SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Augmented Reality Frameworks for Object Recognition in Learning Application Domain: A Systematic Review

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ARTICLE INFO

Article history:
Received 20 May 2023
Received in revised form 12 August 2023
Accepted 19 August 2023
Available online 11 September 2023

Keywords:
Augmented Reality (AR); object recognition; framework; technology-assisted

ABSTRACT

Object recognition is a technology based on computer vision techniques to identify the object in images or video. A previous study revealed that object recognition is useful to improve the learning outcome in augmented reality applications. However, there is yet to be a comprehensive augmented reality (AR) framework on object recognition in the learning application domain setting. This study aims to review the existing AR frameworks in object recognition and highlight the important components needed in AR framework. This Systematic Literature Review (SLR) was developed based on the PRISMA method. A preliminary search resulted in a total of 70 articles. After the removal of duplicates and a more rigorous screening based on the titles and abstracts, the number of articles was reduced to 26 articles. Then, for final review, only 9 articles were chosen. Based on the SLR, the components needed in the AR framework for object recognition are tracking, image classification, object localization, object detection, object segmentation, interface and interaction. Some of the limitations identified from the existing AR framework for object recognition include the lower-resolution camera that uses compressed images and due to the low detection accuracy and the limited of the tools. The proposed framework suggests the initial for AR framework object recognition.

1. Introduction

Augmented reality (AR) has become increasingly useful in many different fields. According to Azuma [1] AR is a technology that:

i. combines real and virtual content
ii. is interactive in real-time
iii. is registered in 3-dimensional (3D)

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https://doi.org/10.37934/araset.32.2.175188

By definition, AR is a computer system that can respond to users' inputs and generate relative graphics in real-time, a display capable of combining real and virtual images and a tracking system that can spot users' viewpoint position.

In short, AR technology allow scanning of an object in which it will expand and add a 3D object to the immersive learning environment. Furthermore, it will enhance reality with highly visual and interactive digital content, such as audio or haptic experience [2], text, animation, video and graphics in the real-world environment through camera.

Statistics have shown that the usage of AR has grown rapidly in the market since 2021 and will expand more henceforth [3]. In the past few years, AR applications were developed rapidly in fields such as entertainment (for promotional video, games, and social media), education (for teaching and learning), medical (such as MRI applications, jaw surgery [4]) and e-commerce (for shopping and home décor) (Puri *et al.,* [4], Çöltekin *et al.,* [5]). Due to the potential of AR in many other fields, developers had been looking for ways to make AR more user-friendly and usable [6]. Furthermore, in the coming years, it is also critical to emphasize how the method of delivering the application's content will affect how we learn, make decisions and interact with physical world. It will change how to train the employees, design and create the product and how the enterprises serve customer by using augmented reality applications [7].

There are different types of AR which are marker-based and marker-less AR. The marker-based AR uses image recognition to trigger objects within the space [8] in which the marker imposes spatial limitations on the simultaneous tracking of space and objects [9]. Meanwhile, marker-less AR includes four categories, which are location-based, projection-based, outlining and superimposition-based AR. Marker or marker-less AR applications had their own tracking approach to identify specific tasks based on the users and to recognize planar images and also complex 3D objects, regardless of their size and geometry [10].

Calvary *et al.,* reported that the factors influencing object recognition in AR were the tracking techniques [12], detection level, the accuracy, the camera resolution, the size and the compatibility of devices to which the users need to carry out the interactive task and the physical environment [11]. In addition, Muff and Fill [13] reported that AR applications for object recognition need to determine the current situation according to action for information display with the devices which have to dispose of different sensors for detecting the environment. This is means using various sensors to assess the current state of the environment and thus derive the artificially generated information for the user through visual means.

As the computer vision technology advances, it leverages on artificial intelligence to overcome marker or marker-less AR deficiencies and provide faster and more accurate detections [14]. For example, an object recognition system will find objects in the real world from an image of the world using the object model [15]. Lee *et al.,* highlighted that object recognition can be used to recognize an object and the information based on the object will appear. This includes the collection of various tasks and techniques that require image processing, object localization, object detection, pattern recognition and machine learning. Moreover, understanding the world around the user in terms of semantics and geometry is needed to make the user experience in AR sufficient to replace traditional computer vision approaches [16]. Therefore, AI-specific computer vision will improve recognition of an object that may show pertinent information and interactive learning experiences that engage the user in the application [17].

