Towards Requirements Engineering with Immersive Augmented Reality

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ABSTRACT

Often, requirements engineering (RE) activities demand project stakeholders to communicate and collaborate with each other towards building a common software product vision. We conjecture that augmented reality (AR) can be a good fit to support such communication and collaboration. In this vision paper, we report on state-of-the-art research at the intersection of AR and RE. We found that requirements elicitation and analysis have been supported by the ability of AR to provision on-the-fly information such as augmented prototypes. We discuss and map the existing challenges in RE to the aspects of AR that can boost the productivity and user experience of existing RE techniques. Finally, we elaborate on various envisioned usage scenarios in which we highlight concrete benefits and challenges of adopting immersive AR to assist project stakeholders in RE activities.

CCS CONCEPTS

• **Software and its engineering → Requirements analysis**; **Requirements analysis**; • **Computing methodologies → Modeling methodologies**.

KEYWORDS

Augmented Reality, Immersive Augmented Reality, Requirements Engineering, RE, IAR, IAR for RE

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1 INTRODUCTION

In immersive augmented reality (AR) users can wear a headset to interact with digital representations embedded in their physical environment. Immersive AR has been successfully employed to facilitate communication and collaboration amongst users in domains as varied as medicine and manufacturing [18, 19]. In requirements engineering (RE), diverse project stakeholders take part in building a common software product vision, so we ask whether AR can benefit RE by boosting communication and collaboration. We analyze state-of-the-art research at the intersection of AR and RE. In particular, we analyzed nine papers [2, 7, 8, 12, 18, 19, 24, 36, 39] that report on the usage of AR to support RE activities. We found that AR improved communication when eliciting requirements based on the presentation of unobstructed information displayed in AR. We also found that requirements validation was supported, for instance, by presenting virtual objects embedded in physical reality as early prototypes. Finally, we present an envisioned usage scenario that exemplifies potential benefits and challenges of adopting immersive AR to support RE activities.

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2 REQUIREMENTS ENGINEERING

In response to the wide adoption of agile software development methodologies, RE activities have had to be adapted. Consequently, new paradigms such as agile requirements engineering (agileRE) and crowd requirements engineering (crowdRE) have emerged. These paradigms involve multiple stakeholders, advocate face-to-face communication, require minimal documentation, and favor iterative requirements evolution [13, 17, 31]. However, such paradigms also bring several new challenges. In this section, we summarize characteristics of RE activities, and discuss issues, especially concerning collaboration and communication.

2.1 Activities

RE consists of various activities namely *elicitation*, *analysis*, *specification*, *validation*, *management* [3], and *negotiation* [34]. Stakeholders select from several techniques and tools to perform one of the above activities; Table 1 lists some of the available techniques.

Elicitation is concerned with identifying sources of information to collect software requirements. To elicit requirements, engineers use various techniques such as interviews or surveys (see Table 1). The available techniques are classified either as *(i)* conversational *i.e.,* techniques that provide a means of verbal communication between two or more people, *(ii)* observational *i.e.,* techniques that provide a means to develop a rich understanding of the application domain by observing human activities, *(iii)* analytical *i.e.,* techniques that provide ways to explore the existing documentation or knowledge and acquire requirements from a series of deductions, and *(iv)* synthetic *i.e.,* techniques that combine above three [41].

Analysis is concerned with understanding requirements' overlaps and conflicts. To carry out an analysis task, engineers use various techniques such as prototyping and interviews.

