A Survey on Large-Scale Requirements Engineering

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ABSTRACT

Large-scale systems have different categories, each having their own unique characteristics. Because of that, current requirements engineering methods may not be effective. In order to perform requirements engineering correctly, new integrated methods and design patterns are required, to ensure that requirements quality is high. In this paper, a set of studies on large-scale requirements have been analyzed and discussed. These studies suggest that with the growth of large-scale systems in size and quantity, new frameworks and integrated methods need to be delivered in order to make sure that the requirements engineering phase is completed effectively.

KEYWORDS: Large-Scale Requirements Engineering, System of Systems, Cyber-Physical Systems, IoT Applications, Cloud-Based Applications

1   INTRODUCTION

Systems are getting more complex by day, bringing new challenges to different fields of system development and software development. Therefore, requirements of such systems need to be integrated to the large-scale architecture. Requirements Engineering helps software engineers to deal with difficulties in capturing, analysing, expressing and managing requirements throughout the system life cycle [1]. However, there is little knowledge of how requirements engineering techniques can be integrated into a unified requirements process [1]. In this paper, large-scale requirements engineering is discussed in five categories of systems: Cloud based systems, Complex systems, IoT applications, System of systems and Cyber-physical systems.

Large-scale systems often have conflicting requirements [2]. Therefore, Large-scale requirements engineering in such systems, cannot be done using the common methods and techniques. Since large-scale system development takes a great amount of time, system requirements may change during development process, thus, requirements engineering methods need to be modified or new requirements engineering methods must be proposed to deal with the changing nature of large-scale requirements engineering. Most of the researches covered in this paper provide frameworks and methods for different phases of requirements engineering in large-scale systems.

This paper discusses different requirements engineering methods for each type of large-scale systems with the objective to point out new techniques to improve requirements elicitation and evaluation in such systems. Section 2 describes how requirements engineering process is done in each category of large-scale systems. In section 3, the overall view towards large-scale requirements engineering is discussed. Finally, a conclusion is presented in Section 4.

2 LARGE-SCALE REQUIREMENTS ENGINEERING

2.1 Cloud Based Applications

Cloud based applications are getting more attention due to their cost effectiveness and functional possibilities [1]. Cloud requirements change rapidly, so organizations need to take advantage of new methods to cope with these changes [2]. Table 1 demonstrates the papers' ideas around the topic of cloud computing and the methods presented for its rapidly changing requirements.

Despite major improvements and advancements in cloud computing, there are still issues in different parts of this field, and the biggest issue in this field is the lack of a standard for requirements specification [3].

Table 1 Literature on Requirements Engineering in Cloud Based Applications

Name	Year	Problem Statement	Objective	Methodology	Dataset	Findings/Outcome
An Improved Requirements Engineering Framework for Cloud Based Application Development [3]	2015	Every technology implies applications appropriate to its requirements engineering activities and techniques	Discover features of requirements engineering imposed by cloud computing based architecture	Presents a framework on the basis of requirements engineering model that contains all necessary phases	Surveys and interviews on this subject	A requirements engineering framework that considers features established within the cloud context
Analyzing Requirements Engineering for Cloud Computing [4]	2017	Cloud requirements can rapidly change over time. The existing works are focused in a limited number of requirements and capabilities for cloud services	Provide a comprehensive literature review of academic researches done in requirements engineering for cloud computing area	A literature review was conducted and five dimensions are discussed to classify cloud characteristics, specify requirements, and support cloud contracts	Other papers on requirements engineering for cloud computing	A simple sample is given to illustrate how to identify cloud dimensions
Handling Dynamic Requirements in Cloud Computing [5]	2015	Existing RE approaches for Cloud Computing are generally focused on a limited number of non-functional characteristics	Explain contribution based on practical experience in projects and existing RE approaches	A conceptual model is initially presented to analyze cloud requirements and services	Security guard company	The presented model can be used in many organizations to support their activities during cloud service adoption
Requirements Engineering for Cloud Systems: A Mapping Study Design [6]	2017	Despite the increasing acceptance of cloud computing within the industry, many important questions remain unanswered	Find the appropriate techniques application in early phases like requirements engineering	Define a design of a mapping study to verify and identify the existence of relevant research gaps	IEEE Xplore ACM Digital Library Science Direct SpringerLink	Encourages the necessity of the complete execution of a systematic mapping study regarding the synergy of requirements engineering

