Requirements Engineering Processes in the Context of IoT and Requirements Validation Techniques

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Abstract. The Internet of Things made possible an increase in the possibilities of automation and facilitation of people's daily lives. From home automation to smart buildings, the rise in IoT's popularity brings a challenge to software development and requirements engineering. Developers and companies are not familiar with the requirements validation processes and techniques that exist in the context of an IoT system. Therefore, possible project failures and rework during software development are issues to be considered by development teams. This work aims at investigating the requirements engineering process and the requirements validation techniques in the IoT context described in the literature. Also, present a guide to support software development teams to have easy access to the processes and techniques proposed in the literature for this context. We conducted a survey of industry practitioners to investigate whether they use and know the processes and techniques identified in the literature. Our findings reveal that the technique most used by practitioners to perform requirements specification are stakeholders meeting and brainstorming and to validate requirements are prototypes and use cases.

Keywords: Internet of Things · Non-Functional Requirements · Software System · Process · Techniques

1 Introduction

The Internet of Things (IoT) allows everyday objects to communicate with the Internet, as long as its electronic resources allow this task [37], [32], [18]. Communication with the Internet is carried out through an electronic device with an integrated module for connecting to the network. Since its creation in 1999, the Internet of Things has proposed sharing information in objects, providing information and allowing devices to control themselves and others [28]. As a result of the evolution of technology areas such as electronics, sensors and embedded

systems, the Internet of Things has gained significant prominence in recent years for people and companies, whose interests converge in having greater practicality and economy in their daily activities [37], [36], [17], since interconnected equipment can reduce electrical consumption. However, Requirements Engineering (RE) faces a challenge with the fourth industrial revolution [19],[26].

Controlled by humans or other equipment connected to the same network, the definition of techniques to validate the requirements of these devices is important so that their operation can be guaranteed because the devices are mere data collectors, but they tend to have more intelligence and needs [26]. In addition, its rapid technological expansion does not advance in step with the legislation in force in many countries regarding issues of privacy and data security [12],[31], [5]. In the context of Requirements Engineering, the elaboration of a software documentation involving the concepts of Internet of Things demands special care due to its complexity [27]. Furthermore, the techniques for requirements validation in applications developed for the context of IoT are insufficient until this moment, compared to the rapid expansion of activities involving IoT devices.

In the scientific and commercial community, there is a great challenge in relation to the requirements validation processes and techniques using IoT device resources, mainly due to the possibility of data being inaccurate. Furthermore, the requirements validation techniques proposed in the literature are little applied in real world applications. Given this scenario, identifying in the literature and in the industry the most appropriate techniques to perform requirements validation in the context of Internet of Things will allow members of software development teams to perform requirements validation in a more effective and less error-prone way, especially in this current scenario we are living in and in the moment that IoT software has become even more important. Thus, the objective of this work is to investigate the processes and techniques existing in Requirements Engineering in the context of Internet of Things (IoT) to perform requirements validation and propose a guide to support practitioners in the area of software development in the context of IoT. In order to achieve this goal we carried out a literature review to investigate the existing requirements engineering processes in the context of IoT and the existing techniques to perform requirements validation in requirements engineering in the context of IoT. In addition, we propose a guideline with requirements engineering processes and techniques for validating requirements in the context of IoT, presenting its characteristics and suggestions for use. The guideline was validated through a survey.

Our main contributions were the construction of a *guideline*, available through an online portal, containing the requirements engineering processes proposed for the IoT context, as well as the existing techniques to perform requirements validation in the IoT context. The guideline will support software development team practitioners to find the processes and techniques existing in the literature in a single place. Furthermore, it will support them in choosing the techniques to be used in their daily activities, making it an important tool for Software Engineers.

2 Study Setting

We performed a literature review to identify Requirements Engineering processes and requirements validation techniques in the context of IoT. So, to achieve our goal we defined 03 research questions (RQ):

1. RQ.1. What are the requirements engineering processes in the context of IoT existing in the literature?
2. RQ.2. What are the techniques used to perform requirements validation in the context of IoT?
3. RQ.3 What is the perception of software development practitioners in relation to RE processes in the context of IoT and the techniques to perform requirements validation?

To answer the research questions RQ.1 and RQ.2, we performed a literature review update of previous work [29] and to answer RQ.3 we performed a survey containing 12 closed and 3 open questions (Table 2).

