Taxonomy, Open Challenges, Motivations, and Recommendations in Augmented reality based on object recognition: Systematic Review

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ABSTRACT

Augmented reality (AR) and object recognition are two relatively new technologies that can be employed to improve the possibility of better human perception and understanding of the surroundings in the real world. The potential benefits of the integration of these two technologies can be found in many areas. This study synthesizes selected papers from 2017 to 2021 to provide a thorough overview of existing AR-based object recognition systems. Several selections and scanning processes were employed using the inclusion criteria on all 2020 papers acquired. However, only 48 papers met the criteria. The study discusses and highlights the challenges, motivations, and recommendations of using the combinations of these technologies. In addition, it provides a classification of the tools and hardware mentioned in the selected studies. Finally, a summarization of the general characteristics of systems and applications developed and implemented in the selected studies. This study aims to enrich the understanding of this type of AR and, hopefully, inspire researchers to assist in the development and growth of AR.

Keywords: Augmented reality; object recognition; AR-based object recognition.

Introduction:

Humans are constantly involved in perception engagement, such as detecting and identifying objects in the real world. Hence, understanding the surrounding environment for decision-making and completing various activities is crucial [1] because the real world is complex and diverse, and people might find it challenging to rapidly identify the objects they seek, leading people to quickly accept various technologies that contribute to accomplishing jobs faster, more accurately, and with less effort [2]. Examples of such technologies include computer vision and augmented reality.

Researchers have focused on designing and implementing object recognition methods in recent years. Object detection technology can reduce the number of user-hands-on actions and provide a new model of engagement that differs from the touch screen, allowing hands to be genuinely liberated and enabling interaction to be more convenient and less burdensome [3]. Many object recognition methods are known today, for instance, you only look once (YOLO) model [4], Single Shot Detector (SSD) [5], homomorphic filtering, and Haar-like features [6]. Convolutional Neural Networks (CNNs) have led to technological improvements in object recognition as a result of their success [7]. The performance of these methods for detecting targets with deep learning is becoming increasingly streamlined, precise, and rapid. The user receives the result of the detection process in the form of a visual bounding box or label enclosing the name of the object.

However, a shortage of information conveyed to the user can be observed and the semantics of objects need to be understood from an interesting point of view rather than simply highlighting the objects or depicting the object name [8]. A difference in dimensionality can also be observed because the real world is 3D and the information related to the real-world objects is presented in 2D formats as in the scripts, images, and videos. As a result of this disparity, the possibilities of leveraging the information to the maximum are limited [9]. Such limitations can be eliminated with Augmented Reality (AR) because of its capability to present an ideal method by integrating 3D virtual data into the 3D real-world environment in real-time [10] .

AR is another type of immersive technology that incorporates virtual information such as text, audio, 3D objects into the real physical world to extend the user's understanding of the real-world or specific point of interest [11]. AR can be used to make imperceptible information easily observable. AR-based object recognition can be implemented in two approaches. The first approach is marker-based and utilizes the 3D object as a marker to activate the AR experience or attaches an artificial marker, such as a fiducial marker or QR code that is employed as a reference point to activate the AR experience [12]. The second approach is markerless and utilizes complex computer vision techniques to detect and track 3D objects in the real world [13]. AR-based object recognition studies indicate promising results in improving human performance in difficult tasks, such as maintenance [14] parts assembly [15], and improving the perception of the surrounding environment [1]. Additionally, it can provide an ideal approach for remote collaboration in a wide-ranging system [16]. It also supports people with special needs, such as people with low vision capability [17]. Autistic children can also benefit from the visualization delivered by AR [18]. The objective of this paper is to provide beneficial insights into AR-based object recognition methods and implementation and assist scholars in understanding existing techniques to fill in the gaps of the topic and present a coherent taxonomy for the literature. The motivations and challenges of the topic are also determined .

This paper is organized as follows. Section 1 introduces AR-based object recognition. Section 2 describes the research process, scope, literature sources, and filtering steps. Section 3 presents the results of the final set of articles in this paper and creates a taxonomy for related literature and statistical information. Section 4 classifies and discusses the motivations, challenges, and recommendations extracted from the final set of articles from 2017 to 2021. Section 5 discusses the conclusions.

Method

The goal of this study is to conduct a systematic literature review (SLR) with the purpose of detecting, evaluating, and understanding relevant research related to the particular fields of application based on the combination of AR and object recognition technologies