In education, technology is used as a medium to deliver information and give students more understanding and experience [18]. Technology can give more benefits to enhance visualisation, excite, and motivate to support understanding in learning applications. There are a few AR frameworks available in relation to learning such as the AR framework on computer-assisted learning for children with ASD based on hand gesture and voice interaction that offers interactivity, engagement, and visual support during school or cognitive therapy sessions [19], FECTS framework: A Facial Emotion Cognition and Training System for Chinese Children with Autism Spectrum Disorder the focuses on autism intervention study for improving the emotion recognition of Chinese children with an autism spectrum disorder [20] and AiLeaD framework for developing an augmented reality immersive learning design. Based on survey paper of [21] analyses the applicability of frameworks in learning and highlights the benefits and challenges of AR frameworks for object recognition, including the key features, capabilities, and limitations of AR frameworks such as ARToolkit, Vuforia, and ARCore and evaluates their effectiveness for educational purposes. Other than that, Kavitha *et al.,* [22] proposed the system that contributes to the child's offering the education attractively and entertainingly. The system consists of an application that renders AR object onto the device screen. However, this research more focus on learning application through the object recognition. Yusoff and Halina [23] review the AR frameworks to support learning engagement in a learning environment, but this research focuses more on the integration of frameworks in supporting learning engagement based on the knowledge visualisation framework through AR and how students can focus during the learning process in an AR environment. There are few research highlights on the challenges of augmented reality object recognition in learning application. Su *et al.,* [24] addresses a key challenge of recognising different types of images in mobile AR. By using the latest approaches in computer vision, this research demonstrates efficient recognition and edge computing and reduces latency for object recognition. Overall, many AR frameworks for object recognition concentrated on a particular task, for example, accuracy detection, image classification, and object localization.

In general, the development of AR applications has been increasing, yet the development for AR with regard to object recognition in the learning application domain was slow and inconclusive. Hence, to obtain a more comprehensive overview on this issue, this SLR paper aims to explore the existing AR frameworks on object recognition and propose an iteration to the existing framework. This SLR also intends to answer specific research questions as follows:

i. RQ1. Which components are included in the AR framework for object recognition?
ii. RQ2. What are the limitations of the AR framework for object recognition?

3. Methodology

The SLR is conducted based on PRISMA approach [25]. Two databases are selected, which are Scopus and Web of Science (WoS). These databases are selected because they contained high quality and peer-reviewed manuscripts.

The search in both databases used the combinations of keywords such as "AR" AND "Augmented Reality" AND "Object Recognition" AND "FRAMEWORK." The inclusion criteria include:

i. scholarly articles in journals and conference papers
ii. papers written in English
iii. published within 2018 to 2022

Meanwhile, the exclusion criteria are:

i. removal of duplicates
ii. papers that are not related object recognition in AR based on the initial skimming of title and abstract.

In the initial stage, the search discovered a total of 70 articles from both Scopus and WoS databases. 1 article is included from the secondary source, which are found from the reference section. However, after the removal of duplicates, the total number of articles was 26. A thorough screening based on the full articles yielded 16 articles to be eligible. In the final list, nine articles are chosen to be reviewed in this study (as shown in Figure 1).

