3D effects has an impact on market growth. For example, Walmart has used AR so that its customers get shopping experience by scouring supermarket aisles for Waffles + Mochi characters to unlock AR content. After scanning a QR code with a smartphone, image recognition technology allows consumers to search for nine different characters hiding in grocery aisles. As shoppers discover each character in the store, they will earn badges and gain access to unlock more games, recipes, stories, and clips from the Walmart app [11].

In the healthcare sector, there is also an increasing demand for AR because it helps with simulations for surgery, training, and patient care. For example, the Mayo Clinic is the best hospital in the world to develop treatments using AR technology. The past decade has seen tremendous growth and expansion in innovative efforts to address the unmet needs of patients, providers, and care systems. To facilitate this effort, the Mayo Clinic Cardiovascular Medicine established a virtual reality innovation group at the Mayo Clinic in Rochester, Minnesota [12].

In the field of education, the results of a study entitled "Investigating Student Attitudes toward Augmented Reality" found that students have positive attitudes towards AR applications, as seen from the increased interest and motivation in an active and interactive learning environment through AR [13]. This proves that AR technology is able to make applications more interesting to use and increase user interest in learning something [14]. In manufacturing, AR is applied to product design and development, quality control (QC) processes, logistics, employee training, equipment maintenance, and more. With the adoption of AR applications, manufacturers can increase productivity, lower costs, and work faster. For example, AR technology and the Internet of Things (IoT) will allow manufacturing systems to self-assess deficiencies or errors that occur in the system [24].

According to a market analysis perspective by International Data Corporation (IDC), the latest projections estimate the AR market will reach $60.55 billion by 2023 [15]. AR is not just an IT technology; it is a link between the digital and physical worlds and becomes a new interface between humans and machines. The world's leading IT companies, such as Amazon, Facebook, Mayo Clinic, US Navy, and others, have implemented AR, and they are seeing the huge impact AR has on quality and productivity for their companies. The main advantage that AR offers to various fields that use it is the power of AR in processing information so that humans can experience unforgettable immersive experiences. With this immersive power, humans can use their five senses to access information at different speeds. From the research results, it is known that vision provides 90% of the information humans obtain through sight. However, accessing information is not easy because it requires mental capacity that is able to absorb and process information [17]. Therefore, cognitive load, as a demand on human capacity, requires mental effort. Like reading instructions from a computer screen, carrying out calculations, and thinking about the information obtained, all of this provides a greater cognitive load compared to listening to the same instructions because the letters must be translated into words. Words must then be represented so that there is a distance or gap between the presentation of information and its understanding in the context of applying the information [18]. For example, when a driver refers to a smartphone and looks for directions while driving, this requires its own focus. The steps that must be taken are that the driver must read the information from the screen, then memorize the information in his memory, look at the screen, and translate the directions from the screen to the physical environment in front of him. Then follow the instructions when operating the vehicle. There is a lot to do, and there is a cognitive gap between the digital information on the screen and the physical reality on the ground where the information must be applied. The combination of the speed of conveying and absorbing information and the cognitive distance involved in its application is like the term "a picture is worth a thousand words"[16]. When humans view the physical world, they absorb vast amounts of information. The information received is almost immediately absorbed. In the same way, an object or image overlaid with information about the physical world places it in context for human knowledge. This can reduce cognitive distance and minimize cognitive load. This reason can explain why AR can become a trend and is in an important position. There is no better graphical user interface than the physical world we see around us when enhanced with a digital overlay of relevant data and guidance on where and when it is needed. AR eliminates reliance on 2D information that is out of context and difficult to process on pages and screens, while enhancing humans' ability to understand and apply information in the real world [19].

III. RESEARCH METHODS

The papers used in this study were collected from a bibliographic database of Scopus and academic publications, such as ERICS, IEEE, Science Direct, Taylor and Francis Journal, and Google Scholar. The required articles were those published between January 2019 and October 2023. The following search keywords resulted in 15,900 papers being collected:

"Augmented" AND "Reality" AND "SDK"

"AR" AND "SDK"AND "Technology"

"AR" AND "Framework" AND "Development"

After selection, there were 235 suitable articles.