Table 1: RE activities and corresponding techniques

Type	Technique	Elicitation	Analysis	Negotiation	Specification	Validation	Management	Reference
Conversational	Interview	✓	✓					[4, 33, 41, 43]
	Workshop/ focus group	✓						[41, 43]
	Brainstorming	✓	✓					[4, 33, 41, 43]
	EasyWinWin			✓				[15]
	Planning game			✓				[14]
Observational	Observation	✓						[4, 41, 43]
	Protocol analysis	✓						[4, 33, 41, 43]
Analytical	Laddering	✓						[33, 41, 43]
	Card sorting	✓						[4, 33, 41, 43]
	Repertory grids	✓	✓					[4, 33, 41, 43]
	Requirements inspection					✓		[30]
	Testing					✓		[30]
	Use case based modeling				✓	✓	✓	[9, 30, 38]
	Survey/ questionnaire	✓						[33, 43]
	Goal-oriented approach	✓	✓		✓			[4, 38, 43]
Synthetic	Scenarios	✓	✓					[4, 41, 43]
	Storyboards	✓						[41, 43]
	Prototyping	✓	✓			✓		[4, 33, 41, 43]
	Joint application Dev.	✓						[33, 41, 43]
	Viewpoint	✓			✓	✓		[30, 38, 43]
	SWOT analysis	✓						[32]
	Theory of change	✓						[32]
	CRC session		✓					[22]
	Problem definition	✓						[32]
	Persona	✓						[32]
Other	Seamless requirements							[28]
	iMuse				✓			[40]
	PCM				✓			[29]
	Petri Nets				✓			[1]
	Baselining						✓	[10]
	Change management						✓	[10]
	Process management						✓	[10]
	Progress tracking						✓	[10]
	Report generation						✓	[10]
	Traceability management						✓	[10]

Negotiation is concerned with the reconciliation of conflicting views and opinions to generate a consistent set of requirements, which can be supported by approaches such as EasyWinWin [15].

Specification is concerned with documenting collected requirements in a form that non-technical stakeholders and developers can both understand. The specification task establishes an agreement between non-technical stakeholders on what the software product should do. To the best of our knowledge, one of many forms such as user stories and UML diagrams can be adopted to document software requirements. Apart from that authors have also proposed techniques such as seamless requirements and iMuse (see Table 1). There also exist the standard ISO/IEC/IEEE 29148:2018[1] that explains how requirements should be specified.

Validation is concerned with the process to ensure that requirements are correctly understood during implementation. In it, multiple techniques can be adopted such as prototyping and use case based modeling.

Management is concerned with controlling the inevitable effects of requirements changes. To the best of our knowledge, there are no dedicated techniques for requirements management, instead, there exist several tools that can be used to assist project stakeholders when managing their documented requirements [35].

RE is an iterative process, in which individual activities are repeated as requirements are derived. Such iterations continue even during other phases in the software life-cycle such as implementation, deployment, and operation [34]. The boundaries between elicitation, analysis, negotiation, and validation are blurry, therefore, we observe that some techniques, such as prototyping, are used to accomplish multiple RE activities.

2.2 Challenges

To identify challenges pertaining to RE, we decided to analyze systematic mapping studies that could give us a consolidated overview of the existing research literature. To find such studies, we used the query string "`requirements engineering mapping`" and searched the titles of the papers published since 2015 on Google Scholar.[2] Consequently, we selected four mapping studies [5, 6, 16, 25] and curated a list of identified challenges. As one objective of our investigation is to identify potential benefits of using AR to support RE activities, we classified these identified open challenges into RE activities.

Elicitation. We identified various challenges, such as *(i) inadequate interactions*. Often, constraints such as time and knowledge gap leads to inadequate interactions between customers and users; *(ii) tacit knowledge sharing*. That is, inability to communicate tacit knowledge can lead to ineffective sharing of information during meetings and interviews; *(iii) communication gap*. Distributed and heterogeneous teams can suffer from communication gaps and misunderstandings. Likewise, maintaining iterative communication with customers might become difficult due to missing contexts; and *(iv) low customer availability*. That is, time, budget, and allocation constraints leads to low customer availability.

[1] https://www.iso.org/standard/72089.html

[2] "Google Scholar", accessed January 29, 2020, https://scholar.google.de/

Analysis. In analysis, we identified various challenges, such as *(i) conflicting requirements*. Often, the requirements tend to generate more conflicts with the involvement of many stakeholders; and *(ii) requirements formats*. Lack of suitable formats leads to inefficiency in requirements analysis and inspection.

Validation. The validation phase suffers from challenges, such as *(i) missing perspective*: That is, the incomplete nature of the system leads to the customer's missing perspective during validation.

