Augmented Reality in the Internet of Things (AR + IoT): A Review

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Submitted: **04/10/2021**; Accepted: **15/11/2021**; Published: **30/11/2021**

Abstract−Augmented Reality (AR) and Internet of Things (IoT) devices can converge, we call it AR + IoT. The integration of AR and IoT has promising opportunities for future product research and development. IoT is a tool for communicating, monitoring, and remotely controlling with connected products, while AR is a means to see and find out what is happening with connected products based on visualization/interface based on additional information. The mapping review method was used to carry out this research. The result is that as many as 43 papers from 2014-2020 are the main targets of review. The largest publication database is in the IEEE Xplore Digital Library, the application dominates in the field of social life, the research objectives are varied, and the recommended future work is to maximize the potential for integration between AR and IoT or even with other promising devices. Then comfort, convenience, and user experience are also recommended in implementing AR + IoT.

Keywords: Advanced Mobile Computing; Augmented Reality; Human-Computer Interaction; Internet of Things; Literature Review; Mapping Study; Trend and Challenges

1. INTRODUCTION

Internet of Things or IoT is a technology that connects various objects to the internet media, so humans can retrieve information from those objects at any time. The potential utilization of IoT is very much and can be applied in various fields such as agriculture, health, transportation, and so on. Not surprisingly, IoT is called The Next Big Thing after smartphones and social media in the 21st century. According to research from McKinsey [1], the estimated potential of the IoT market especially in Indonesia reached $3 billion by 2020. Based on this value, four categories will dominate the IoT market in Indonesia, namely vehicles, industry, smart cities, and retail.

The study [2] states that to increase the potential and capability of IoT, in implementation and to maximize its performance it can be integrated with smart cities, data mining, virtual objects (wearable technology), real-time analysis, and so on. Based on the rapid development of the IoT, where smartly connected objects enable extensive optimization and accurate predictions on the production line. However, this is not the only benefit that IoT can produce in an industrial setting. Augmented Reality (AR) can provide additional value to serve IoT data as a visualization tool in the realm of stores. Operators can achieve better results in a shorter time in several use cases by using AR devices to use the latest contextual information about machines that are IoT capable.

According to [3] AR is an alternative method that provides a stretch of virtual objects into the real environment. Furthermore, according to [4] AR is the integration of digital information with the user's environment in real-time, where this AR technology uses the environment in the real world then adds new information on it with the help of computers, webcams, smartphones, special glasses, and other assistive devices.

The convergence between AR technology and IoT devices has been explored, one of its aims is as a bridge in terms of visualizing information in real-time and addressing the gap between the physical and digital worlds. In the future, the convergence of AR + IoT will continue to be considered to be a promising prospect and become the latest research pathway [5].

The few studies that conducted survey studies and reviews of ideas and the development of integration between AR and IoT are from [6] which states that the combination of AR and IoT has opportunities in the future as an effort to improve services, user experience, operations, and processing of results in the form of visualized information. This research is a collection of initial ideas from AR + IoT and more will be realized in the future. The implementation has a great opportunity, namely in the field of commerce and medical practice. Further research from [7] presents an overview, concepts, and challenges of the development of smart cities that implement the IoT infrastructure based on AR services. The challenges ahead are in terms of service, hardware availability, and security, then it is proposed to expand the field of implementation.

Research from [8] conducted a survey and collection of articles around issues about creating an intelligent and interactive environment by proposing the integration of IoT and AR. The classification of issues and problems consists of data management, device viewpoints, interaction methods, and user interfaces. Submission of implementation with a combination of IoT and AR in the realm of data distribution and peer-to-peer communication, object-centric guided tracking, and AR interaction framework for an object class. Furthermore, prospective features can also be explored when combining IoT and AR such as data management, object-guided tracking, and AR-based object control and interface.

The research proposed now is different from previous related research, we use a mapping review method to review papers that discuss the combination of AR with the IoT tool (AR + IoT). Based on these potentials and trends, this paper

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focuses on reporting ideas and developments from the integration of IoT devices with AR that has been carried out by researchers from 2014-2020, the information contained in this paper includes the number of articles found, year of publication, publication place/database, fields of application, research objectives, and proposed future work.