The evaluation used the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method with five stages used to conduct a literature review, namely defining eligibility criteria, defining information sources, selecting literature, collecting data, and selecting data items as shown in Fig. 1. Meanwhile, for the presentation of the results of the literature review that has been carried out, it can be seen in Table I below:

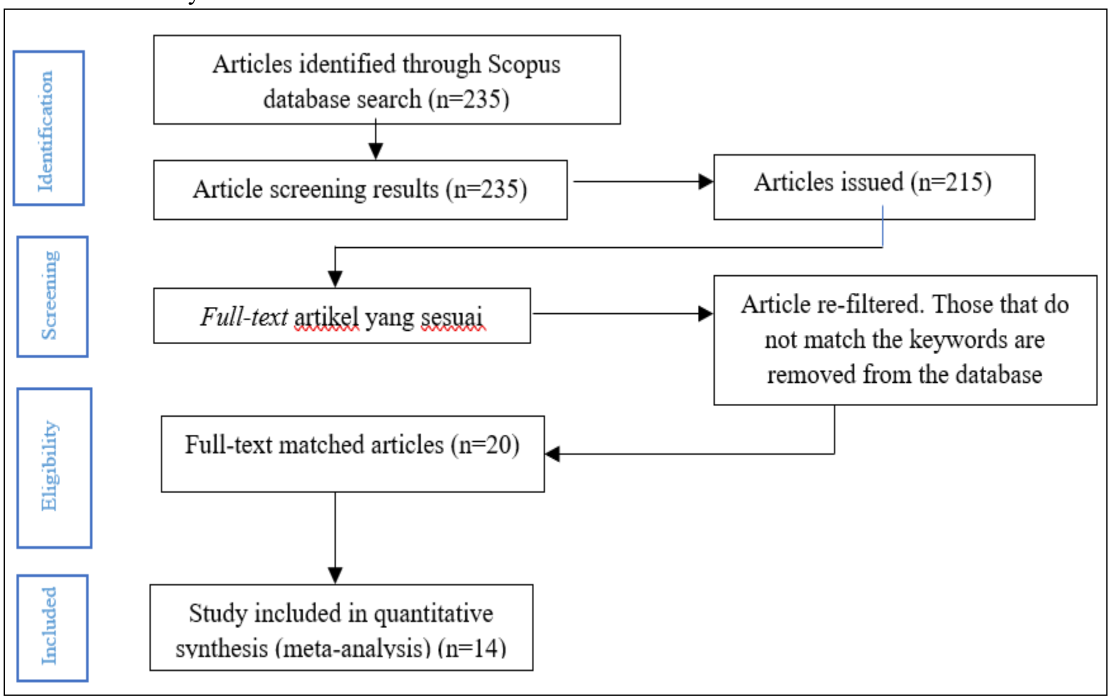

Fig. 1. PRISMA diagram (adapted from Moher et al (2009)).

IV. ANALYSIS OF FRAMEWORKS AND PLATFORMS

From the results of a literature study on AR development tools to explore the functionality and applications used by AR, 15 tools were found that can be used to perform analysis and testing. The data obtained for the development of AR resources is shown in the table below:

1) ARToolkit: Currently for developing AR applications. ARToolkit has the most libraries and the most users. The main advantage of ARToolkit is that it is open source, offers other supporting features, and allows multi-platform use. Its open-source nature allows ARToolkit to continue to develop, and its advantages in tracking planar targets, geolocation, and several other targets can develop along with the needs of AR developers [20][21].

2) Realitykit: The main advantage of Realitykit is rendering realistic photos, creating animations, physics, providing camera effects, and more that are created specifically for AR frameworks. Realitykit makes AR development easier than other tools due to its Native Swift API, ARKit integration, spatial audio, highly realistic physics-based rendering, animation frameworks and transformations, and spatial audio and physics rigid objects, all of which support AR development [2].

3) Aurasma: Aurasma offers an AR platform for education and personal use for free. With support for creating its own mobile applications and web-based platforms, it allows AR developers to transform objects, images, and places. This advantage provides new interactive opportunities using graphic, animation, video, audio, text, and 3D content, enabling planar target tracking and geolocation, as well as tracking via cloud storage in the form of 3D AR [1].

4) BlippAR: The main advantage of BlippAR is that users can register their own bookmarks and connect with many dynamic and interactive visual assets for smartphones. BlippAR supports deep learning algorithms with artificial intelligence, allows users to use cloud technology to track planar targets, and supports learning of various things that AR developers may need [1][2].

5) CraftAR: The main advantage of CraftAR is that it has a multi-platform SDK, offers mobile applications and a web-based platform, tracks planar images through the cloud, and registers their own bookmarks in various forms such as 3D models, images, audio, video, and more [3].

6) EasyAR: The main advantage of EasyAR is that it has simple and efficient features, is easy to use, and has advanced functions that AR developers have long awaited, such as dynamic target recognition loading, screen recording functions, hard decoding, and more than 1000 types of local target recognition. Apart from that, the web-based platform is also an advantage because it can make it easy for users to register their projects and obtain the necessary licenses. This license is useful for testing and releasing user applications and offers some planar target tracking functionality [1].