Specification. Likewise, requirements specification suffers from *(i) inefficient requirements formats*: That is, incomplete notational systems such as story cards and the wall lead to ineffective documentation for geographically dispersed teams. Likewise, several documentation formats leads to communication issues; *(ii) lack of documentation*: The lack of documentation leads to difficulties in bringing new team members on board; and *(iii) diagrams are inadequate*: Diagrams are not enough to obtain feedback as they are identified by customers to be less useful in finding faults.

Table 2: Publication venues

Venue	CORE
Symposium on Virtual and Augmented Reality	-
IEEE Consumer Electronics Magazine	-
Workshop on Just-In-Time Requirements Engineering	A
International Requirements Engineering Conference	A
International Symposium on Mixed and Augmented Reality Adjunct	A*
Requirements Engineering	B
Summer Computer Simulation	B
Frontiers in Education Conference	B
International Workshop on Requirements Engineering for Self-Adaptive, Collaborative, and Cyber-Physical Systems	A

Management. Finally, we identified challenges in requirements management, such as *(i) too many tools*: Several involved tools lead to inefficient control in changing requirements.

3 STATE-OF-THE-ART OF RE WITH AR

AR has been used in several domains such as medicine [19], construction [42], and situated visualization [27] to assist users in accomplishing their tasks by augmenting virtual objects over the actual physical objects. However, the potentials of AR to assist software engineering tasks, particularly RE activities is not yet fully explored.

3.1 Method

To identify relevant research papers at the intersection of AR and RE, we used popular search engines and digital libraries. We defined the query string `"augmented reality" AND "requirements engineering"`, as it captures the main concepts on which we focus. We searched on IEEE Xplore,[3], ACM DL,[4], and Google Scholar.[5] The query resulted in a total of 27 publications. To exclude false positive results, namely papers that include the keywords in the search criteria but focus on a different topic, for each paper we analyzed their titles, abstracts, and introductions. We found 9 papers that are in the scope of this study (see Table 2). For each paper, we extracted seven dimensions, namely: *(i)* publication venue, *(ii)* year of publication, *(iii)* number of citations, *(iv)* supported RE activity, *(v)* employed AR device, *(vi)* software stack, and *(vii)* evaluation type.

3.2 Results

In Table 2, the first column indicates the publishing venue with a hyperlink, followed by the CORE (Computing Research and Education Association of Australasia) rank. We observe that the analyzed papers [2, 7, 8, 12, 18, 19, 24, 36, 39] only appeared in recent years *e.g.,* 7 out of 9 papers were published during the past five years. One paper [36] was published in a journal, and the remaining papers were published at well-ranked venues (based on their A^*, A, and B classifications in the CORE ranking [6]). Despite being a relatively new research area, two recently published papers [8, 36] have obtained respectively 25 and 12 citations indicating that researchers are interested in this topic.[7] Certainly, we found various types of papers: (i) three papers [12, 24, 39] present techniques that use AR to support particular RE activities, (ii) three papers [2, 7, 18] elaborate on requirements for AR technology, (iii) two papers [19, 36] do both, and (iv) one paper [8] with a similar goal as our study focuses on the relationship between virtual reality and RE.

Activities. We found that immersive AR has been used for: *(i)* requirements elicitation [12, 19, 36], specifically by using AR glasses in scenario-based walk-throughs [36], using AR simulators to augment information visualization for head-up displays [12], and through the concepts of gamification such as rewards and badges to encourage use of AR in learning [19], and *(ii)* requirements analysis and negotiation [24, 39], specifically by using AR glasses during project meetings to display contextual content [24, 39].

Devices. We identified three AR devices, namely: *(i)* head-up displays (HUD) [20], *(ii)* Google Glass [23], and *(iii)* Microsoft HoloLens [37].

Software Stack. Amongst the papers we identified, only one [12] discussed various software tools they used to implement AR systems. To implement a driving simulator the authors used: *(i)* Unity 3D[8] for creating a 3D model of a small section of a city, *(ii)* CityEngine[9] for modeling 3D objects such as buildings and roads for the city, *(iii)* Autodesk Maya[10] for the development of 3D models *e.g.,* vehicles, and *(iv)* Tree[d] for modeling trees in the simulated city.