2. RESEARCH METHODOLOGY

The mapping review method or mapping study is a means to provide an overview in terms of trends or the state-of-the-art of a research topic and to identify future research gaps [9]. Mapping reviews provide a procedure for identifying data from an empirical study that is provided as a means to answer research questions systematically and objectively [10]. In reviewing this mapping using the stages that must be passed, the selection of papers is not done subjectively, but instead uses protocols and filters that have been determined previously. The results of this mapping review are in the form of clustering and classifying the findings obtained on a research topic. Sometimes also as a means to identify future research trends.

This paper using a research method with a type of mapping review, where the process in general, namely (1) Defining research questions; (2) Select the appropriate reference database; (3) Identifying the appropriate search string; (4) Screening (articles are excluded or included to obtain the final results determined based on predetermined inclusion and exclusion criteria); and (5) The relevant data is extracted and then synthesized.

First stage. The research questions (RQ) asked are:
RQ1. Does the research paper discuss the integration of AR and IoT?.
RQ2. How many research papers discuss the integration of AR and IoT each year from 2014-2020?.
RQ3. The results of research on the integration of AR and IoT are published in what database?.
RQ4. Integrate AR and IoT in what fields?.
RQ5. What research objectives are offered in integrating AR and IoT?.

RQ6. What future work recommendations are offered in the integration of AR and IoT?.

Second stage. The database is recommended in finding various types of published article references, namely: (1) IEEE Xplore Digital Library; (2) ACM Digital Library; (3) SpringerLink; and (4) Multidisciplinary Digital Publishing Institute (MDPI). We selected five databases taking into account quality and availability.

Third stage. In formulating the search string we propose the main keywords in the form of a paper title consisting of Augmented Reality and the Internet of Things, then added with supporting words taken from the similarity (convergence, combination, integration, hybrid, mixing, merging) and (implementation, application). Then each of these keywords is associated with logical AND/OR operators, so the resulting formulation is shown in Figure 1.

("Implementation" **OR** "Application")
AND
("Convergence" **OR** "Combination" **OR** "Integration" **OR** "Hybrid" **OR** "Mixing" **OR** "Merging")
AND
("Augmented Reality")
AND
("Internet of Things")

Figure 1. String Search List

Based on Figure 1, is a list of search strings that will be applied to each reference database, it is also important to be careful in adjusting the usage recommended by each reference database when defining the logical operators.

Fourth stage. Carrying out the screening process, we formulated a series of inclusion and exclusion criteria in an effort to select relevant papers. Included in the inclusion criteria are: (1) The paper discusses the integration between AR and IoT and can indirectly answer RQ1; (2) Published papers for 2014-2020; (3) International publications (journals/proceedings) indexed by leading institutions. Then the exclusion criteria are: (1) The paper does not discuss the integration between AR and IoT (only AR or only IoT) or does not answer RQ1; (2) Papers not from international publications (journals/proceedings); (3) Papers with incomplete standard contents (such as abstracts, introduction, research objectives, results and discussion, conclusions and future work, and references); (4) Papers do not use English; (5) Duplicated papers (the same papers are taken from different databases); (6) part or all of the contents of the duplicated paper (same or different databases).

An overview of the stages of the paper screening process is shown in Figure 2.
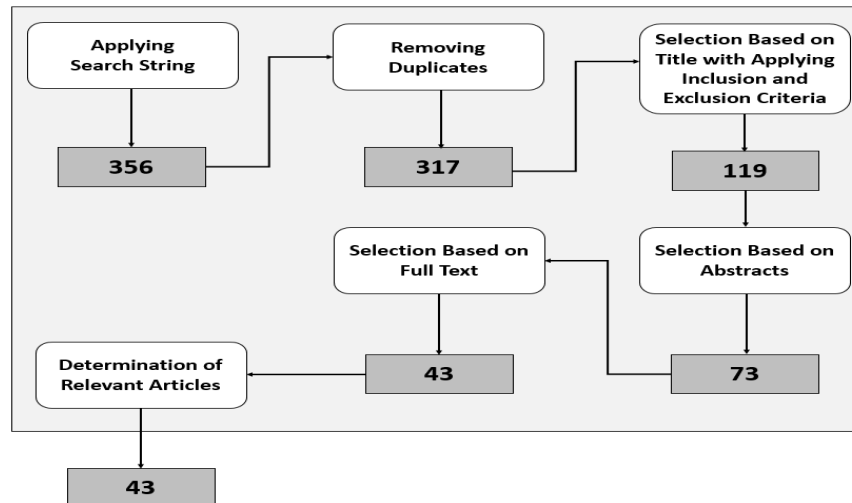
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Figure 2. Paper Screening Process