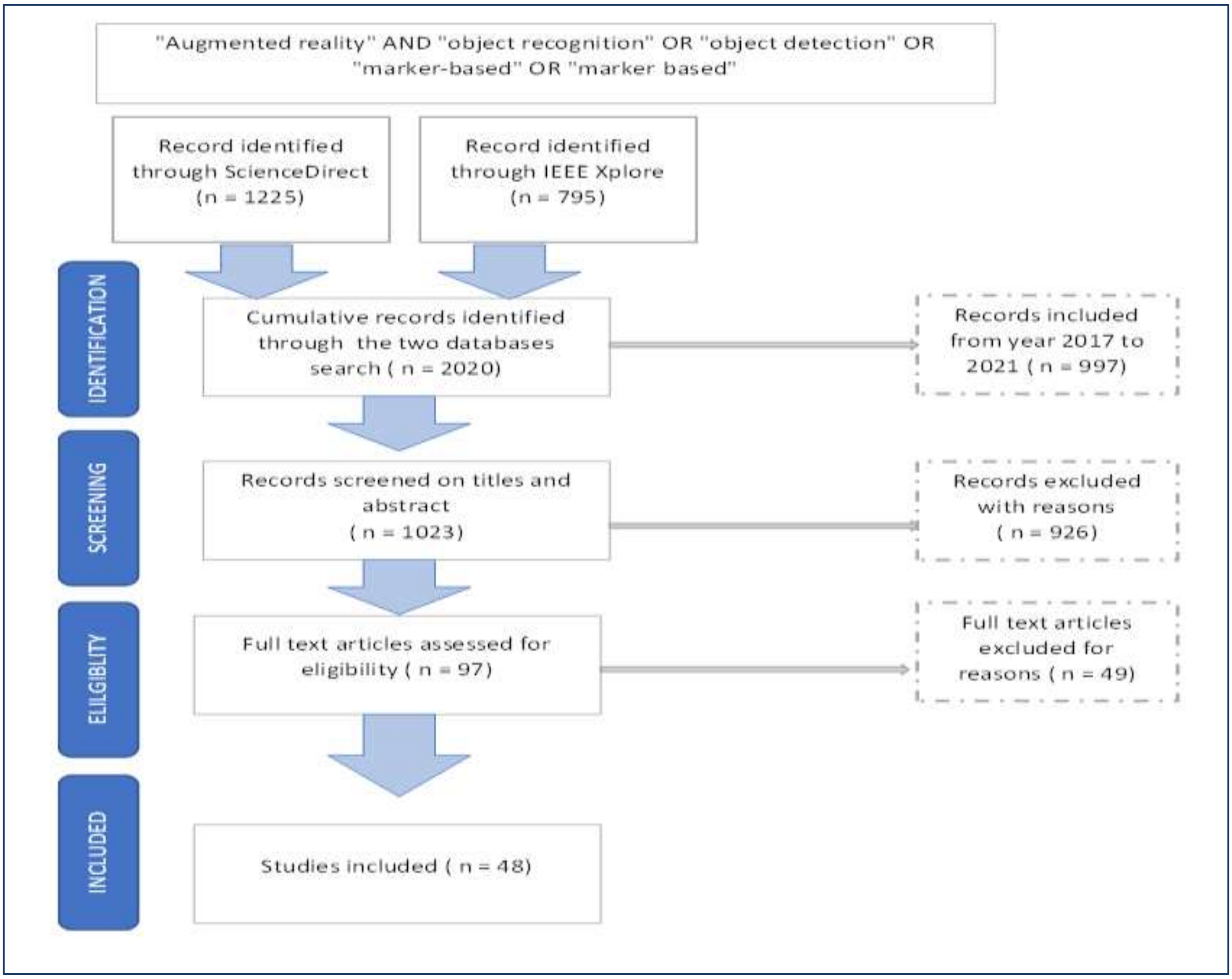
Search strategy and data collection

We used the following online bibliographic databases to conduct our search: IEEE Xplore and Science Direct. The search commenced on September 27, 2021, using the 'advanced search' in the databases. The Searching step consists of browsing databases mentioned above separately by utilizing the string: ("Augmented Reality") AND ("object recognition" OR "object detection" OR "marker-based"). The results of this searching step are the collection of 2020 documents as seen in (Table 1). This phase was carried out separately for each database. The PRISMA diagram was used in the main study selection process as shown in (Fig. 1). The study selection process consisted of searches in the two digital databases and screening and filtering processes. The first iteration excluded the duplicates and irrelevant articles by scanning the titles and abstracts, while the second filter categorized the articles after a thorough full-text reading of the screened articles from the first step.

Table 1. number of documents returned.

Database Name	Search Fields	Documents returned
ScienceDirect	Title-Abs-Key	1225
IEEE	Title-Abs-Key	795

Figure 1. PRISMA flow diagram describing the selection process



Eligibility Criteria

Inclusion criteria were considered in the study selection process to obtain relevant studies that belong within the scope of this literature review. The following inclusion criteria were used to ensure a successful selection process:

- Only 3D objects are used as triggers;
- Must use AR technology;
- Only articles that are written in the English language;
- Only peer-review articles;
- Available within the two selected databases; and
- Full text is available online.

Taxonomy And Statistical Information Of Articles

Searching the databases mentioned above produced 2020 studies from the study selection and criteria process. After setting the timeline from 2017 to 2021, only 1023 studies remain. After the screening process of titles and abstracts, only 97 publications met the preliminary selection criteria. Following a thorough examination of the full texts and a quality assessment, 48 studies met the inclusion criteria and were included in the final review, which was grouped into three main categories. The first category (43/48; 89.5%) includes experiment studies related to solving problems in the work environment or evaluating AR performance with object recognition or supporting users at work or in their daily activities. The second category (4/48; 8.3%) includes framework proposals to develop user support systems using mobile and wearable devices. The third category (1/48;2%) includes a review study related to identifying food objects. We have scanned and captured the overall categories of studies and refined the classification into the literature taxonomy shown in (Fig. 2). The observed categories are listed in the following sections with simple statistics depicted across the discussion