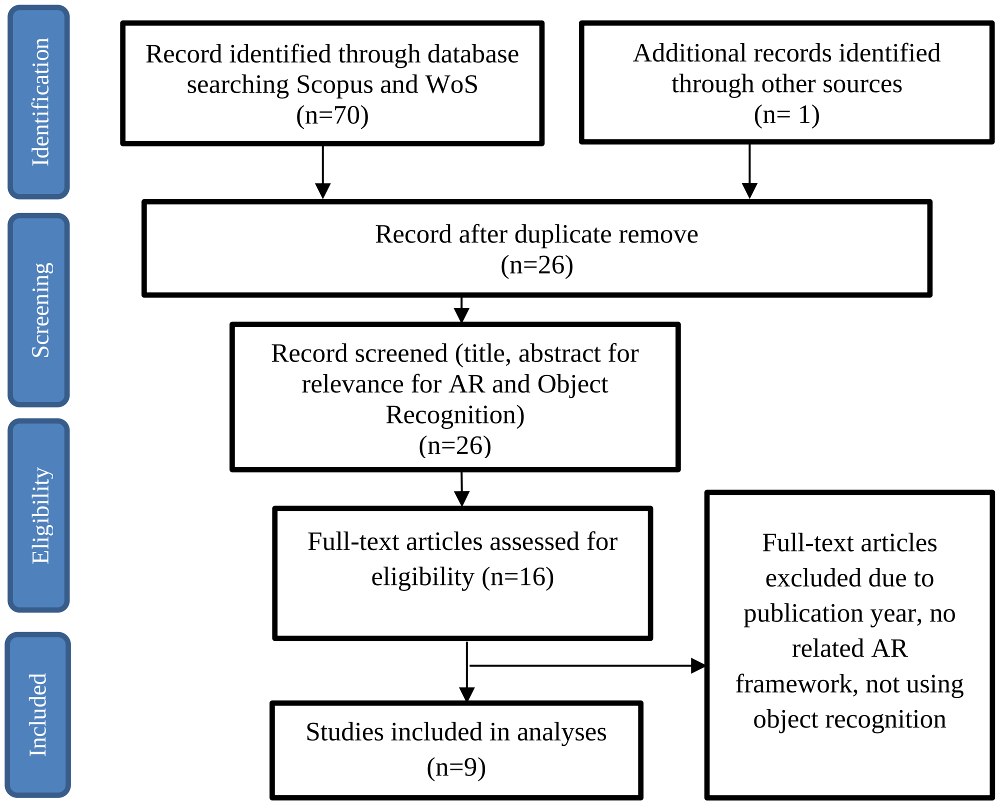

Fig. 1. Selection of the final list of articles for the SLR review process

4. Results

Table 1 showed the SLR review result on AR frameworks for object recognition in the learning application domains. In the context of learning application domain, many AR frameworks for object recognition are developed for AEC industry, maintenance and work safety compared to learning application for education.

For AR types, the frameworks are mostly curated to cater for the development of marker-based AR applications. The most commonly used techniques are object detection (Kaul *et al.,*) with software ARKit and MobileNet. (Tiffany Y. Tang, Xu & Winoto and Brandon Huynh *et al.,* used the same image detection and tracking techniques developed by Google's TensorFlow. Next, image recognition is well used as tracking techniques with convolutional network and deep learning enable apps built using AR Core with Vuforia engine [29], AR Core and AR Kit [30] and Unity by [31].

The aim is to delve into the components, advantages, and limitations of the AR framework for object recognition. The researchers [29] have focused on the context-aware AR system (CaARS) and addressed the benefit where AR augmentation serves to increase design and cognitive understanding, decision-making, and task support but has limitations on scanning objects in the construction field based on anamorphic images obtained from the completed construction project. Interaction, AR development, and user interface were among the framework features. On the other side, it is important to analyse the work of [26] which covered the components of interaction and usability, with 3D audio detection and limitation on prototype implementation was still rough due to the low detection accuracy and the limited range of MobileNet v2 and inexact plane detection of ARKit. [27], centred on augmented reality development and the foundation of the Universal Design for Learning (UDL) framework that reflects that the application is appealing enough for autistic children to learn anywhere and at any time through object detection. The limitation of the framework is based on the fact that the accuracy of the offline object recognition model significantly compromised its acceptability. In addition, [32] used a CAD model to enhance the techniques in AR development and perceptions of the environment to recognize an object whose 3D pose is detected and tracked in real-time (online training), but has an issue with visible conics in the image. The work of [13], which focused on AR technology for object recognition and used context-dependent AR of machine learning, ontologies, and reasoning, found that the framework benefits genericity and flexibility in the object pattern but has limitations due to simulating object recognition by using marker patterns that provide information about the recognized objects. The research by [33] also focused on AR technology and showed the benefits of designing a cache and matching system but had limitations on cache size in the component framework. Furthermore, research [34] on a low-latency framework that benefits applications reduce end-to-end AR latency and accuracy but requires determining the physical size of a recognized object, and research [35] on detection that benefits users. The limitation of the framework is the need to focus on stability in wall detection.

