Augmented Reality in Information Systems Research: A Systematic Literature Review

Full Paper

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Abstract

Augmented Reality (AR) is one of the most prominent emerging technologies recently. This increase in recognition has happened predominantly because of the success of the smartphone game "Pokémon Go". But research on AR is not a new strand of literature. Especially computer scientists investigate different technological solutions and areas of application for almost 30 years. This systematic literature review aims at analyzing, synthesizing and categorizing this strand of research in the information systems (IS) domain. We follow an established methodology for conducting the literature review ensuring rigor and replicability. We apply a keyword and backward search resulting in 28 and 118 articles, respectively. Results are categorized with regard to the focus of the research and the domain of the application being investigated. We show that research on user behavior is underrepresented in the current IS literature on AR compared to technical research, especially in the domains gaming and smartphone browsers.

Keywords

Augmented reality, systematic literature review, information systems survey.

Introduction

Augmented reality (AR) is gaining much public interest since the launch of the smartphone game "Pokémon Go" in July 2016 (Tassi 2016). Tim Cook, CEO of Apple, stated that "AR is going to take a while, because there are some really hard technology challenges there. But it will happen, it will happen in a big way, and we will wonder when it does, how we ever lived without it. Like we wonder how we lived without our phone today" (Leswing 2016). In 2013 the industry evolving around AR was estimated with a volume of more than $200 billion (Hyman 2013). This statement combined with numerous acquisitions of AR start-ups by large technology firms like Apple (Wolde 2015) or the image messaging company Snap Inc. (formerly Snapchat) (Loizos 2016), shows the attention AR gets in the industry and therefore the practical importance of investigating this topic. Although the idea of AR stems already from the 1960s (Sutherland 1968), there is not a large stream of literature available in information systems (IS) research, nor is it yet directly promoted by the community - for example by providing augmented reality/virtual reality tracks at the high quality IS conferences. At this point, we have to acknowledge that this paper is not the first literature review on AR. Azuma (1997) provides a comprehensive assessment of - at that time existing - AR applications which is updated by Azuma et al. (2001) four years later. Both papers are very important for the technological understanding and advancement of AR which is also visible through almost 1300 and 700 Web of Science citations, respectively. But, to the best of our knowledge, this is the first review in the IS domain on AR. Furthermore, we believe that it is essential for future developments in AR to analyze and understand not only the technological aspects of AR, but also the behavior of users with regard to the systems properly. This task lies in the natural domain of IS research. We argue that research in computer science like the reviews by Azuma (1997) and Azuma et al. (2001) has to be augmented by insights from IS in order to enhance the technology itself and the understanding of human behavior when interacting with it. Based on this relation, this review provides a valuable theoretical contribution. Thus, the research goal and contribution of this literature review is the analysis and conceptualization of the current state of AR research in the IS field in order to lay the groundwork for future work in this area. Before discussing the methodology and the outline of the paper, a brief definition of augmented reality is given as this is the key concept of this

work. AR is defined in many different ways. Azuma et al. (2001) provide a comprehensive definition by stating that "[...] an AR system [...] combines real and virtual objects in a real environment; runs interactively, and in real time; and registers (aligns) real and virtual objects with each other" (p. 34). Examples fulfilling this definition are head-mounted displays (HMDs), real-time augmentations in sports broadcasting on television screens or smartphones. The differentiation towards virtual reality (VR) is not always clear in the current public discussions about AR. One widely employed concept to address this ambiguity, classify and differentiate AR at the same time is provided by the "Reality-Virtuality (RV) Continuum" (Milgram et al. 1994). It shows graphically on an x-axis the dimensions mixed reality (MR) consists of (Figure 1). In this case, MR is the umbrella term that describes different classes ranging from a completely virtual environment with added virtual objects to the real environment augmented by virtual objects. AR is situated at the left point of the axis in Figure 1, which is defined as the real environment.