7) Kudan: This framework offers an SDK that can be exported to various platforms. Additionally, Kudan has extensive documentation and practical examples and has a support forum for fellow communities. SLAM is also available, allowing the tracking of fewer markers [22] [23].

8) LayAR: Developers can use many features on LayAR, such as adding buttons for social media, web pages, phone calls, email, downloading, voting, shopping, and adding contacts. The programming language used is Java, with back-end XML, PHP, MySQL, and others that support the JSON format. For use on iOS, the iPhone is LayAR's mainstay for integration with specific SDK hardware requirements [2].

9) PixLive: Using PixLive allows the use of media such as images, 3D models, 360-degree images, audio, and video. Developers can also add buttons to social media, web pages, and PDF files and use images and text as buttons. To create scenes and buttons or timers to navigate between scenes, PixLive allows the use of resources for drawing applications and the use of geolocated resources [3].

10)Vuforia: Vuforia is one of the most popular platforms for developing AR. Vuforia provides a web-based environment where users can create and manage their bookmarks and obtain the necessary licenses. Licenses are required to test and publish their applications. Vuforia can also be used to track planar targets, geolocation, multiple targets, text, and 3D objects. Cloud technology can also be used on Vuforia to store data locally on the user's device. Vuforia even enables marker less tracking through two technologies, namely extended tracking and smart terrain.

11)Wikitude: The main advantage of Wikitude is the ability to track planar markers, 3D objects, geolocation markers, multiple targets, and the use of marker less SLAM technology. This platform is paid and offers a web-based 3D AR display and management platform to mobile users. Bookmarks can be created by users and linked to 3D models and other virtual elements.

12)Metaio: A library for creating AR mobile applications. Metaio can perform pattern tracking which will then be compared with existing references. In Metaio, the AR application design has embedded four marker tracking methods to carry out the marker recognition process. These methods have a threshold in the process of recognizing markers[23].

13)D'Fusion: A development platform for building Augmented Reality applications that provides tools for creating all kinds of immersive augmented reality experiences. The platform can also manipulate 3D visuals, combine marker less and gesture recognition, and easily set up and deploy complex AR. More than 300 parameters in advanced functionality are available in this graphical configuration for object recognition and beyond [2].

14)ARMedia: A platform that can help develop Augmented Reality applications effectively and efficiently. This SDK can be used to track unique 3D models from simple AR projects to very complex ones. The SDK provides recognition tools and includes 3D Object, Planar, Location, and Motion Tracking. ARmedia is not only able to recognize planar images and locations, but also 3D objects regardless of size and geometry. The ARMia SDK supports building advanced applications and systems that serve across a wide range of application domains. ARmedia SDK with any 3D Engine and Writing Environment like Unity 3D and Open Scene Graph[1].

15)ARCore: ARCore is a platform for building AR that focuses on mobile devices. The advantage of ARCore is that it can use different APIs; the user's device can observe and receive information about its environment and interact with that information [20][1].

Apart from these 15 tools, there are other tools such as ARUco, ZapWorks, Augment, HP Reveal, PTAM, HandyAR, ARGON, Amazon Sumerian, Mixare and others. It's just that based on the many tools, these 15 tools are the most widely used in research that has been done previously. For tracking target the main attributes in this classification follow a set of criteria that will be used to compare in each SDK. The analysed attributes are:

1) Text recognition: It is used to recognize words and/or groups of words for analysis.

2) Image recognition: It is used to benchmark its planar image recognition.

3) 3D object recognition: It is used to track cylindrical, conical, and general 3D real objects as investigated landmarks.

4) Multi-target recognition: It is used to track multiple targets simultaneously for analysis.

5) Geolocation recognition: It is used to test and verify which tools support geolocation targets.

6) Marker-free recognition: It is used to identify marker-free AR platforms.