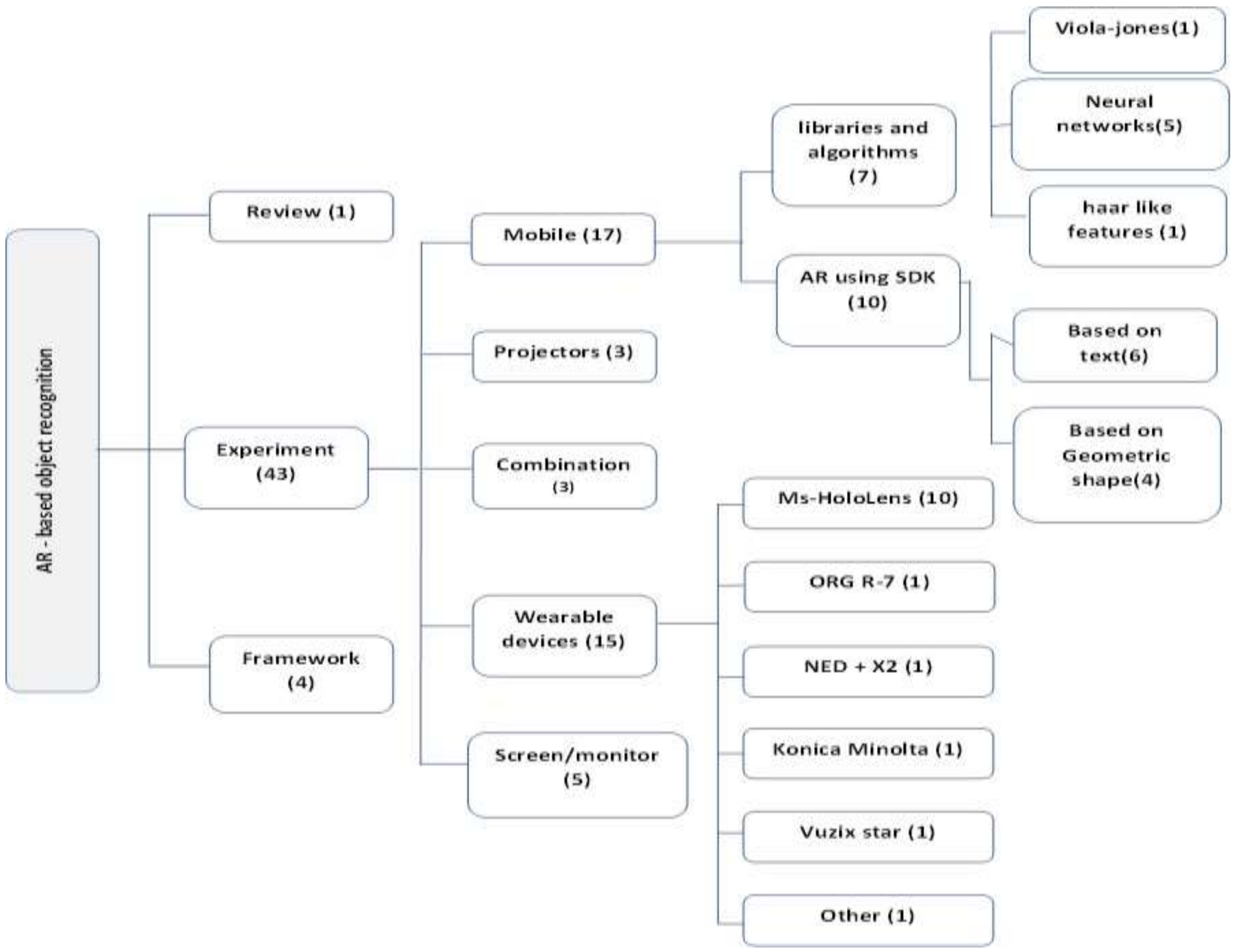


Figure 2. Taxonomy of research literature on object recognition based on AR

1. Review

The fundamental purpose of AR survey and review studies is to comprehend current considerations and demonstrate the need for future studies on relevant areas that have been neglected or largely unexplored. Despite the importance of these types of studies, among the 48 studies, only one study belonged to this category. This review paper summarized and evaluated eleven systems of food recognition based on six stages, and three systems from the total eleven systems used augmented reality [19].

2. Experiment

This section reviews the studies of different AR systems and their usage. The majority of the studies gathered through the research process (43/48 studies) belong to the experiment category. These papers were divided based on the output device used to display the virtual content. The first category (17/43) contains studies that use mobile devices, such as smartphones or tablets. Under this category, (10/17) of the studies employed AR SDKs as the implementation of their systems. The further classification was applied to these ten studies depending on the detection features and (4/10) studies utilized features that include text and painting [10, 17, 20, 21], while (6/10) used features based on the geometric shape of the objects [16, 18, 22-25]. Other studies (7/17) utilized artificial neural networks and libraries of functions to implement the proposed systems [6, 11, 26-30]. The second category contains (15/43) studies that employed wearable devices, such as smart glass and head-mounted devices because of their advantages, such as mobility and the ability to use both hands. Further classification based on the brand of the wearable device was conducted [2-4, 8, 13, 31-40]. The third part (5/43) includes studies that employ monitors or screens because of their low cost and availability, and the option to display the virtual information simultaneously to several users [1, 12, 15, 41, 42]. The fourth part (3/43) includes studies that employ projectors because of their capabilities of projecting virtual information on the surfaces of the real world, which makes the virtual information visible without restrictions on the field of view and without the need to use additional hardware [43-45]. The fifth part (3/43) includes studies that employ a collection of devices aimed to support workers during the execution of tasks. The range of devices includes smartwatches, projectors, wearable devices, and tablets [5, 46, 47].

3. Framework

Some of the studies collected (4/48;8.33%) were included in the framework category in our taxonomy. They present general frameworks or modules for system development. Two studies involve framework and system design related to worker support in work scenarios, such as maintenance, inspection, repair, and operation [14, 48]. Another paper introduces system architecture for gesture detection technology that can be used to control smart glasses [49]. Finally, a single paper presents a framework for a language teaching interface based on AR that identifies and places virtual labels on objects that exist in the users surrounding in a different language [7].

Discussion

The primary goal of this study is to provide an update on state-of-the-art AR-based object recognition and the focus of the research trends. This section introduces the most significant challenges, motivations, and recommendations discovered in the studies.

Motivations:

This section shows the different aspects of motivations, which are grouped into several categories related to their specific benefits. (Fig. 3) highlights the groups of AR-based object recognition motivations.