Evaluation. We found two papers that report on controlled experiments that measure the effect of applying AR to various business areas. In particular, one experiment [12] engaged 20 drivers who used an AR simulator to elicit requirements for head-up displays (HUD). The authors analyzed the impact of information display on a driver's behavior, specifically, the effect of lateral deviations and impact on information recall while driving. Another study [24] performed a controlled experiment to measure how effective it is to use Google Glass to display information during project meetings. In particular, the authors examined an application that notifies the participants with the availability of additional information to the past and current presentation slides on their Google Glass. They ran their experiment with 16 students to discover that: *(i)* there is a lack of research on ideal formats and methods for delivering and visualizing the additional information during the meeting, and *(ii)* smart watches or smartphones are a better alternative to Google Glass when delivering additional contextual content.

Experiments were primarily carried out to evaluate the applicability of AR to certain domains, or to identify specific requirements for AR devices. There were no experiments that validate the benefits of adopting immersive AR to support specific RE activities. Similarly, in the experiment that involved an AR simulator, AR helped authors as: *(i)* immersion offered by AR helped to reproduce the conditions of driving a real car in a realistic fashion, and *(ii)* AR simplified controlling the variables measured in an experiment.

[3] "IEEE Xplore Digital Library", accessed November 29, 2019, https://ieeexplore.ieee.org/Xplore/home.jsp
[4] "ACM Digital Library", accessed November 29, 2019, https://dl.acm.org/
[5] "Google Scholar", accessed November 29, 2019, https://scholar.google.de/
[6] "CORE Rankings Portal", accessed November 28, 2019 http://www.core.edu.au/
[7] "Google Scholar", accessed December 1, 2019, https://scholar.google.de/
[8] "Unity", accessed December 1, 2019, https://unity.com/
[9] "Esri CityEngine", accessed December 1, 2019, https://www.esri.com/en-us/arcgis/products/esri-cityengine/overview
[10] "Maya", accessed December 1, 2019, https://www.autodesk.com/products/maya/overview

Requirements for AR. Although developing an AR system could require special support for RE activities, *e.g.,* prototyping, we only found requirements for AR devices. One paper [2] describes elicitation of requirements for AR-HUDs such as required resolution, luminance, and contrast ratio. Another paper [7] presents a teaching strategy to help students elicit requirements for developing AR systems. The authors presented students an AR application and consequently asked them to identify requirements for improvement for an imaginary scenario. Kammerer *et al.* [18] discuss requirements for using AR to support software process management, in particular, for developing cyber-physical systems. Among other things, they discuss: *(i)* various types of AR displays such as optical see-through (OST) and video see-through (VST) that one can utilize to display information, and *(ii)* camera tracking techniques such as marker-based and marker-less that help to create environment model of the cyber-physical systems. Finally, another study [36] identified usability problems of VR and subsequently used AR to solve those. In particular they identified three usability issues with VR prototypes, namely: *(i)* less than perfect rendering of the user's natural action, *(ii)* lack of haptic feedback, and *(iii)* inadequate graphics, which AR can address elegantly.

3.3 Discussion

The observed usage of AR can stir discussion about how it can further be used to improve RE. Any speculation should, however, be followed up by properly designed experiments.

As we have seen, AR has been primarily used to support requirements elicitation, analysis, and validation. AR technology exhibits several aspects which we speculate are particularly helpful for RE. For instance, the *embodiment* of AR is important for prototyping as it gives the user an opportunity to interact with the augmented version of the final system. Similarly, *collaboration* and *communication* aspects of AR are useful in scenario walkthroughs and meetings as they enable the participants to follow audio-visual clues and to manipulate shared augmented objects that are involved in a specific scenario. On the other hand, requirements such as appropriate values for resolution and luminance improve *mediated reality* offered by AR.