From the results of previous research, it is known that there are several support platforms that support the AR SDK including Windows, Linux, OSX, Android, IOS, MAC OS or OSX, Smart Glasses and the Web. From the results of the study conducted by the researcher, the data shown in Table I below was taken:

TABLE I. ANALYSIS OF FRAMEWORKS AND PLATFORMS

Tools	Extension/ Platform	Text Recognition	Image Recognition	3D Object	Multi Targets	Geo-location	Marker less
ARToolKit	Windows, Mac OS, Linux, iOS, Android, Unity Package, Smart Glasses	x	✓	x	✓	✓	x
RealityKit	App (Android, iOS, Windows, Mac)	x	✓	x	x	x	x
Auras-ma	App (Android, iOS)	x	✓	x	x	✓	x
Blipp-AR	App (Android, iOS)	x	✓	x	x	x	x
CraftAR	App (Android, iOS), Unity Package, Apache Cordova	x	✓	x	x	x	x
EasyAR	Windows, Mac OS, Android, Unity Package	x	✓	x	✓	x	x
Kudan	Android, iOS, Unity Package	x	✓	x	✓	x	x
LayAR	App (Android, iOS e BlackBerry)	x	✓	x	x	x	x
PixLive	App (Android e iOS), Apache Cordova e Google Glass	x	✓	x	x	✓	x
Vuforia	Android, IOS	✓	✓	✓	✓	✓	✓
Wiki-tude	App (Android e iOS), Unity Package, Cordova, Titanium, Xamarin e Smart Glasses.	x	✓	x	✓	✓	✓
Metaio	Android, iOS, Unity Package	x	✓	✓	✓	✓	✓
D'Fu-sion	Windows, iOS, Android, Smart Glasses, Unity Package	x	✓	✓	✓	✓	✓
AR-Media	Android, iOS, Unity Package	x	✓	✓	✓	✓	✓
ARCore	Android, iOS, Unity Package	x	✓	✓	✓	✓	✓

In general, AR SDK has similar features, but if we look deeper, each AR SDK has main differences and makes each SDK have specializations that differentiate it from other SDKs. For example, there are some SDKs that have advantages in tracking, but other SDKs excel in recognizing objects. The main feature advantage of all the SDKs studied in this research is their tracking system. Tracking can be done in various ways and each solution offered has its own advantages and disadvantages in the AR experience to be created. There are four main geographic characteristics as seen in Fig. 2 below.

The explanation of Fig. 2 above is as follows:

1) Plane tracking is the localization of one or both ny of the translational offset (X, Y, Z) with rotational orientation (roll, pitch, yaw) in an object with respect to the origin. In AR, the point of origin is usually a mobile device with an embedded camera and almost all AR SDKs have plane tracking although individual results vary.

2) SLAM typically uses Apple ARKIT and Google ARCore as AR SDKs that perform marker less tracking.

3) A common example of face tracking technology is facing tracking with Snapchat AR lenses which uses algorithms to accurately track a user's face. Apart from tracking faces, this technology can also add digital makeup such as eye shadow or lipstick. For game creation, players can become avatars. Face tracking AR SDKs include Vuforia, DeepAR, and Aurasma.

4) Object recognition allows the AR system to identify objects in the real world. This process is still in development but can already display digital information about objects into the field of view and penetrate various areas of life such as education, manufacturing, construction, and design as well as health care.

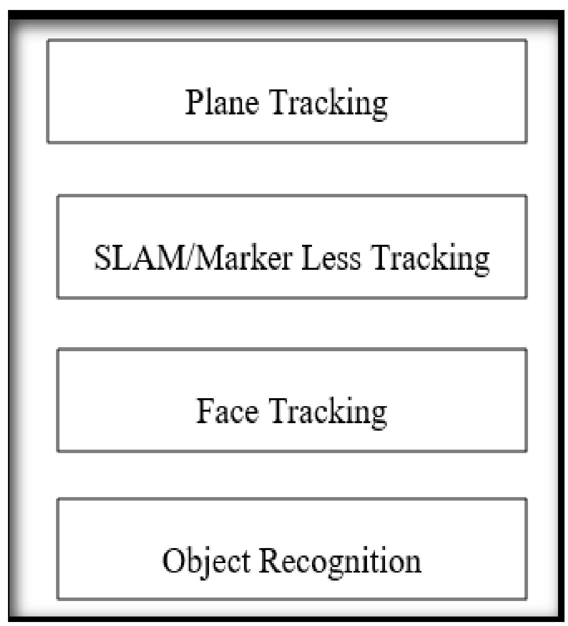

Fig. 2. AR SDKs and Tracking.

V. Result Discussion

Based on a comparative analysis of the features and virtual elements available for application development with the AR SDK, researcher suggests that the main functions of the AR SDK where to be able to offer AR application Editing Platform and facilitate software creation without requiring knowledge of algorithms. Besides that, it is possible to establish some general observations regarding the benefits and limitations of the AR SDK in this study as shown in Table II.