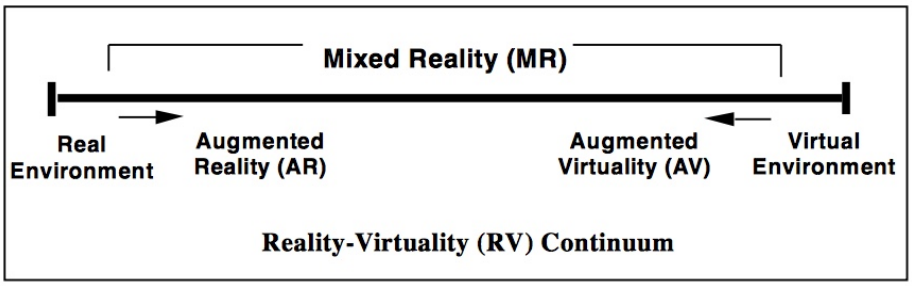

Figure 1. The Reality-Virtuality Continuum by Milgram et al. (1994)

Literature reviews or surveys can be conducted following several different methodologies. In order to have replicable and well documented results, we have decided to follow the methodology for conducting literature reviews by vom Brocke et al. (2009), combined with a concept-centric approach for synthesizing the results (Webster and Watson 2002). Due to the massive amount of IS journals and conferences today, the literature review covers only a representative basket of high quality journals and conferences from the IS field for the search process. This is a regular boundary condition for systematic literature review since it is close to impossible to cover all existing outlets of a discipline. To partially overcome this limitation, a backward search process is employed for the found articles. In addition, we do not claim to cover anything, but rather a representative selection of journals and conferences that includes the important research in the field (Cooper 1988).

The remainder of the paper is as follows. Section 2 describes the methodology. Section 3 presents the results of the literature review and the analysis and synthesis. Section 4 shows future research opportunities. The last section concludes the paper by summarizing the main findings.

Methodology

The literature review follows the framework by vom Brocke et al. (2009). Based on this framework, a taxonomy is created in order to provide a structure for the literature review (Table 1).

Characteristic	Categories			
Focus	research outcomes	research methods	theories	applications
Goal	integration	criticism	central issues	
Organization	historical	conceptual	methodological	
Perspective	neutral representation	espousal of position		
Audience	specialized scholars	general scholars	practitioners/politicians	general public
Coverage	exhaustive	exhaustive and selective	representative	central/pivotal

Table 1. Taxonomy of the Literature Review (vom Brocke et al. 2009)

The characteristics and categories of the taxonomy are based on the work by Cooper (1988). The grey cells show the applicable categories of this literature review. The review aims for research outcomes, theories and applications. This broad focus is needed for this fundamental research as we do not want to exclude any kind of research on AR in the IS field ex ante. The categories for the characteristics can overlap and a review can try to fulfill multiple purposes (Cooper 1988). The goal is to analyze central issues and integrate the findings to provide a common ground for future researchers. This combination of central issues and integration is occurring commonly in literature reviews (Cooper 1988, p. 110). The structure of the results is supposed to be conceptual with a neutral representation of the results. The review aims at the audience of scholars specialized in the field of MR, especially AR. The coverage strives for representative results with respect to the chosen journals and conferences (cf. Table 2).

Journals	• Communications of the ACM (CACM) • European Journal of Information Systems (EJIS) • Information Systems Journal (ISJ) • Information Systems Research (ISR) • Journal of the Association for Information Systems (JAIS) • Journal of Information Technology (JIT) • Journal of Management Information Systems (JMIS) • Journal of Strategic Information Systems (JSIS) • Management Information Systems Quarterly (MISQ)
Conferences	• Americas Conference on Information Systems (AMCIS) • European Conference on Information Systems (ECIS) • Hawaii International Conference on System Sciences (HICSS) • International Conference on Information Systems (ICIS) • Pacific Asia Conference on Information Systems (PACIS)

Table 2. Selected Journals and Conference Proceedings included in the Literature Search

The selection of the included journals is based on the Senior Scholars' Basket of Journals of the Association for Information Systems (AIS 2011). As suggested in the introduction to this list, the review augments this selection by the journal CACM, in order to cover technical research and by five IS conferences to cover most current research (ACPHIS 2013). The literature search was conducted between January 10 and February 10, 2017. To follow the goal of this literature review and provide a profound and diverse insight into AR research in the IS domain, only one keyword - "augmented reality" - was used to search the selected outlets in the respective databases. All publications issued through the keyword search are regarded as “Hits”. Subsequently, the hits are evaluated thoroughly based on their titles and abstracts. If a paper is considered as potentially being concerned with AR, it is considered as a "Final Hit" and analyzed in-depth.