Table 1
A review of AR frameworks for object recognition in the learning application domains

Framework	Details	Learning Application Domains	AR Types	Technique / Algorithm Used	Development tools	AR Framework Component / Features	Advantages	Limitations	Ref
Framework for an intelligent Context-aware AR System (CaARS)	The framework considers novel enablers, including multi-object scanning, a model slicer for customizing a single 3D model, using anamorphic images for object recognition, and an interactive user interface	Architectural Engineering and Construction Industry (AEC)	Marker-based	AI component image recognition	ARCore, Vuforia	• Interaction • AApp Development - Model Slicing - Anamorphosis and anamorphic images ıterface and User Experience	Seeks to address the multiple scenarios where AR augmentation serves to increase design and cognitive understanding, decision-making, and task support.	• The current development allows scanning objects in the construction field based on anamorphic images obtained from the completed construction project.	[29]
A Framework for Context-Dependent Augmented Reality Applications Using Machine Learning and Ontological Reasoning	The concept of augmented reality permits to embed virtual objects and information within the real context of a user. This is achieved using various sensors to assess the current state of the environment and thus derive the artificially generated information for the user through visual means	Work safety	Marker-based	• Machine Learning • Context reasoning algorithm - object pattern	Microsoft HoloLens2	• machine learning • ontologies soning	• Flexibility • Generic	• The WebXR Device API does not yet contain machine learning-based image recognition • Simulated object recognition by using marker patterns that provide information about the recognized objects • Need to test the framework with more complex use cases including bigger ontologies.	[13]

Scene and object recognition framework	People with visual impairments face challenges in scene and object recognition, especially in unknown environments. The combination of ARKit and MobileNet allows keeping recognized objects in the scene even if the user turns away from the object	People with Visual Impairments	Marker-less	Neural network- Object Detection	• ARKit MobileNet	• Interaction Usability	Users can find items without visual feedback using the proposed application	• Prototype implementation was still rough due to the low detection accuracy and the limited range of MobileNet v2 and the inexact plane detection of ARKit • Exchanging MobileNet v2 with YOLOv5x and switching to an iPhone 12 Pro	[26]
An Augmented Reality-Based Word-Learning Mobile Application for Children with Autism to Support Learning Anywhere and Anytime: Object Recognition Based on Deep Learning	Present a mobile vocabulary-learning application for Chinese autistic children especially for outdoor and home use. The core object recognition module is implemented within the deep learning platform	Autism, Learning, Mobile learning application	Marker-less	Deep Learning - Object Detection	Google's TensorFlow1	• AR Development - Google's TensorFlow1 machine learning framework • UDL Theory framework: i- Engagement ii- Representation iii- Action & Expression Feasibility & usability	• The general applicability of the application • Attracts children's attention	• The accuracy of the offline object recognition	[36]
Smart-Decision Framework For Real-Time Mobile AR Applications	Combines the advantages of the on-device mobile AR system and the edge-based mobile AR system to achieve real-time object recognition	Mobile learning application		Deep Learning - Image classification	• GoogleMobileNets • Tensorflow Lite	AR technology • The advantages of the on-device mobile AR system • The edge-based system to achieve real-time recognition tasks.	• Design a cache and matching system to enhance the performance of mobile AR applications when the on-	Inference Accuracy - cache size is limited.	[33]

							device deep learning models have poor performance. • The quality of mobile AR applications is improved		
ARGitu Framework	To generate and present virtual and augmented information, including the tools required for the development of new contents	Industrial maintenance	Marker-based	object recognition, CAD Model (offline training),	Vuforia	• AR Development - set of libraries software (including multimedia information) - usability of the interface Perception of the environment	• The 3D pose of the object is detected and it is tracked in real-time (online training).	The requirement of visible conics in the image.	[32]
In-situ labeling for augmented reality language learning	Introduced a framework for realizing in-situ augmented reality language learning.	Language learning	Markerless	Convolutional Neural Networks (CNNs) Object Detection API, using the SSD mobilenet v1 coco model, which has been pre-trained on MS COCO	• Microsoft Hololens, TensorFlow	• Environment sensing with object-level semantics • Attention-aware interaction • Personalized learning models	The ability to conduct both object recognition and environment mapping in real-time using a convolutional neural network	A lower-resolution camera that uses compressed images (such as the camera on the HoloLens)	[28]
Demo: Low latency mobile augmented reality with flexible tracking	The primary goal of Jaguar is to reduce end-to-end AR latency close to the interframe interval for	Mobile application, movie poster	Marker-based	Deep Learning - Image Recognition	• ARCore ARKit	• A low-latency image retrieval pipeline	• Jaguar reduces the end-to-end AR latency to ~33 ms and achieves	The client should be able to determine the physical size of a recognized object and transform its 2D boundary into a 3D	[34]