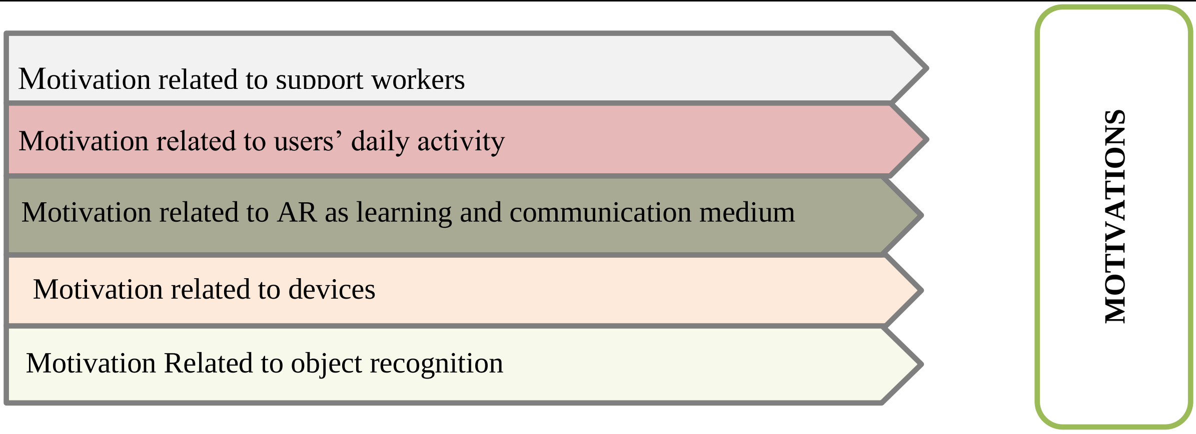


Figure 3. motivation categories for AR-object recognition

1. **Motivation related to support workers**

Since the declaration of the 4th industrial revolution, various manufacturing businesses have been motivated to incorporate AR with their operation units [27] facilitate individuals' jobs [16, 40, 47] including assisting the worker in complicated assembly tasks [15, 31], as well as in operations, such as maintenance, repair, and product inspection [6, 8, 11, 14, 29, 32, 34, 35, 48]. Decreasing costs and time consumed in the process of training workers is one of the motivations of the study [13]. In addition, worker safety during operations is the motivation for study [45]. Another motivation was improving communications in Human-Robot collaboration to increase the production line and general productivity of workers [5, 42, 43, 46].

2. **Motivation related to users' daily activity**

The broad availability of AR motivates researchers to employ it in different aspects of daily life activities, such as helping users in shopping to choose the proper products [20] and the process of selecting the correct kit tool [33]. Another motivation is to assist in driving to reduce fatal accidents and improve driver attention [4, 44]. The widespread usage of mobile devices has also motivated the exploration in the use of AR to aid visually impaired and blind people and guide them in identifying objects in their environment [10, 17]. Another motivation related to the daily activity is eating, such as controlling food portions and selecting the proper food [19].

3. **Motivation related to AR as a learning and communication medium**

The capability of AR to run in real-time and display visual information in 3D models has led researchers to apply AR as a learning and education medium such as learning computer hardware [22]. Education in complex topics, such as engineering, can be simplified with the help of AR [12, 25]. AR has also been used in language learning by labeling the objects virtually in the user environment [7, 38]. In the medical field, AR has been used to facilitate communication between doctors and patients concerning the location and size of tumors [26]. Another study adopted AR in the teaching of autistic children because it can enhance the experience and decrease reliance on parental supervision [18]. Another study implied that using AR in tourism can improve the understanding of painting and motifs by tourists because of the damage and difficulty to perceive the arts [21].

4. **Motivation Related to devices**

AR devices have also been the focus of upgrading and improvement with the development and advancement of AR technology. However, despite the sound features and effective specification of devices, such as HoloLens, several studies have further extended the capabilities of the wearable device [2, 36, 49]. The growth of mobile devices used as AR devices has also been the subject of several studies [23, 24].

5. **Motivation Related to object recognition**

Providing effective object recognition methods for implementing and using AR successfully [3, 28] and for implementing object recognition on texture-less objects has also motivated researchers [30]. Developing better recognition methods of a 3D object in the real world has also been explored because of the necessity of object recognition in AR [1, 41]. Another study focused on the precise recognition of objects and distinguished different objects belonging to the same category [37]. Further studies are necessary to improve the capability of the assembly instruction-based AR depending on the error feedback [15].

Challenges:

Different AR-based object recognition challenges have emerged in the analysis of academic literature. Researchers have reported numerous challenges related to the AR-based object recognition process itself and those related to the systems that employed the technology. The following subsections classify and report on the major challenges and their references. (Fig. 4) shows the major challenges found in the academic literature.