The conducted backward search is following a similar process as the keyword search. When analyzing the final articles, the references are investigated with regard to augmented reality. Each paper that has AR in the title or abstract is downloaded and analyzed with regard to the content, independently of the discipline. Thus, papers from related disciplines like human-computer interaction (HCI) and computer science are included in the backward search for two reasons. First, papers from these disciplines often contain small user evaluations which can provide interesting ideas for future IS research. Second, outlets from related disciplines partially accept IS research and overlaps between the disciplines are possible. The amount of these articles is shown in the "Final Hits" column in the "Backward" row. During the backward search, various citations occurred in more than one of the final articles from the keyword search. These doublings can be regarded as an indicator for the saturation of a review (Boell and Cecez-Kecmanovic 2014, p. 273), thus overcoming the limitation of our representative literature review to a certain degree. Furthermore, cited papers which reoccur several times, indicate that the pivotal articles are found in the review. The doublings are only counted once in the "Final Hits". A forward search that would have investigated all papers that cited the final articles at a later point in time is not conducted due to space limitations and the established saturation which could be observed during the process of conducting the backward search. Table 3 presents the results of the literature search. The structure is based on the proposal by vom Brocke et al. (2009). The provision of additional information about searched databases, fields and coverage makes

it possible to replicate the search process of the study and contributes to a transparent presentation of results. Table 3 is included at the end of this section, as we argue that the knowledge presented in this table is essential for understanding the methodology of the literature review.

	Journal/ Conference	Database	Search	Coverage	Hits	Final Hits
1	CACM	EBSCOhost	"all fields"	since 1965	84	11
2	EJIS	EBSCOhost	"all fields"	since 1991	0	0
3	ISJ	EBSCOhost	"all fields"	since 1991	2	0
4	ISR	Informs	"anywhere"	since 1990	91	0
5	JAIS	EBSCOhost	"all fields"	since 2003	3	0
6	JIT	EBSCOhost	"all fields"	since 1986	0	0
7	JMIS	EBSCOhost	"all fields"	since 1984	8	2
8	JSIS	Elsevier	"all fields"	since 1991	0	0
9	MISQ	EBSCOhost	"all fields"	since 1977	5	0
10	AMCIS	AIS Electronic Library	"all fields"	since 1995	170	4
11	ECIS	AIS Electronic Library	"all fields"	since 2000	89	0
12	HICSS	IEEE Xplore	"Full Text & Metadata"	since 1992	13	7
13	ICIS	AIS Electronic Library	"all fields"	since 1980	147	2
14	PACIS	AIS Electronic Library	"all fields"	since 1993	57	2
15	Backward	--	--	--	-	118
Total (no. in parentheses equals the sum of keyword and backward results)					669	28 (146)

Table 3. Summary of the Literature Search Findings

Results

This section discusses the results of the literature review. As not all individual papers can be discussed and categorized due to space limitations, only selected contributions are presented in more detail in order to explain the research landscape in Table 4. The results of the keyword and backward search are synthesized in Table 4. The keyword search yields 28 hits. The backward search yields 118 relevant hits. Only selected papers from the backward search that are representative for a certain area of research are categorized. These references are presented in Table 4 in italics. The total number of articles in that area can be seen in parentheses behind the respective reference[1]. The results are divided based on the foci of the papers and the application domains that are investigated. All domains are grounded in the data. Still, we observe two grey cells, indicating that no paper could be found that deals with the respective topic. The last row and column show the total number of articles broken down by domain, focus and the ratio of keyword (K) and backward (B) search results. The latter is provided to distinguish between IS literature and related disciplines, since all articles found during the backward search are published in related disciplines, except for one paper by Huang and Hsu Liu (2014) that was published in an IS journal. A clear prevalence of technical papers (T) can be observed with 114 out of 146 articles having a focus on technology.