	continuous recognition, as it does not require users to pause their cameras at an object of interest for seconds					Mobile application that enriches ARCore with object recognition	accurate six degrees of freedom (6DoF) tracking.	pose, as ARCore's tracking happens on the physical world scale	
Mobile augmented reality framework - MIRAR	Presents the architecture of MIRAR, a Mobile Image Recognition based Augmented Reality framework.	Mobile application, Museum	Marker-based	Convolutional Networks - Image Recognition	Unity	• The detection and recognition of museum objects • The detection, recognition and tracking of objects as the user moves along the museum • Detection and modeling of the museum walls • Detection of persons that are moving into the museum	Impactful relation between the museum's user and the museum's objects	• Need focus on stability in wall detection • Filtering the occasional bad results of tracking	[35]

5. Discussion

Based on Figure 2 presents the initial proposed diagram for AR framework object recognition. The AR framework-based object recognition is very important to identify the suitable elements to use before the development process. Object recognition was used to recognize an object to deliver virtual information. To make the object recognition, they used a tracking and AI algorithm to make the object more accurate in detection, classification, and localization to render and deliver the AR experience and view the AR interface to make user interact with the object to. Since the AR framework requires the identification of the environment and component elements, there is a challenge to having the best framework to develop AR applications. The first research question focuses on the application that covers the AR framework for object recognition. The comparison shows the most applications AR object recognition framework covers in the AEC industry [29], work safety [13], and industrial maintenance [32] which means the most AR object recognition are beneficial in engineering industry domain using the deep learning or computer vision techniques. This is supported by [37] which various object recognition systems are evaluated in a service-robot domestic environment, where the final task to be performed by a service robot is the manipulation of objects. Although there is the least research on the AR framework for object recognition in learning applications, there is one work that presents a mobile vocabulary-learning application for Chinese autistic children especially for outdoor and home use that is implemented within the deep learning platform [36] and for visual impairment. In contrast, the work of [34] and [28] focused on the technology of detection and classification of the object. The AR framework for object recognition specifically focused on accuracy and reducing end-to-end AR latency close to the interframe interval for continuous recognition, as it does not require users to pause their cameras at an object of interest for seconds.

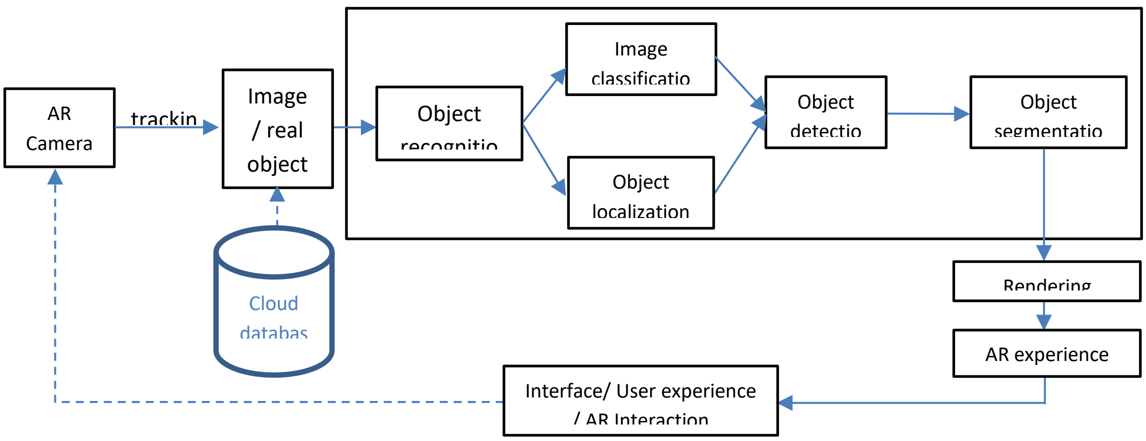

Fig. 2. Initial proposed diagram for AR framework object recognition

From the review, the technique of computer vision-based, software and hardware has been the most used in AR object recognition. The finding agrees with to use of computer vision to overcome the tracking and efficiency of object recognition. Therefore, the finding found that such as selection of author tool, stability or filtering of the object. Author tool usage, the developer must identify the security of applying the algorithms, and compatibility with the tracking to scan the object more accurately in development technology. The tracking is important to be able to make the physical object determine the size of a recognized object and transform that happens in AR application. This is supported by Daniel Antonio *et al.,* which the authoring tool has the software libraries that support the database for the information and guidance to present the information using the mobile device which can provide interactive ways to display the information. Using computer vision, we can make the detection and localization of objects toward the solution of the visual perception in recognizing the object [38]. All the visual appearance for object detection, recognition, scale and speed up the features used in computer vision techniques are stored in the database of the software [39].