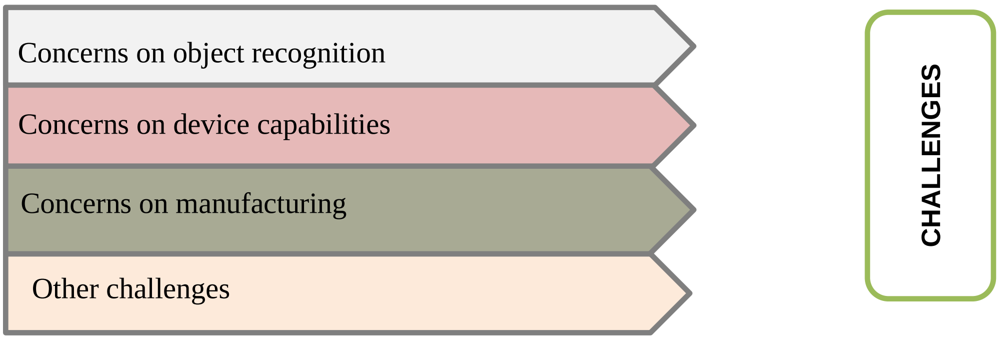


Figure 4. Challenges for AR-based object recognition

1. **Concerns on object recognition**

The AR technology depends on object recognition to be triggered and function accurately hence, different object recognition techniques have been proposed and utilized. However, the performance of these object recognition degrades when the target objects are small in size, such as pills and cable brackets, and the features of objects that are not distinct force obstacles in the labeling process. Additionally, text labels imprinted on the objects also pose challenges because of the deformation and numerous text styles that can be used [7, 10, 31, 38]. The traditional methods of using a marker whether fiducial or 2D images require attaching the markers to the target objects and the necessity of pre-registering the markers. Moreover, whether the span between the camera and AR marker is large or the marker is partially covered may cause instability and incompatibility problems [29, 34]. Additionally, the small size of the marker leads to a very narrow visual space for users, which serves as a limitation on placing and tracking the virtual 3D model [1]. Another challenge in using AR markers is the consuming time process because of the preparation needed for placement markers [13], especially in medical applications. Another challenge is the sense of disturbance caused to patients upon placing the markers on them [26]. Restraint in different aspects in traditional object recognition algorithms minimizes the accuracy of 3D object recognition that affects the performance of AR applications. For instance, the algorithm Canny edge detection misses critical information related to object boundary [41]. Additionally, the growth of the use of mobile devices and the rise in their capabilities to support AR applications require adjustment and modification in object detection to work on a mobile device, which affects its capacity to recognize an object with less texture and fewer features [30]. Researchers in several studies have attempted to test the efficiency of AR in different settings, for instance, the performance of Vuforia SDK regarding distance, light, camera angle and by occluding part of the target object [12, 22] and the potential of a large-scale AR system in outdoor settings [23]. Furthermore, the lack or unavailability of concentrated visual recognition that understands the semantics of the object rather than just simple recognition was also a major challenge [8, 11]. In addition, precise identification of objects not just the general category or class of the object is required in numerous complex tasks [37]. Another aspect related to sensors used in building robotics is that it considered mainly the acquisition and basic analysis of a single type of sensory data, and thus, for more advanced object recognition and interaction, additional sensors must be incorporated and merged into one smart system, which is a significant challenge [28]. The complexity and versatility of the real world have emerged as a constant challenge for object recognition networks because the networks are trained to detect only general objects in the dataset rather than distinctive objects not existing in the trained dataset in the real environment [2].

2. Concerns on device capabilities

Usability, computational power, and the weight of device issues were major concerns in devices used in AR. Various issues have been considered main concerns for smart glasses like HoloLens, such as limited processing power and short battery life [40]. With the fast growth in AR technology, the challenge to develop or expand AR support devices has also increased. Furthermore, the challenge to improve the interaction between device and user, such as recognizing hand gestures demands the acquisition of high accuracy of object recognition [49]. The object tracking feature is essential to obtain the full functionality of the AR experience because depth data are a condition to implement object tracking, and devices like HoloLens that lack this type of data introduce important issues [36]. Occlusion problems also occur in android smartphones because of the lack of depth sensors [24]. Moreover, consideration of wearable devices concerning their weight, comfortability, ease of use, and implementation in real-world scenarios can be challenging [27, 47]. Finally, conventional devices, such as a mouse, touch screen, and keyboard have limitations when used as interactive devices [3].

3. Concerns on manufacturing

The challenges related to manufacturing vary and are considered from many perspectives, including flexibility, complexity, collaboration, performance, large-scale operation, and worker support. As noted in the literature, the worker in the HRC system needs to be able to dynamically allocate assembly instructions to a robot rather than follow predefined instructions from the manual [42]. Another aspect of the HRC system is the safety system utilized leads to restrictions in workers' actions and an increase in the interruptions of the work cycle that would be in direct opposition to HRC's fundamental goal [46]. Furthermore, the current assembly tasks system based on AR lacks monitoring of the posture of operators while performing complex assembly tasks for a long duration, thereby increasing the risk of causing musculoskeletal injuries [45]. The pressure of rapid production lines and shorter life cycles, and the need for workers to achieve complex, hazardous, and tedious jobs was another challenge [15, 43]. Since the declaration of the fourth industry generation, manufacturing has shifted to automating its production process by incorporating technologies, such as artificial intelligence and AR. However, designing AR-based systems remains a challenge because of the time and skill-intensive process, and current methods are based on the design of basic AR content [14]. Additionally, user acceptance of these systems, particularly the HRC, is still limited [5]. Moreover, the need for staff training and the many stages in designing and implementing the product is expensive and time-consuming [35]. Comprehensive and large-scale systems consist of several sections and units that span a large area that present challenges related to the isolation of operating units and the need for an efficient collaborative approach in constructing a real-time information flow between the center unit and the operator on the field, such as in power substations [6, 48], and in management building facilities [16]. Other challenges related to the requirements of simultaneous data transmission, rapid data processing arriving from multiple sensors, dealings with many on-site workers at the same time, and AR wearability and portability are presented in [32].

4. Other challenges

One of the main challenges faced by people in their general life actions or specific activities is the correct understanding and right perception of real-world scenarios. Daily activities, such as collecting the correct items in a short period in a large warehouse and accessing the desired information of product remain a challenge [20, 33]. Furthermore, using AR to help the driver by increasing the awareness of the surrounding environment and displaying the visual information to the driver is a challenge [4, 44]. Another issue is the correct perception and understanding of difficult material, for instance, in a hybrid vehicle, the number of parts in the system and the diverse functionality of each part pose issues in the learning and training process [25]. Additionally, in culture and heritage outdoor sites that contain historical motifs, exposure to distortions and environmental effects and the high expense of other preserving methods have also caused difficulties [21]. With the advancement of technology, developing applications that target people with disabilities, such as blind people [17], autistic children, and children with learning problems can also be an obstacle [18]. Another challenge was extending the usage of AR to applications that implement AR as an interface to support users emotionally [39].