[1] The full reference list, including the results of the keyword and backward search process, is available under https://m-chair.de/images/documents/publications/Supplements_Review_on_AR.pdf

Focus / Domain of Application	Technology (T)	User Behavior (UB)	K+B=Tot. (T/UB)
Browser	Langlotz et al. 2013, *MacIntyre et al. 2011 (2)*		1+2=3 (3/0)
Collaboration/ Communication	Billinghurst et al. 2002, Brockmann et al. 2013, *Zhong et al. 2001 (19)*	Djamasbi et al. 2014, *Billinghurst et al. 2002*	3+20=23 (21/2)
Commerce/ E-Commerce	Nguyen et al. 2012	Kumar et al. 2016, Ross & Harrison 2016, *Olsson et al. 2013*, *Huang and Hsu Liu 2014 (IS outlet)*	3+2=5 (1/4)
Construction/ Manufacturing	Biocca et al. 2007, Biocca et al. 2006, Caudell & Mizell 1992, *Klinker et al. 2001 (2)*	Saggiomo et al. 2016	4+2=6 (5/1)
Education/ Learning	*Cooperstock 2001 (14)*	Deng & Christodoulidou 2015, Salvador-Herranz et al. 2013, Shatte et al. 2014, *Arvanitis et al. 2009 (6)*	3+20=23 (14/9)
Gaming	Piekarski & Thomas 2002, *Thomas et al. 2002 (4)*		1+4=5 (5/0)
Geography/ Travelling/ Navigation	Huang et al. 2012, *Feiner et al. 1997 (10)*	Adelakun & Garcia 2015	2+10=12 (11/1)
Health	Scharver et al. 2004, Weghorst 1997, *Bajura et al. 1992 (4)*	Zahedi et al. 2016, *Nilsson & Johansson 2007 (3)*	3+7=10 (6/4)
Home-Entertainment	Jones et al. 2015	Ernst et al. 2016	2+0=2 (1/1)
Maintenance	Feiner et al. 1993	Krishna et al. 2015, *Tang et al. 2003 (2)*	2+2=4 (1/3)
Military	*Livingston et al. 2011 (8)*	Hix et al. 2004	1+8=9 (8/1)
No specific domain	Azuma 1993, Roesner et al. 2014, Tatham 1999, *Billinghurst & Lee 2012 (35)*	*Swan II & Gabbard 2005 (6)*	3+41=44 (38/6)
Total	114	32	146
Keyword+Backward	16+98	12+20	28+118

Table 4. Augmented Reality Literature Concept Matrix

Technology papers are either developing or reviewing AR technologies. Oftentimes, this is also combined with a small user test. But for all papers in this category holds, that this is not the main focus. Research that investigates user behavior (UB) with regard to AR technologies accounts for 32 out of 146 papers (~22%). These papers specifically focus on users' behavior without going into technical details, e.g. by just using an existing technology like the Microsoft Hololens (e.g. Ernst et al. 2016) and testing the behavior of users with it. If there were any cases of articles falling under more than one domain, we would have sorted them into

both categories. Since we ground the domains in the search results, by reading at least the abstract and introduction of each paper, we provide application domains that cover several dimensions of the overall topic. An example for that process is the domain Geography/Travelling/Navigation in Table 4. The paper by Adelakun and Garcia (2015) deals with voluntary geographic information (VGI) and the possibilities of AR for the future of VGI. The article by Huang et al. (2012) is about AR navigation, which is a more specific case of geography. Thus, we decide to collapse these papers in one domain. This process is done based on the entirety of the search results and yields eleven domains and one category where all papers without a specifically assignable domain are included. An example of a technical paper with no domain is the one by Roesner et al. (2014) who investigate the privacy and security issues of AR technologies. It can also be seen that many articles of the backward search with a technical focus do not have a specific domain. The representative example is research on multimodal interfaces for speech and gesture interaction with AR (Billinghurst and Lee 2012). Fundamental research on AR technologies like that, was assumed to take an important place in the research of the last years as AR is a technology in development.