4 USAGE SCENARIO

Our analysis of the state-of-the-art in AR used to support RE activities shows that most of the proposed applications concentrate on requirements elicitation and analysis. We think that the particular characteristics of immersive AR such as *(i)* a combination of real and virtual worlds, *(ii)* real-time interaction, and *(iii)* accurate 3D registration of virtual and real objects makes it a good fit for other RE activities such as specification or management. In the following, we first describe the potential of AR recognized from previous studies, and consequently describe our envisioned usage scenarios that highlight benefits and expose challenges of adopting immersive AR to support various RE activities.

Potentials of AR. AR has been proved to be useful to support collaboration as it can *(i)* improve the effectiveness of users by reducing their mental effort when carrying out assembly tasks, *(ii)* enable an effective guidance of remote users, *(iii)* reduce the time needed to solve a task, *(iv)* facilitate communication of engineering processes, and *(v)* support mutual understanding when testing a hypothesis, and so leading to consensus [21]. Indeed, there are several aspects of AR that can be particularly helpful in RE, namely: *(i)* collaboration, *i.e.,* facilitating remote collaborative experience through visualization, *(ii)* communication, *i.e.,* providing augmented visual communication cues, *(iii)* embodiment, *i.e.,* supporting sensory-motor capabilities, *(iv)* mobility, *i.e.,* creating augmented environment anywhere, *(v)* mediated reality, *i.e.,* changing the appearance of physical objects, *(vi)* pervasiveness, *i.e.,* continuous experience based on mobility, and *(vii)* privacy, *i.e.,* restricting access to certain information as discussed in a previous study [26]. We illustrate these aspects in our following envisioned usage scenario.

MegaWare is a giant warehouse in Canada that wants to transition to Industry 4.0 to optimize its services such as storing, locating, and delivering goods to its customers. They hired SoftCom, a software development company based in Germany, which is specialized in consultation on Industry 4.0. SoftCom partially outsources its software development work to TechCrunch, an IT service provider based in India. Similarly, SoftCom outsourced their testing tasks to a company based in Singapore called TestIT. Responsible people from all these companies need to work closely to make this project a success. Although this setup is economically viable for all of them, there are certain constraints that challenge the efficiency and smooth functioning of the project. For instance, physical distance makes it expensive to visit MegaWare often, leading to several digital meetings. Likewise, different time zones make it hard for people to be present in their respective offices to participate in cross-continent team meetings. The collaboration and mobility aspects of AR can help requirements engineers to deal with these challenges.

Elicitation. Anna is a requirements engineer who works for SoftCom and her responsibilities include requirements elicitation, negotiation, and specification. The importance of these RE activities is significant in building future software systems for domains such as Industry 4.0 [11]. As it is infeasible to travel to Canada very often due to company policies, during her first visit to MegaWare she leverages *mobility and mediated aspects* of AR during *observation and protocol analysis.* She wears an AR headset while observing clients at their workplace. An object recognition software installed in the headset displays for her pertinent information next to the physical objects when visiting the warehouse. Using hand gestures *i.e.,* leveraging *embodiment* aspect of AR, she can annotate objects and add them to the domain model as she walks around the warehouse. Once she understands her client's needs, she prepares an *interview* session to gain deeper insights. During the interview, additional contextual information (based on earlier annotated video recordings and a preliminary domain model) is automatically presented through her headset, leveraging *communication* aspect of AR, as well as on the presentation screen as an input to a specific question to her client, augmenting her perception. For instance, she can point to a certain action in the video recording to ask the rationale behind it. Similarly, for a specific question, she sees a rudimentary domain model of involved domain entities and navigates through possible connections by using hand gestures. She then confirms with her client whether the flow of data between those domain entities is modeled accurately.

Analysis. Back in Germany, to discover conflicts amongst elicited requirements, she conducts a *workshop* with the client, offshore development, and testing representatives. As participants of the meeting are located in different time zones, they decide to hold an augmented workshop session. They do not need to be present in a specific conference room, leveraging *mobility* aspect of AR, instead, they wear their AR headsets and have the exact view of the meeting room in India where Raj, the lead developer, is participating along with fellow developers. In contrast to only seeing the participants' faces in conventional conference software, participants actually feel like they are present in one location. To clear certain things about the physical characteristics of the warehouse, Anna asks the client representative to simply walk through the warehouse using his AR headset leveraging *collaboration* aspect of AR. An application installed in the headset helps her client with exact navigation directions to reach the places in the warehouse that they wanted to discuss, and in turn the team members get a live view along with annotated objects on their projected screen.