Based on Figure 2, is the general stage of the process of finding a paper. First, through the implementation of the search string implemented in each database 356 papers were found. This followed by checking the duplication of papers obtained by 39 papers with the same title in different databases, finally, the output of this process left 317 papers. Then the selection is based on the suitability of the title (it will implicitly discuss the integration of AR and IoT) and also apply the inclusion and exclusion criteria, about 119 papers successfully passed this process.

A total of 119 papers have to go through a selection process based on abstract content, the review team is more careful because some abstracts are unclear and also do not match the proposed title. From this process, 73 papers were obtained. The final process is selected based on a full paper, in which the review team is very careful because it will answer research questions and the quality of the paper to be reviewed in the final version. Based on the final selection process, 43 papers were successfully passed and determined as relevant papers and were the main review in this mapping study.

Fifth stage. We perform data extraction processes using Microsoft Excel applications as a means to summarize relevant data. During the data extraction process, 43 main papers were analyzed in full. We collect key information from each paper and it is directly related to the direction of the answers to the research questions that have been defined previously. The information is in the form of research title, author's name, year of publication, a database of publication, abstract, the field of application, research objectives, and future work recommendations. The results of the synthesized data are presented in the next section.

3. RESULT AND DISCUSSION

In this section, the results and discussion of the mapping review are presented, based on research questions and efforts in generating answers to these research questions, then other information such as general research objectives and future work recommendations are also presented.

RQ1. Does the research paper discuss the integration of AR and IoT?
This RQ1 aims to investigate whether this paper addresses the full integration of AR and IoT. Based on the results of the final review, 43 papers were obtained which thoroughly discussed the integration of AR and IoT (See Table 1).

Table 1. Mapping based on Title Usage

Use of Title	List of Papers	Total
AR	[16], [17], [19], [22], [23], [26], [27], [38], [41], [48], [49], [53]	12
IoT	[12], [40]	2
AR + IoT	[11], [13], [14], [15], [18], [20], [24], [25], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [39], [42], [43], [44], [45], [46], [47], [50], [51], [52]	28
Others	[21]	1
Total Number		43

Based on Table 1, a total of 43 papers in the main study have been thoroughly reviewed. RQ1 has been answered with the results of information in the form of a full paper discussing the integration of AR + IoT, this has happened and research papers are available.

The next information is the use of the title, we are interested in investigating this because not all titles are included in two words namely AR + IoT, but some use just one word such as AR or IoT, some even use other than AR + IoT, like the word Smart, or just the frill Internet of Things only. But procedurally, so that the research paper can be fully