2.2   IoT Applications

With internet being accessible everywhere these days, most simple devices are becoming smart, meaning they can operate various tasks and provide more functionality than old models with no internet connectivity [5]. This level of advancement in Internet of Things (IoT) can build up the foundation of smart homes and smart cities [6]. In order for this type of technology to work expectedly, a new set of functional and non-functional requirements must be taken into account to prevent any intolerance in IoT services and applications [5]. Table 2 shows a portion of studies on this matter, and the solutions given to address the issue of defining functional and non-functional requirements for this type of technology.

Table 2 Literature on IoT Applications

Name	Year	Problem Statement	Objective	Methodology	Dataset	Findings/Outcome
Catalog of Invisibility Requirements for UbiComp and IoT Applications [7]	2018	Invisibility (NFR) has not been cataloged regarding its subcharacteristics and solutions, making its design and requirements specification in such applications a challenging task	Capturing subcharacteristics and solutions for Invisibility and cataloguing them in a Softgoal Interdependency Graph (SIG)	Systematize the definition of Invisibility SIG using the following well-defined research methods: snowballing, database search, grounded theory and questionnaires.	Solutions extracted from questionnaires sent to experienced developers of UbiComp and IoT applications	An Invisibility SIG composed of two main subcharacteristics, twelve subsubcharacteristics, ten general solutions and fifty-six specific solutions
Major Requirements for Building Smart Homes in Smart Cities based on Internet of Things Technologies [8]	2016	Due to emerging of smart homes and smart cities, IoT related requirements require more attention	Define the major requirements for building SH	Seven unique requirement recommendations are defined and classified according to the specific quality of the SH building blocks	-	IoT adapted requirements and the challenges that need to be addressed before full smart homes and IoT implementation
RE and Society - a Perspective on RE in Times of Smart Cities and Smart Rural Areas [9]	2018	Nowadays, in times of smart cities and their counterpart smart rural areas, a new and challenging context arises for RE, which opens up new research questions	Find out whether our RE methods are appropriate in this new "social context" or not	Present a framework comprising both an initial classification of social contexts, particularly their end users, and a classification for RE methods	3 usage scenarios for the proposed framework	There is a huge potential and huge demand to explore new ways of conducting RE activities in social contexts

2.3 System of Systems

Systems of systems are defined as large systems, each containing individual subsystems [10]. These systems are mostly used for global societal needs, such as energy-water-food nexus, global activities and integrated transport [10]. These systems are mostly characterized their decentralized platform, support for multiple platforms, continuous evolution and development, as well as inconsistent and changing elements [2]. Due to their large scale definition and requirements, ordinary methods and principles used in systems cannot be applied to systems of systems [10]. In order to address this issue, many studies are being dedicated to delivering methods and techniques to integrate available requirements engineering methods with these large-scale systems, or new frameworks to present new structures on which requirements engineering for systems of systems is defined. Table 3 demonstrates the studies on this subject.

Table 3 Literature on Systems of Systems

Name	Year	Problem Statement	Objective	Methodology	Dataset	Findings/Outcome
From Requirements Monitoring to Diagnosis Support in System of Systems [2]	2017	Support for subsequent diagnosis of violations is rather limited and often even neglected	Improve the capabilities of diagnosis support in system of systems	Outline a tool-supported framework based on a runtime artifact model and pre-defined diagnosis actions	An available runtime artifact model	Discussions about the required capabilities for diagnosis support in SoS
On Systems of Systems Engineering: a Requirements Engineering Perspective and Research Agenda [10]	2018	Cyber-Physical Systems of Systems are becoming increasingly complex and more difficult for current requirements engineering (RE) practices to handle	Highlight the challenges that the RE discipline must respond to	Outline a requirements engineering perspective and research agenda that identifies 'top-10' research themes	A cluster of four Systems of Systems Engineering projects funded by the European Commission's Horizon 2020 research program	Most current RE methods, tools and techniques would need to be revisited or evolved as proposed in this paper in order to cope with the challenges of System of Systems