Next, Anna displays augmented Class-responsibility-collaboration (CRC) cards on her physical whiteboard, and asks her clients and Raj's team to collaboratively arrange those to emulate a *CRC session*. The clients are in an office with a physical whiteboard, so they interact with the CRC cards as Anna does leveraging *collaboration* and *mobility* aspects of AR. Although Raj's team is in a conference room without a whiteboard, they still can participate in the activity as they can interact with virtual representations of the whiteboard and cards. Anna reflects that when clients perform this activity in immersive AR, they are willing to spend more time on it, and they have a more positive attitude, which improves the outcome of the activity. As a consequence, additional domain concepts are discovered, which are marked to be added to the existing domain model. To schedule the next meeting, Anna uses the voice recognition capabilities of the device to ask the software to show free time slots from all the participant' calendars on a shared augmented screen. The software displays available time slots that suit everybody, and subsequently they schedule the next meeting by pointing and clicking on a specific suggested date and time leveraging *embodiment* aspect of AR.

Specification. Anna has collected a set of initial requirements. In subsequent meetings with clients, she collaboratively draws diagrams, sketches user interfaces on paper that are captured using the headset camera and attached to elicited requirements to support traceability. Sometimes, she uses the meeting room to display dozens of these attached contents in immersive AR leveraging *mobility* aspect of AR to identify overlooked relationships. She thinks that using her hands to drag and drop requirements is beneficial to create a model of the domain.

Anna obtains an interactive view of the underlying domain model in her immersive AR headset. An application in the device helps her to view the domain model using domain entity connections, class diagrams, as well as finite state automata. Particularly, the zoom feature helps her to navigate between detailed and abstract views just by using hand gestures leveraging *embodiment* aspect of AR. In a similar way, she can walk through a business scenario.

Raj wears an AR headset as a companion device to his computer screens. When he is inspecting the source code of a class in the integrated development environment (IDE) on the screen, a CRC card representation pops up in AR, which allows him to stay focused on the intention of that specific class. Similarly, as he creates an object of a particular class, a visualization of the state of the object pops up in his AR headset, which helps Raj to observe for any property changes to it leveraging *pervasiveness* aspect of AR.

Management. Raj explains an architectural decision to Lucy, a product owner, and *walks her through* the user stories that are affected by this choice. He accomplishes this task simply by streaming his augmented point-of-view of the reality and using hand gestures, which saves him multiple context switches between applications on his laptop. In turn, Lucy re-prioritizes requirements to maintain a defined deadline. AR helps the project team in visualizing the links various project artifacts such as epics, use cases, user stories, and domain entities as a big mesh which can be traversed by zooming in and out. For instance, all the augmented artifacts related to a specific epic can be projected in a room for a team to get a bird's eye view on the current state.

In summary, we envision a future in which immersive AR provides requirements engineers appropriate support to link the artifacts produced at the various stages of RE. In it, engineers, for instance, would collaboratively interact with CRC cards in AR, as well as, manipulate domain concepts to model software systems using hand gestures. Consequently, immersive AR could facilitate the co-evolution of software requirements with the domain model, and the implemented application. We think RE supported with immersive AR could become a pervasive activity that is not limited to working on a desktop computer or to the constrained mobility of a laptop, but that could be addressed at anytime and anywhere.

5 CONCLUSION

We analyzed nine papers at the intersection of AR and RE to discover potential synergies between these two fields, in particular, to speculate how AR can support RE activities. We reflect on the challenges pertaining to RE, map those challenges to specific RE activity, and identify aspects of AR that can support corresponding RE techniques to mitigate these challenges. Furthermore, we envision usage scenarios to elaborate how aspects of AR can boost collaboration and communication between project stakeholders.

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