3 Results

In the literature there are several Requirement Engineering processes proposed to perform the requirements elicitation for applications in the context of IoT. Table 1 presents a synthesis of the requirements engineering processes identified in the literature for the context of IoT. These processes were proposed in order to reduce the gap in requirements engineering in the context of IoT.

3.1 RQ.1.

In the literature review, 22 Requirements Engineering processes were identified in the context of Internet of Things, as shown in Table 1. The processes were classified into seven categories according to the methodologies used by the authors.

1. **Diagrams:** In this category we place the existing processes in Requirements Engineering for the context of IoT that used UML diagrams and affinity diagrams. These diagrams were used by 50% of the identified processes [30], [7], [8], [4], [16], [10], [40], [20], [38], [41], [21];
2. **BPMN:** 18.2% of the identified studies used business process modeling [33], [35], [6], [14] to elicit, analyze and validate requirements in the context of the IoT;
3. **Diagrams and Templates:** The use of templates together with UML diagrams corresponded to 9.1% of the processes identified in the literature review [13], [34];
4. **Goal Model:** In this category, the use of the Goal Model - or Objectives Model - corresponded to 9.1% of the identified processes [39], [9];

5. **CORE, Diagrams and Goal Model:** The authors used CORE to propose a process for eliciting, analyzing and validating software requirements in the context of IoT. The authors used the UML and Goal Model diagrams, corresponding to 4.5% of the identified processes [15];
6. **Templates:** 4.5% of literature studies used templates to perform the specification and analysis of software requirements [22];
7. **5W1H:** Finally, the 5W1H methodology was used in only one of the identified works, corresponding to 4.5% of the identified processes [24].

Table 1: Requirements Engineering Processes in the IOT context

ID	Reference	Process Summary
E1	[33]	The authors proposed an RE process in the context of IoT composed by three sub-processes: 1) Definition of the project scope; 2) Definition of the IoT system; and 3) Definition of requirements for the IoT system. The authors used Business Process Model and Notation (BPMN) to model the process.
E2	[30]	The authors proposed the IoTReq, a process for requirements elicitation and specification in IoT systems. The IotReq is composed of three steps: 1) Construction of a model for the IoT domain; 2) Schematic model for visualizing the system's goals/relations and; 3) Finally, the specification of strategic, operational and strategic objectives. The authors used UML diagrams.
E3	[13]	The authors proposed TrUStAPIS to perform requirements elicitation and specification. The process is divided into seven domains: usability, identity, security, availability, privacy, protection and reliability. The authors used UML templates and diagrams.
E4	[35]	The authors proposed the REM4DSPL, a method for RE for the Dynamic Software Product Line (DSPL). The process has the following phases: 1) Requirements Elicitation; 2) Requirements Specification; and 3) System mutability management. The authors used BPMN.
E5	[7]	The authors proposed SysML4IoT to perform requirements specification and modeling in the context of IoT, as well as system modeling and design. The authors used UML diagrams and the standard ISO/IEC/IEEE15288:2015.
E6	[8]	The authors proposed the IoT-RML, a process to support requirements specification in IoT systems. The IoT-RML can be used to specify functional requirements as non-functional (Quality of Service) and uses the SysML language to represent the models used in the process and UML diagrams.

E7	[4]	The authors used Design Science and the ThinkLets tool to propose a tool to create detailed documentation for IoT systems. The tool uses 5 parameters: 1) Role distribution; 2) Analysis of roles; 3) ThinkLet PopCornSort to establish relationships and dependencies on use cases; 4) Description and development; and 5) Evaluation. The authors used UML diagrams and Brainstorming.
E8	[16]	The authors proposed a tool using the concept of *smartness* and UML diagrams. The proposed framework has five steps: 1) Identification of Stakeholders; 2) Requirements Elicitation; 3) Requirements Analysis; 4) Requirements Specification; and 5) Methods.
E9	[10]	The authors proposed a RE process for IoT using Design Thinking and described a method for requirements elicitation and design using the user journey technique and affinity diagrams. The authors proposed the use of existing tools, such as IoT Design Deck; Tiles IoT TookKit; and IoT Service Kit.
E10	[24]	The author proposed a framework using the 5W1H methodology with three steps: 1) Conception, with subroutines – Characterization, Concerns, Investigation of facets and Proposal of a framework; 2) Development, with the subroutines – Construction of the knowledge base, Project definition, and Definition of engineering guidelines; 3) Evaluation, with the subroutines – Feasibility and Observations.
E11	[22]	The authors proposed a process to analyze and specify non-functional requirements for IoT systems. The proposed framework performs the analysis of non-functional requirements from three perspectives: performance, storage capacity and maintenance limitations. The authors used templates and checklists.
E12	[40]	The author proposed a framework to support the joining of different use cases of an IoT system. The framework has three phases: 1) Identification of the interaction between use cases; 2) Identification of coordination; and 3) Impact identification. The author used UML diagrams and checklists.
E13	[39]	The authors proposed a model for integration and analysis of space-time requirements in systems development in the context of IoT. The authors used Goal Oriented Requirements Engineering (GORE) and Goal Models to represent the Keep All Objectives Satisfied (KAOS) object models.
E14	[34]	The authors proposed the Requirements Engineering process for IoT-based Software Systems (RE_{IoT}). The process has 4 steps: 1) Conception; 2) Requirements Elicitation in IoT; 3) Validation and Negotiation (performed in parallel); and 4) Analysis, Specification and Verification in IoT. The documentation was prepared using templates and use-case diagrams, and the techniques $SCENARI_{oT}$ [27] e $SCENARIoTCHECK$ [37].