Recommendations:

In the literature, many aspects of recommendations were identified, whether related to the need for additional studies, enhancement regards performance, or further development. This section addresses some of those mentioned in the literature (Fig. 5) presents the recommendation categories of AR-based object recognition

Figure 5. Recommendation categories for AR based object recognition

1. Further studies

In the literature, different recommendations for the conduct of additional studies have been made from different viewpoints. For instance, further studies are necessary to establish the efficiency and effectiveness of AR systems. Evaluating the spatial AR in supporting workers while performing tasks and monitoring safety in more demanding conditions was recommended [45]. Additional research to analyze the AR performance in smart manufacturing, taking into account the human aspect, usability, and potential limits has also been called for [27]. Further studies are needed to understand the efficiency of object state recognition in terms of decreasing errors and optimizing user speed in the repair process [11] and 3D object recognition from different angles of view in terms of maintenance tasks

[8]. Further studies are also necessary to improve the capability of the assembly instruction-based AR depending on the error feedback [15]. More studies are needed to increase the system's reliability and decrease the number of failures in specialized workers' training [13]. Further studies were recommended to evaluate the system of AR visualization of a brain tumor on actual patients to achieve the best engagement [26]. Further evaluations of the efficiency of AR systems in language learning [38] and product manufacturing under more demanding circumstances have also been recommended [35]. Additional research is needed to validate the proposed method and investigate additional AR techniques for better use [33]. Additional research is also recommended to decrease the cost of implementing these systems and make them more affordable [40].

2. Performance improvement

Various recommendations have been made to improve performance from several aspects. Implementing faster and less demanding methods to build datasets [5, 31] and to increase the dataset size, as well as using different object recognition method [10] and implementing a combination of machine learning algorithms to increase performance are some of the recommendations [37]. A study recommended enhancing the object recognition method for better performance in difficult situations [23]. Another study proposed the improvement of system scalability in a complex work setting [43]. Enhancement related to the users' immersive level including expanding to mixed reality [18] and adding the feature of selecting power equipment by users was also put forth [6]. Several studies recommended improving the speed of transmission networks, for instance, between HoloLens and the device [5, 36] and the network of object detection [2]. One study recommended including additional languages in the system and supporting customers from different countries [20].

3. Hardware implementation

In the selected studies, numerous studies recommended the employment of different hardware devices for a more acceptable AR experience. The adoption of head-mounted devices, such as the HoloLens headset was recommended [10, 42]. Another study recommends reducing the weight of the wearable device to make the user experience more comfortable [31]. Utilizing different techniques to project virtual content on the surface of the real-world environment, i.e., spatial AR, instead of displaying the AR content through a mobile device to improve worker acceptance is another recommendation [16] .

4. Advanced development

Many researchers have recommended developing the prototypes and frameworks of the proposed AR systems [14, 35, 42] and developing the introduced components to build the full system [7]. Another study recommended the additional development of applications and features, such as remote cooperation to extend the capabilities of the AR system [46] and improve the HRC [29]. Developing several object recognition techniques and more comprehensive test settings [22] in addition to testing more libraries to enhance user interaction is recommended [21]. Deploying the application to other platforms such as iOS and Windows Mobile is also recommended [17]. Another study related to enhancing driving awareness recommends allowing other vehicle passengers to view the augmented view in real-time of the driver [4]. One study recommended the use of the TensorBoard tool to further understand the performance of developed CNN [14]. Another study recommended upgrading the proposed method by developing a remote cooperative system that aims to assist in performing different tasks [34].

5. Other recommendations

A study recommended extending the use of the application to support users emotionally by displaying happy memories to help those who live distantly from their families [39]. Another recommendation was that the methods introduced in this research could be applied in a variety of applications in the future [49].

Dataset:

The selected studies utilized various types of datasets. Datasets are an essential part of the object recognition process [50] since a successful 3D object recognition is required to develop an AR system [41]. Our analysis of the academic literature recognized that self-built datasets, public datasets, and a combination of both were used. (Fig. 6) depicts the number of datasets per category mentioned in the literature