Research on user behavior with no specific domain is only found in the backward search. The example by Swan II & Gabbard (2005) makes an important contribution by summarizing existing user studies on AR. They investigate specific AR outlets like the proceedings of the International Symposium on Mixed and Augmented Reality (ISMAR). Although their results are 12 years old and cover other outlets than the review at hand, the ratio we observe between technical papers and user studies in our research is almost the same (21.92% in our case vs. 22.18%) (based on their findings on HCI-related publications plus user-based experiments, as we did not make this distinction). This shows that IS research is able to contribute a lot in research on user behavior with AR technologies as it was and is still underrepresented.

The single application domains also reveal interesting insights. There are only 3 articles investigating AR browsers on smartphones. All three have a technical focus. Thus, no research deals with the respective behavior of its users although it is a relatively easy to use technology which requires no additional hardware. Requiring only a smartphone with internet connection, a large potential user base exists for assessing existing applications like Blippar, a visual browser that uses AR to enable users to recognize objects with their smartphone camera and provide the corresponding information for the object (O'Reilly 2016).

Another domain with interesting results is gaming. Against our assumptions, research on user behavior in the gaming domain was not found in the representative IS outlets. As AR gaming applications on smartphones gained popularity in 2016 with the huge success of Pokémon Go, opportunities for large scale user studies dealing with AR arise, as they are possible to conduct with regular smartphone users which use these apps. The research on AR smartphone applications can by nature not cover not all aspects of an immersive AR experience with a head-mounted display (HMD). But it can yield important first insights of user behavior for the further developments of AR smart glasses until this technology eventually reaches the mass market. This development makes it also possible to overcome regularly observed problems in user studies, like small sample sizes or students as participants. There is also relatively few research on AR in the commerce and e-commerce domain for both foci. This is surprising as AR potentially enables retailers to approach their customers in a more efficient way. For example, Olsson et al. (2013) investigate how customers perceive mobile AR solutions and what they expect from them in shopping centers based on semi-structured interviews. Furthermore, there are only three articles in the home-entertainment domain. Rauschnabel et al. (2015) investigate personality traits and how they relate to the adoption intention of AR smart glasses for media usage.

Domains that are more industry-related are construction/manufacturing and maintenance. HMDs can serve as helpful tools in work processes where additional augmented information is needed (e.g. Feiner et al. (1993) for the case of airplane manufacturing). Against the backdrop of an increasing interest and usage of AR in the industry (Castellanos 2016), researchers are able to address highly relevant issues in this domain. In summary, the low number of articles in the previously discussed domains suggest, that it is important to do further research in these domains. Research on collaboration/communication and education/learning based on AR numbers among the domains which are investigated by many articles. Technical papers in the domain collaboration deal mainly with possibilities to make communication more personally compared to current video conferencing technologies (e.g. Billinghurst & Kato 2002). The large amount of research in the education and learning domain shows that AR is supposed to enhance learning capabilities. Results like those by Salvador-Herranz et al. (2013) indicate that AR can improve learning and teaching significantly. We could find 9 user studies in this domain, which accounts for 28% of all articles

with this focus. This shows that research in AR is relatively far compared to the other domains in our review. Interesting applications in the health domain are AR applications for helping patients with Parkinson to walk (Weghorst 1997) or providing professionals helpful information in carrying out their work in hospitals and evaluate the use behavior based on a technology acceptance model (Nilsson and Johansson 2007). The domain geography/travelling/navigation includes research about AR applications used for geographic and travelling information (e.g. Feiner et al. (1997)) or navigational purpose (Huang et al. 2012). The last domain is about applications for military purposes. The papers investigate mainly AR training applications arising out of the occurrence of increasing urban war scenes (Hix et al. 2004). Papers with a technical focus were only found during the backward search. The article by Livingston et al. (2011) provides an overview of military AR applications. The article by Hix et al. (2004) is the only one in the user behavior category. The authors describe an iterative development process of a military application with several user evaluations. Thus, we categorize this paper under user behavior.