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recognized, it must be specified in the title specifically, this depends on the researchers' perceptions. In this case, the use of the title with the word AR + IoT is most widely used in 28 papers, so it is very easy to recognize, but it needs to be thoroughly reviewed to avoid bias and content mismatch with the title. An example of implementing the AR + IoT integration is shown in Figure 3 in studies [14], [20], [37], [43].
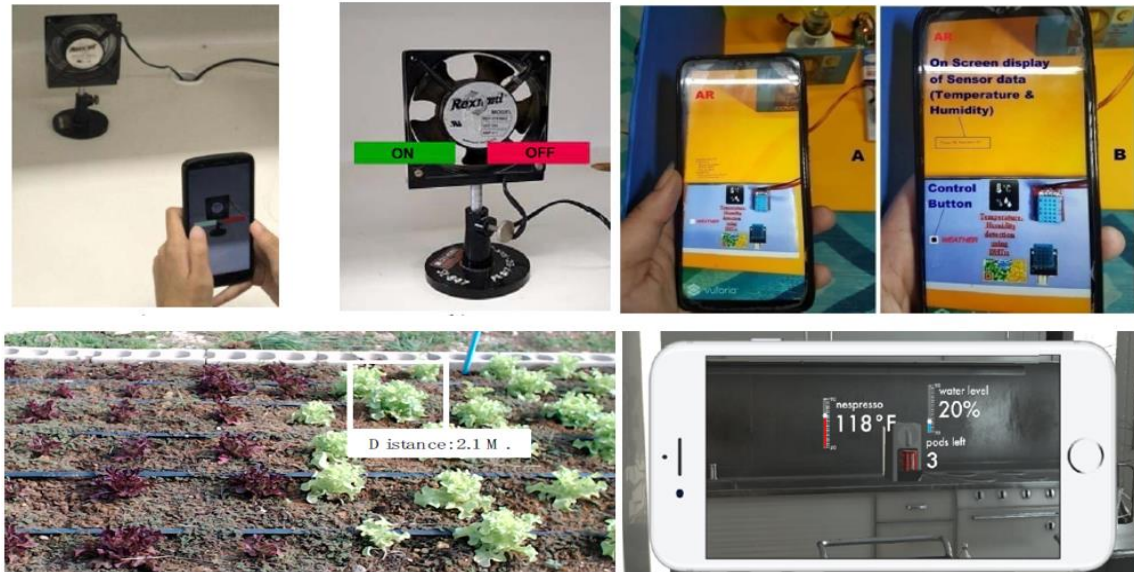
Figure 3. Application of AR + IoT Integration

Based on Figure 3, is the integration of AR + IoT that can monitor and control objects around through the AR interface connected to the IoT device.

In this integration, on average researchers must master their knowledge and expertise in the application of AR + IoT. Specifically, IoT consists of many hardware and various sensors. Researchers also tend to use Arduino (microcontroller) and Raspberry Pi (microprocessor) as a means to develop IoT-based technology. For AR, expertise is needed in terms of designing interfaces, computer vision, and connecting them with IoT devices. Both of these technologies do need skilled human resources and have a strong problem-solving mentality and innovation.

RQ2. How many research papers discuss the integration of AR and IoT each year from 2014-2020?
This RQ2 aims to investigate the year of publication for the 43 main papers that began in 2014 until 2020, then do the mapping in each of the years presented in Table 2.

Table 2. Mapping based on Year of Publication

Publication Year	List of Papers	Total
2014	[35]	1
2015	[44]	1
2016	[19], [28], [29], [34]	4
2017	[12], [23], [27], [31], [36], [39], [40], [41], [46]	9
2018	[11], [13], [15], [17], [20], [26], [38], [45], [48], [49], [52]	11
2019	[14], [16], [18], [24], [25], [30], [32], [33], [42], [43], [50], [53]	12
2020	[21], [22], [37], [47], [51]	5

Based on Table 2, information that can answer RQ2 is that for 2014 and 2015 there was only 1 paper, in 2016 it began to increase to 4 papers, in 2017 it also increased by 9 papers, in 2018 there were 11 papers, and in 2019 there were 12 papers. Every year there has been an increase in research and publications in integrating AR + IoT. In 2020, we only found 5 papers, this might increase because we did it in mid-2020, there will likely be a specific update in 2020, we predict that there will be more improvement compared to last 2019.

RQ3. The results of research on the integration of AR and IoT are published in what database?.
For the RQ3 to investigate and mapping which databases have published papers on the integration of AR and IoT and how many are in each (See Table 3).

Table 3. Mapping based on the Publication Database

Publication Database	List of Papers	Total
IEEE Xplore Digital Library	[11], [13], [14], [15], [17], [19], [21], [22], [25], [28], [29], [32], [33], [34], [35], [38], [39], [40], [41], [44], [45], [46], [48], [49], [50], [51], [52]	27

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Publication Database	List of Papers	Total
ACM Digital Library	[16], [18], [20], [23], [26], [27], [42], [53]	8
SpringerLink	[12], [24], [30], [31], [36], [37]	6
MDPI	[43], [47]	2

Based on Table 3, RQ3 has been answered with information in the form of a publication database consisting of four pieces and the number of publications in each database. Papers that report the integration of AR + IoT tend to be widely publicized and are mostly in the IEEE Xplore Digital Library database. We only recommend these four databases, because the papers are still small if found in other databases and even that is still worrisome in the discussion.