TABLE II. Analysis of Advantages and Limitations of Augmented Reality SDK

	Advantages	Limitations
ARToolKit	- These tools can create AR applications for iPhone and iPad. - ARKit helps developers develop AR applications that can support two devices to share the same virtual item thereby making the AR experience more engaging.	- In less accurate tracking even when the camera and markers are stationary (It does not support location-based). - Free access to AR Library but its development documentation is quite limited.
RealityKit	- High-performance 3D simulation and rendering experiences.	- No Concave Models - No Transparency or Opacity - No Videos - No Shaders
Aurasma	- Allows the association of touching actions on the screen, to start and end the app and after a determined amount of time. - Doesn't required the knowledge to implement algorithms.	- The lack of a control group with which to compare the participants fidelity of videos.
BlippAR	- No coding skills are required. This tool is free for educational use for the next 3 months. - Allows detection of markers and entities. - Allows for a reasonable amount of graphical rendering and animation. - Supports 3D markers for standard shapes.	- Not support marker less AR, though this will be supported soon. - Not support real-time shadows for rendering at present; this will need to be 'faked' by the content creator
CraftAR	- This SDK is most used by iOS apps in the Magazines & Newspapers genre, followed by the Book genre. - Doesn't required the knowledge to implement algorithms.	- Expensive and must be updated to recognize more targets or produce different behaviour.
EasyAR	- EasyAR is an SDK that lives up to its name. The features are simple, easy to use, and efficient. The functions of this SDK are quite advanced according to the needs of AR developers, including hard decoding, dynamic target recognition loading, screen recording functions, and a superior function, namely the recognition of more than 1000 local targets.	- Not free, pricing and payment details are listed on the EasyAR SDK product page. A free trial for EasyAR SDK Pro is provided. Each application will be given a limited time in the trial period.
Kudan	- Kudan is faster than other frameworks. This tool helps mobile AR applications to map multi-polygon models and import 3D models from any of the modelling software packages. - For the number of image recognition is not limited and requires less memory to store files on the device.	- This framework manual is brief and requires additional information. - Limited built-in functionality without direct access to OpenGL.
LayAR	- Offer interactive interactions to users in the context of a brand. Instead of instructing users to download the Screen App, users can bring LayAR interactivity directly into the app without needing to code everything themselves.	- SDK screen is NOT free. A 30-day Trial Period to play with the SDK before proceeding with purchases. But during this trial period users can use the SDK without any restrictions.
PixLive	- Multi-directional recognition and faster synchronization. - Doesn't required the knowledge to implement algorithms.	- Does not provide marker less and offline recognition.
Vuforia	- Enable to maintain tracking even when the target is out of view and view them from greater distance. - Cloud database allows storing thousands of image targets.	- The downside of the Vuforia SDK for Android is that the database is limited; it can only support 100 target images and does not feature any utility functions for loading 3D models, making it difficult for AR developers to create image formats.
Wikitude	- AR Content can be programmed using basic HTML5, JavaScript and CSS. - Enables the use of media such as images, video and 3D models. Allows the insertion and edition of text and buttons for social media. - Doesn't required the knowledge to implement algorithms.	- The SDK component could be a bit heavy, in terms of size. - Tracking of object sometimes was getting reset.
Metaio	- Powerful 3D rendering engine with capability load 3D model of .obj format. - No limit on number of trackable objects depends on device memory.	- Rendering 3D objects is very difficult using this SDK, and it is not easy to carry out developments related to the size of the model to be created.
D'Fusion	- To create high-quality 3D content, this SDK makes it easy to create several different 3D object formats. - Provide encrypted media to prevent privacy or tampering risks. - More than 300 parameters in advanced functionality are available to meet your needs with this graphical configuration tool for object recognition and tracking.	- Video file supported but audio associated with video can't be played.
Armedia	- Depth camera calibration provided which created more immersive experience	- Doesn't support all type of textures for 3D objects.
ARCore	- Its advantages are in motion capture, environmental perception, and light source perception.	- Sometimes it is difficult to scan big virtual object.

VI. CONCLUSION

From the results of the analysis and comparison of features in the AR SDK and virtual elements that have been carried out, the researchers suggest that the main function of the AR SDK is that it can be a platform for editing AR applications and makes it easy to create AR applications without needing to know algorithms or have knowledge of algorithms. The main attributes and supporting platforms were also examined in this study so that they could provide developers especially for the beginners with AR application knowledge. The results of this study showed that the main functions of the AR SDK were to be able to 1) offer an AR application Editing Platform and 2) facilitate software creation without requiring knowledge of algorithms. Developers and especially AR beginners do not need to write any code for the algorithm. These two functions could be in Aurasma, BlippAR, CraftAR, LayAR, PixLive, and Wikitude.

VII. SUGGESTION

Regarding the future perspective, this paper suggests conducting more investigations of the framework, AR functionality and features which required in AR development.

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