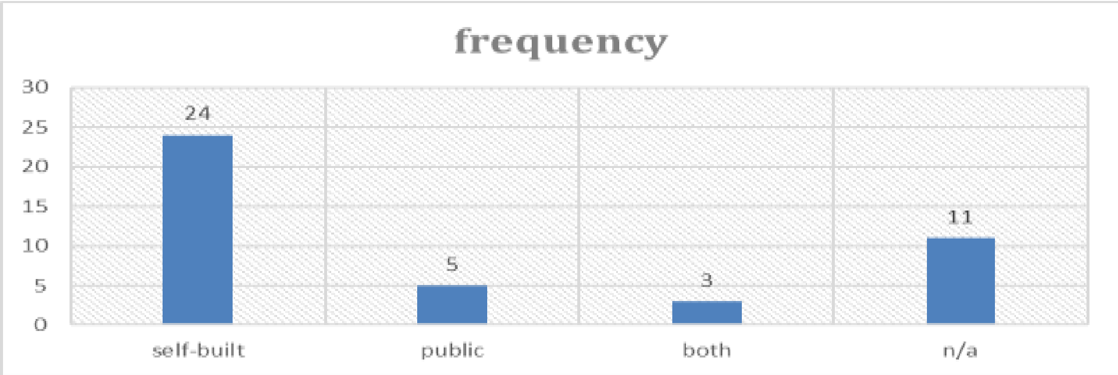


Figure 6. number of datasets utilized in academic literature

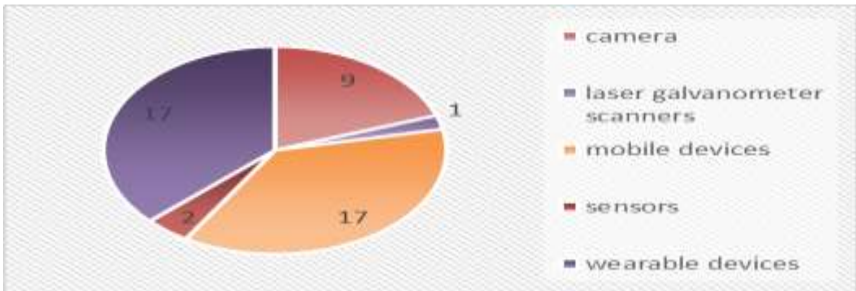
Input Device:

The input devices can be identified and organized into five categories by analyzing the available studies

- Mobile device camera (n =17)
- Wearable device camera (n = 17).
- Cameras (n = 9).
- Laser scanner (n = 1).
- Sensors (n = 2).

(Fig. 7) shows the number of input devices utilized in the literature. Beginning from the camera segment and moving clockwise, the camera segment shows the number of occurrences of cameras used in the literature. Different types of cameras were found in articles, such as web cameras [15, 47], monocular cameras [41], RGB-D cameras [1], Kinect camera [36, 45], and windshield-mounted cameras [44]. Other studies, such as [12, 42], did not specify the type of camera used. The second segment in (Fig. 7) shows the number of laser scanners utilized in the literature. In [43], laser galvanometer scanners were used, and the logic behind choosing this device is because of the high requirements and precision required in the welding process. The third segment in the chart contains studies that utilized mobile devices, with the majority of the studies utilizing smartphones as the input device[10, 11, 17, 18, 20-26, 29, 30], while very few studies utilized tablets. The fourth segment in the chart shows that only two studies used sensors as an input device, [28] used the triboelectric tactile sensor and triboelectric bending sensor to acquire data, while [37] utilized RFID sensor. The fifth and final segment in the chart shows the studies that utilized wearable devices.

Figure 7. Input devices mentioned in the literature



Development Platform and Tools:

Several platforms and tools are available to develop an AR system. (Fig. 8) shows the number of times different development platforms and tools were used across the studies. These platforms and tools were organized as follows:

- libraries and algorithms (n= 25)
- AR SDK (n = 15)Self-developed (n = 2)
- Unity 3D (n = 25)
- not specified (n = 2)

(Fig. 8) reveals that libraries, such as OpenCV and TensorFlow, and algorithms had been widely utilized. AR SDK was also employed in the development of AR systems, such as Vuforia SDK (n=13) and AR Toolkit (n = 2). Two studies built their algorithms based on existing ones [30, 41], while other studies did not specify the implementation used in the development process [33, 46]. The Unity 3D game engine was widely used as the environment to build AR systems.

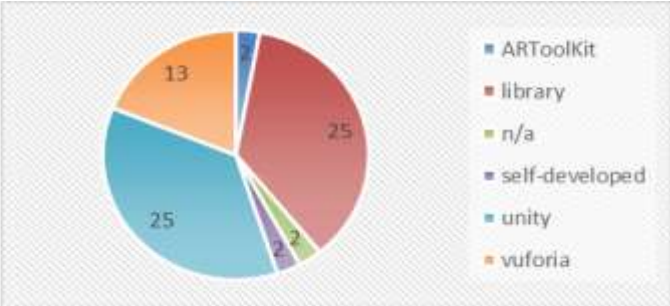


Figure 8. Development platform and tools throughout the literature.

- Driver safety (n = 2)
- Emotional support (n = 1)
- Cultural heritage (n = 2)
- Learning (n = 6)
- Manufacturing (n = 23)
- Shopping (n = 3)
- Visual impairment (n = 2)

(Fig. 9) shows the number of studies per application category. The majority of the studies focused on the manufacturing field by providing virtual instructions through maintenance, repair, and assembly processes [8, 14, 15, 29, 31, 45]. Other studies focused on the learning field to improve the comprehension activity [7, 22, 25, 38]. other studies focused on different applications, such as assisting people with no or low vision in navigation [10, 17] and assisting drivers by reducing their cognitive load [4, 44]. Product shopping can also be time-consuming because of the immense number of products that need to be selected [20, 28, 33]. Finally, other studies focused on preserving cultural heritage and displaying digital visualization that mimics the original composition of motifs [21]

Outputs:

The selected studies utilized different forms of augmented information, including visual and audio data. These augmented data act as an interaction medium between the AR system and the user. The digital output can be classified into four types:

- text
- 2D graphics
- 3D graphics
- audio

The majority of the studies utilized a combination of virtual outputs to increase the overall interaction and efficiency of the information to be delivered to the user [11, 18, 20, 21, 27, 32, 34, 40, 45, 47]. Other studies chose the output style simply as text [3, 10, 22, 37, 38, 43] or as 2D graphics as in [2, 30] or 3D graphics [1, 23, 24, 26, 41]. Another study used digital audio as the output [17] because the target audience of the system was blind people .