2.4 Cyber-Physical Systems

A cyber-physical system is defined as "a system where the physical world interacts extensively with -often networked- software" [10]. Because of the continual nature of cyber-physical systems, we have to cope with real-time requirements [10]. This requires special requirements definitions and implementations, to support different states of the system [10]. Furthermore, non-functional requirements such as safety and performance must be taken into consideration, due to the continual nature of the system [11][12].

Papers on this field of study mostly present solutions for continuously changing requirements of cyber-physical systems. One of the reasons cyber-physical systems are getting attention these days, is the fact that they can be used with other complex systems and technologies [13]. In order to get better feedbacks from cyber-physical systems, requirements, design and physical system modelling must be completely separated. Table 4 contains the studies covered around cyber-physical systems.

Table 4 Literature on Cyber-Physical Systems

Name	Year	Problem Statement	Objective	Methodology	Dataset	Findings/Outcome
Modeling and Requirements on the Physical Side of Cyber-Physical Systems [11]	2013	We have to contend with not only real time requirements but also the continuous and continual nature of the system	Write well defined requirements to address crucial issues not commonly addressed in the software domain	Outline how early modeling in the continuous domain serves as a crucial aid in the elicitation of requirements	Basic automotive cruise control Drug infusion pump	Early modeling of the physical aspects of the proposed system is an invaluable resource when eliciting and clarifying requirements
Straightforward Specification of Adaptation-Architecture-Significant Requirements of IoT-enabled Cyber-Physical Systems [12]	2018	One key challenge is the identification and specification of simple and concise architecture significant requirements	Propose Adaption Terms	Present blueprints comprising a sufficient set of information to properly architect adaptable IoT-enabled cyber-physical systems	Feedbacks from the professionals of different domains	The approach is enabling the specification of simple and concise architecture significant requirements centered on adaptation
Toward a Rigorous Approach for Verifying Cyber-Physical Systems Against Requirements [13]	2017	Verifying that complex cyber-physical systems satisfy the requirements that ensure their proper operation is difficult due to the large number of potential situations	Explore many different solutions and avoid unacceptable behavior	Present a new framework for supporting a methodology that aims at reconciling innovation and safety	Power plant statistical data	There should be a clear separation between requirements, design, and physical system modeling
Towards Cyber-physical Requirement Engineering Elicitation Tool Support [14]	2018	Cyber-physical systems represent extra and more essential difficulties in communication between different components and their requirements	Developing a requirement engineering tool that can be used to increase the requirement elicitation	A model-based requirements engineering tool to link non-functional requirements and functional requirements	The CubeSat Development Initiative system	The developed software tool is helpful for the cyber-physical systems, complex spacecraft and autonomous systems where requirement elicitation is the key consideration

2.5   Other Large-Scale Systems

Complex systems, adaptive systems and large-scale systems in general require different strategies to complete their lifecycle process correctly. One of the major factors that impact large-scale requirements engineering and implementation of a large-scale system, is management techniques and strategies [14]. Combining requirements engineering and management process can improve the means of planning, coordination and stakeholder engagement [14]. One of the qualities of large-scale systems, is the dynamically changing of its situation [15]. This requires requirements engineering and software engineering methods to elicit the dynamic requirements, allowing the system to adapt itself with the new situation [15]. Stakeholders play a major role in defining requirements and putting them into good use [16]. Thus, large-scale requirements engineering requires working methods for engaging stakeholders in different phases of the system development, without them carrying the burden of intense requirements meetings and sessions [16]. In Table 5, a group of studies performed on large-scale requirements engineering is delivered.