In summary, it can be said that studies about users' behavior with AR systems are currently underrepresented in the IS literature. Furthermore, there are application domains in the category user behavior which reveal research gaps. Especially research on user behavior with regard to AR technologies in gaming and AR smartphone browsers could not be found in this study.

Future Research Opportunities and Limitations

By synthesizing our results in the previous section and showing underexplored categories, a roadmap for future work can be derived. Based on this synthesis, we highly encourage research with the following characteristics. First, more user studies should be conducted. Opportunities arise due to the diffusion of smartphone AR applications in the mass market. This makes it possible to conduct also large scale user studies that are currently missing due to a relatively small user base. This makes it also possible to address common sampling problems like student samples. This in turn potentially increases the explanatory quality of the results and facilitates the understanding of expectations and perceptions of users about AR. Second, actual research gaps were found for research on users' behavior with respect to gaming and smartphone browser AR applications. As gaming is in general an important industry for technological progress and generates billions of Dollars in revenue each year, it is important to enhance our understanding in this sector. User studies on AR gaming technologies are still challenging to manage with regard to research practicability when they investigate AR with smart glasses. It can be promising to utilize current trends like Pokémon Go and conduct large scale user studies based on the relatively large degree of diffusion. AR browsers on the other hand, can have the potential to personalize and augment several different experiences for customers with additional information in a commercial and uncommercial environment. In order to understand the complex interactions, user studies are also needed in this domain. Besides these two domains, almost every other domain of our literature review with a focus on user studies is worthwhile to investigate. Although we only considered IS literature in the keyword search and we think that the share of technical papers is relatively high, it is still necessary to improve AR devices with regard to several factors. An example for urgently needed technological developments are solutions that allow smart glasses to be smaller and less striking in order to be perceived as less intrusive by the environment surrounding the user.

This study has some limitations. First, the representative selection of IS journals and conferences is by nature leaving some research out. Therefore, our analysis regarding research gaps is only based on the selection of high-quality IS outlets including the respective references from the backward search. We think that we could address this drawback, inherent to many literature reviews, by establishing a certain degree of saturation in the backward search process as we found several doublings. Second, we only aimed at covering IS research. Combining outlets from different disciplines or from more specialized outlets like those reviewed by Swan II & Gabbard (2005) might also yield additional insights. Third, searching with different keywords like mixed reality could potentially yield additional insights. Fourth, the results could be differentiated with regard to other dimensions like utilitarian or hedonic motivated applications or personal and business contexts. We refrained from doing that as such a differentiation was oftentimes ambiguous for our results. For example, education and learning is oftentimes both and very user-specific of whether it creates pleasure and fun by itself or whether it is just utilitarian for other purposes. Other domains are more straightforward like gaming which is hedonic by design. Besides these problems, such differentiating characteristics are important for researchers and developers to consider, as they influence both, technology and user study questions and design.

Conclusion

The goal of this work was to analyze central issues of AR research in the IS field and integrate those findings to provide a common ground for future researchers. Throughout this systematic literature review we established that there are many promising areas for future work on augmented reality. We divided the results of the keyword and backward search based on the focus and the application domains of the articles. In total, we found 146 articles whereas 114 articles focus on technology and 32 articles focus on user behavior with AR technologies. Thus, user studies are highly underrepresented and should be investigated in future research. Understanding users' perceptions about technologies is a crucial requirement for the future acceptance and success of augmented reality systems of any kind. In the domain of AR smartphone browsers and gaming, we find actual research gaps with no research conducted yet. Research in these domains is fostered by the current massive diffusion of such applications on the smartphones of millions of users. Other application domains show large potential and importance for future research, too. An example is the manufacturing domain with the increasing usage of AR in work processes. We think that we could advance the understanding of AR in the current IS research with this work and showed research gaps that are interesting for future work. As the practical importance of AR is so large, we want to encourage researchers to engage in this promising and fascinating research field.

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