Field Of Application:

The analysis of the literature produced (39/48) studies that we classified based on the field of application. The AR applicability was grouped into seven categories:

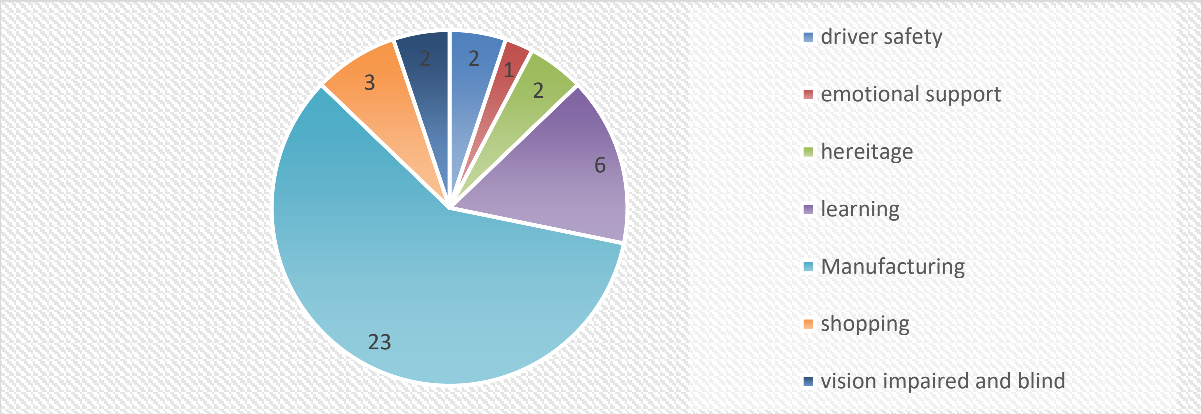


Figure 9. Application fields mentioned in the literature.

General Characteristics Of AR-Based Object Recognition Systems:

The selected studies in the literature varied in the attributes of their AR systems. Different aspects influenced the preference of these attributes, such as the speed and accuracy of execution, information privacy, institutions' size benefiting from the system, and the required functionality from the AR. (Table 2) shows the characteristics of the AR systems. The attributes being examined are the deployment type, environmental setting, object name, and size. Different deployment approaches were recognized. The majority of the studies deployed AR as a stand-alone system that works independently and is not connected to a network where data are transmitted for processing. Thus, data processing in stand-alone systems occurs locally. Several studies deployed the AR system on different types of network infrastructure because of the abilities offered by networks. Regarding the environmental setting, few studies have designed and tested the systems in an outdoor setting, and an indoor setting. All the studies focused on 3D object recognition. However, the size of the objects utilized as targets varied. Many studies have focused on small and medium-sized objects, while few studies have focused on large objects

Table 2. General characteristics of AR systems

Ref.	Deployment type	Environment	Objects name	Object size
[31]	Stand-alone	Indoor-outdoor	brackets	small
[10]	Stand-alone	indoor	Pills and drugs	small
[22]	Stand-alone	Indoor-outdoor	Hard drive	medium
[48]	Network	outdoor	Power grid	large
[14]	Network	indoor	CNC milling machine and tools	Large - medium
[5]	Network	indoor	Assembly parts and tools	Medium - small
[25]	Stand-alone	outdoor	vehicle	large
[23]	Stand-alone	outdoor	Rocks	Medium
[40]	Network	indoor	Assembly parts and tools	Medium - small
[21]	Stand-alone	outdoor	motifs on rocks	medium
[4]	Stand-alone	outdoor	vehicles and pedestrians	Large - medium
[3]	Network	indoor	Laptop – monitor – cup - chair	medium
[36]	Network	indoor	piston motor	medium

[32]	Network	outdoor	Electricity box	Medium - small
[6]	Stand-alone	outdoor	substations, transformer	large
[28]	Stand-alone	indoor	ball - fruits - tape - disposable cups – food	Medium - small
[44]	Network	outdoor	Pedestrians	Large - medium
[37]	Network	indoor	Clothes	medium
[17]	Stand-alone	indoor	Food (instant noodles, wafer, and jelly powder)	Medium - small
[15]	Stand-alone	indoor	Assembly parts and tools	Medium - small
[42]	Stand-alone	indoor	Assembly parts and tools	Medium - small
[38]	Network	indoor	screen, mouse, keyboard	Medium - small
[11]	Stand-alone	indoor	Computer parts	Medium
[46]	Network	indoor	machine parts and tools	medium
[45]	Stand-alone	indoor	Smart phone parts	small
[33]	Stand-alone	indoor	Kit tools	Small
[20]	Stand-alone	indoor	Shopping items	Medium - small
[16]	Network	indoor	BIM elements	medium
[13]	Stand-alone	indoor	Ship engines	large
[34]	Network	indoor	3D printer – robot arms – small artifacts	Medium - small

Conclusion:

This study aims to demonstrate, through a systematical approach, the state-of-the-art AR-based object recognition as a promising technology for supporting different types of industries and generic situations. The first contribution of the study is that the development of taxonomy in this research is founded on studies that were classified based on the utilized devices then further classified based on the implementation methods and algorithms. In the second contribution, we discussed the main focus of the selected studies, including motivations, challenges, and recommendations. We highlighted the motivation related to worker support, the effect of AR as a learning medium, the usability of AR in daily life activities, and the convenience of AR devices. Our analysis presented a variety of concerns stated by researchers. Therefore, we highlighted these challenges regarding device limitations, object recognition methods, and manufacturing. We also highlighted the recommendations related to users' need for further studies and more development and testing of the AR systems in complicated conditions. Finally, we highlighted the methodological approaches of the selected studies, which covered the utilized datasets, types of input devices, different implementation tools and platforms, and the field of applications. This paper might allow researchers with diverse interests to extend their knowledge in this type of AR and hopefully assist in the development and advancement of AR as well as expand the application of this technology in other fields.

Authors' declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.
- The author has signed an animal welfare statement.
- Authors sign on ethical consideration's approval
- Ethical Clearance: The project was approved by the local ethical committee in University of Baghdad.

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