RQ4. Integrate AR and IoT in what fields?

In RQ4, the aim is to investigate and map which areas have implemented the integration of AR and IoT, this will indicate which areas apply the most (See Table 4).

Table 4. Mapping based on Applied Fields

Fields	List of Papers	Total
Control Machinery	[27], [32], [34], [49]	4
Education	[21], [52]	2
Electricity	[13]	1
Environmental Sustainability	[12], [44], [45], [47]	4
Farming	[43]	1
Health	[11], [25], [38]	3
Networking	[15], [36], [41]	3
Robotics	[18]	1
Social Life	[14], [16], [17], [19], [20], [22], [23], [24], [26], [28], [29], [30], [31], [33], [35], [37], [39], [40], [42], [46], [48], [50], [51], [53]	24

From Table 4, mapping based on the applied fields in integrating AR + IoT obtained nine fields, namely Control Machinery, Education, Electricity, Environmental Sustainability, Farming, Health, Networking, Robotics, and Social Life. The most dominant applied in the field of social life consists of 24 papers that have been submitted, the general reason is that the application of AR and IoT devices tends to be widely recommended in facilitating daily activities, for researchers it is very important that technology can be utilized appropriately to help human life.

RQ5. What research objectives are offered in integrating AR and IoT?.
The purpose of RQ5 is to investigate what research objectives have been proposed in the AR and IoT integration research papers, then summarize them more generally to find the research objectives most often used.

Based on the 43 papers reviewed, the most frequently used research objectives consist of curiosity and want to prove that AR and IoT can be integrated, application development and innovation, for the development of smart cities, can help and facilitate human activities and various other fields, learning media integrated and more interesting, explaining the use of AR + IoT, improving the performance of AR + IoT, and considering the use of AR + IoT in the future.

RQ6. What future work recommendations are offered in the integration of AR and IoT?.
RQ6 is used to investigate future work recommendations that have been offered in the integration of AR and IoT. Then also summarize the most commonly proposed future employment recommendations.

Future work that is frequently proposed based on 43 papers that have been reviewed consists of enhancing interaction design and user interface, enhancing user experience and comfort, visualizing information that is more interesting and can be understood by users, speed of detection time, adding devices to improve the system, combining it with methods in artificial intelligence, and expanding the field of application in integrating AR + IoT. Researchers tend to agree that the integration of AR + IoT will slowly increase and become a new research area opportunity with various innovations and state-of-the-art in it.

AR is a technology that can realize dreams in the future that can be collaborated [54]. However, it should be noted that the integration of AR + IoT must be applied to the right, useful, and beneficial fields for human life. It doesn't just stop in the form of research publications, but it is hoped that in the future it can be implemented in the wider community so that the research and applications submitted have a real contribution.

Threats to Validity
In this mapping review, there is no doubt that there are major threats that can affect their validity. Especially in the case of search string restrictions, year of publication, publication database, and status of papers (international journals/proceedings). To overcome the effects of these restrictions, we established a research protocol. For the division of the review team, as much as possible has been carried out according to their respective duties, because the main study papers are not too many to be reviewed, so the level of team focus is very high.

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4. CONCLUSION

Along with the rapid development of AR technology and IoT devices, we have discovered and investigated the convergence between AR and IoT, as many as 43 papers as the main study reviewed. The result is generally IoT devices are used as a standard in terms of remote monitoring and control, while AR is applied to user interface interactions that produce information visualization of what IoT devices are doing, then accessed virtually in real-time. This is very interesting for further research, but it should be noted that the integration between AR and IoT must be carefully planned because it is combined with hardware and software, interface interaction and user convenience must also be considered. Furthermore, in the future, we plan to conduct a review of Virtual Reality (VR), Mixed Reality (MR), and Extended Reality (XR) which is converged with IoT devices, or maybe with other devices/technology and it looks interesting to add new research space.

ACKNOWLEDGEMENTS

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