Most of the study has taken a step-in direction of the framework of AR-based object recognition technology. The development of an AR-based framework of object recognition is possible can develop based on the selection of an authoring tool reflecting the requirement of the application itself to get more efficient in object recognition. In addition, the tracking that provides in computer vision with the extent of features can support in detection and recognize objects that are more robust to scale, rotation, deformation and occlusion limits in traditional computer vision techniques but are still relevant to use. Object detection accuracy will impact the overall performance of recognition. If the object detection component struggles with complex or occluded objects, it can decrease the accuracy and reliability of the recognition system. From there, it will decrease the user experience and reduce the effectiveness of the learning context. Therefore, developers need to consider the arrangements between accuracy and performance to ensure they meet the requirements of specific learning applications. On the feature extraction, the quality and effectiveness of feature extraction play crucial role in accurate the object recognition. The limitations in feature extractions will impact the ability to capture the distinctive features of objects, leading to reduced recognition accuracy and robustness. The limitation in recognition and tracking component will directly affect the reliability and real-time performance of the system. The affect such as inconsistent recognition results, difficulty in matching features to reference data and tracking errors can result incorrect or unstable object recognition. The limitation on the scalability of AR framework for object recognition will impact the deployment of large-scale AR learning applications. More object to recognize, the performance of recognition may decline, leading to challenges in managing the library of objects. So that, the developers should consider the scale and complexity the objects to the learning application to ensure the optimal performance of the scanning object.

The approach outlined for this study should be considered for the features used for the efficiency of tracking, and detection in computer vision. The traditional features can be replaced by the extraction of features such as deep learning that can extract the complex features for more detection, express the image in more detail from the recognized object, and learn a specific task more efficiently. Therefore, to contribute to the AR framework based on object recognition, advanced AR technology with adding computer vision that incorporates the AR camera into smartphone applications and object recognition must study to fill the important consideration in tracking use, a software application that encompasses the previous limitation.

There are lots of strengths and challenges when applied to the learning application domain. By using AR object recognition, it will bridge the gap between theoretical knowledge and real-world applications. From there, learners can see the actual concepts and the relation of the theories to the environment. Therefore, it is important to consider the limitations while developing or using the AR frameworks for object recognition to meet expectations and try to overcome some challenges. The advancement of technology in computer vision algorithms and hardware will improve the capabilities of AR framework object recognition.

6. Conclusion

In conclusion, the existing AR framework on object recognition is mostly developed for the AEC industry and work safety in the learning application domain and is more focused towards marker-based AR applications. Meanwhile, the technique that was frequently used was deep learning computer vision technique. Despite the numerous advantages from the AR framework, some limitations to the AR framework on object recognition include viewpoint variation, deformation, and stability of detection. Therefore, the proposed framework is developed to identify the elements and components used in object recognition to apply in object recognition in learning application. All the components in object recognition used to allows the identification and localization of the object in an image, video or real object.

Despite the findings obtained, the tools with the technology of computer vision are very important to develop the AR application to make the tracking object more efficient and accurate. From the scanning object to the computer vision with providing extended features and software library supports the database will enhance the display of digital content such as animation, video, text, audio and image. It is very effective in recognizing different types of objects, size and the advanced technology of AR that can view the object in 360° will give the solution to a limitation in traditional computer vision in object recognition. As the limitation presents more challenges, it is important to note that AR frameworks for object recognition have continued to improve as technology advances. Researchers and developers are actively finding solutions to the limitations through computer vision algorithms, hardware capabilities, and techniques. As the technology evolves, limitations and AR frameworks are closely related to each other to become more balanced, robust, and reliable in recognition in learning applications.

Acknowledgment
This study is supported by Universiti Kebangsaan Malaysia through Geran Galakan Penyelidikan, GGP-2020-020. High appreciation is given to the sponsor.

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