Table 5 Literature on Large-Scale Systems

Name	Year	Problem Statement	Objective	Methodology	Dataset	Findings/Outcome
A Requirements Engineering and Management Process in Concept Phase of Complex Systems [1]	2016	Despite numerous requirements engineering techniques, there is little knowledge of how to integrate them into a systematic requirement process	A process for integration of requirements engineering and management techniques is proposed	The process integrates a set of methods and techniques of requirements engineering and project management	Concept phase of a complex defense system	Requirements engineering and management process help to create an effective means of planning, coordination, and stakeholder engagement
Automatic Glossary Term Extraction from Large-Scale Requirements Specifications [15]	2018	Glossary term extraction methods focus on achieving a high recall rate and neglect the benefits from reducing the number of candidates by statistical filter methods	Demonstrate how to automatically extract relevant domain-specific glossary term candidates from a large body of requirements	The approach combines linguistic processing and statistical filtering for extracting and reducing glossary term candidates	The CrowdRE dataset	With a careful combination of linguistic and statistical extraction methods, a fair balance between later manual efforts and a high recall rate can be achieved
Engineering requirements for adaptive systems [16]	2014	The increasing demand for complex software calls for novel software engineering methods to create systems able to autonomously adapt to dynamically changing situations	present a framework for Engineering requirements for adaptive software systems	The approach, called Tropos4AS, combines goal-oriented concepts and high-variability design methods	Statistical results of the case studies	The experiments provide an empirical evaluation of the proposed method, pointing towards the effectiveness of the modelling approach for gathering requirements of adaptive systems

Exploring factors affecting decision outcome and lead time in largescale requirements engineering [17]	2015	Achieving low decision lead time requires a better understanding of factors that may affect both decision lead time and outcome	Minimizing lead time that enables software companies to remain competitive within the changing software market	Conducted a two-stage case study that combines the statistical analysis of seven possible relationships among decision characteristics	Survey results of industry participants	The number of products affected by a decision increases the time needed to make a decision
Needs and Challenges for a Platform to Support Large-scale Requirements Engineering [18]	2018	The increasing complexity of software require the development of methods and tools for improving largescale requirement engineering.	Identify and understand the characteristics and challenges of a platform to support requirement engineering for individual stakeholders when dealing with a large number of requirements	Conduct a multiple case study with three companies in different domains	Collected data through ten semi-structured interviews with experts from these companies	The main pain-point for stakeholders is handling the vast amount of data from different sources, it should also offer stakeholders an estimation of how long a requirements engineering task will take to complete

3   DISCUSSION

Literature on large-scale requirements engineering suggests that ordinary requirements engineering methods do not work for large-scale requirements engineering. Therefore, most of the papers provide frameworks and integrated methods for large-scale requirements engineering. These solutions can improve requirements quality and affect overall performance and behavior of the system.

Cloud based applications have constantly changing requirements [4], and the studies provided in this paper present frameworks and solutions to deal with this issue. However, rapidly changing requirements can affect other phases of software lifecycle, hence, other phases of the lifecycle also have to be responsive to these rapid changes.

The emerging phenomenon of smart homes and IoT applications and systems has its own requirements and design patterns [8][9]. Therefore, IoT systems require more attention not only for their requirements engineering phase, but also for other phases of the system life cycle [9].

Systems of systems and cyber-physical systems bring out new challenges to the field of requirements engineering. Due to their large-scale requirements and design, current requirements engineering methods are not effective, hence, these methods need to be revised and a new set of integrated methods are required for large-scale requirements engineering [10]. Furthermore, performing the requirements engineering tasks on such systems takes a lot of time, and early modeling of the physical sides of cyber-physical systems, may result in inconsistencies [11].

Large-scale requirements engineering present new challenges in the management aspect of the project. Managing the intense amount of requirements can be a difficult task [1]. Furthermore, the system has to be adaptive to changes in requirements and workflows [16] which seeks more attention in requirements management and project management principles.

4   CONCLUSION

Systems are growing fast in size and complexity. While they ease a lot of tasks and provide functionalities, they require new methods to handle their requirements. These large-scale systems will not operate properly without integrated requirements engineering techniques. The studies reviewed in this paper provide solutions for this matter in each category of large-scale systems. With the expanding nature of large-scale systems, new requirements engineering methods are needed to cope with the new situation.

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