E15	[20]	The authors proposed the IoT Composer comprising the stages of design, composition and development using a web interface for end users to design intelligent IoT systems even without programming experience. The process consists of four steps: 1) Selection of objects; 2) Programming the code; 3) Checking; and 4) Plan generation and implementation. The authors used UML diagrams.
E16	[38]	The authors proposed a process using UML diagrams, User Experience Design (UXD) and UX requirements to perform system requirements specification in the context of IoT.
E17	[41]	The author reinforced key issues for the development of an IoT system and proposed a process with phases: 1) Stakeholders and Users; 2) Requirements elicitation and analysis; 3) Groups and coalitions; 4) Avatar; and 5) Smart Things. The author used UML diagrams.
E18	[6]	The authors proposed a process to identify non-functional requirements capable of cataloging eventual conflicts and providing a better system experience for end users, according to their hierarchy. The process consists of 5 steps: 1) Selection of a quality characteristic to be analyzed; 2) Refinement of the quality feature into sub-features; 3) Identification of methods for the subtrait; 4) Analysis of correlations; and 5) Knowledge storage for a catalog. The authors used BPMN.
E19	[9]	The authors proposed an Objectives Model to illustrate the functionality of a system. The model is based on emotions and has the following steps: 1) Requirements capture – using role models, goal model, motivational scenarios, interaction model, scenario models and behavior model; 2) Requirements modeling; 3) Design and development; and 4) Evaluation. The authors used questionnaires.
E20	[14]	The authors carried out a study in relation to publications that already exist in the literature that use System Development Methods (SDM) in the context of IoT. The authors used BPMN.
E21	[21]	The authors proposed a method with three categories: tracking people, tracking equipment, and tracking people and equipment simultaneously. The authors used the UML diagrams and the technique (*rich picture*).
E22	[15]	The authors proposed a methodology to carry out the requirements elicitation and analysis using the Capacity Oriented Requirements Engineering (CORE) with the phases: 1) Elicitation of information; 2) Modeling of business requirements; and 3) Modeling system requirements. The authors used UML diagrams and Objective Models.

3.2 RQ.2.

In the literature review, 8 requirements validation techniques were identified in the context of IoT:

1. **Use cases:** The use of the use case technique to perform requirements validation in the context of IoT corresponds to the percentage of 11.1% of the studies identified in the literature review [3];
2. **Test Cases:** The use of this requirements validation technique within the IoT scope, mainly aimed at industries, corresponds to 11.1% of the identified studies [2];
3. **Scenario:** The use of scenarios as a requirements validation technique within the scope of IoT corresponds to the percentage of 11.1% of the studies carried out [36];
4. **Checklist and Use Cases:** The use of checklist as a requirements validation technique, combined with use cases, corresponds to 11.1% of the studies identified in the literature [40];
5. **Checklist and Scenario:** The use of two requirements validation techniques in Internet of Things represents the percentage of 11.1% of the studies carried out [37];
6. **Scenario and Persons:** In the literature review, we identified only one study that used the Scenario technique (iterative flows) and Personas, corresponding to 11.1% of the studies [27];
7. **Checklist:** Having the highest percentage among the publications reviewed, the percentage of 22.2% corresponds to studies that used checklist as a validation technique for IoT [25], [22];
8. **Questionnaire:** The use of questionnaires as a requirement validation technique in the context of the Internet of Things corresponds to the percentage of 11.1% of the identified studies [9].

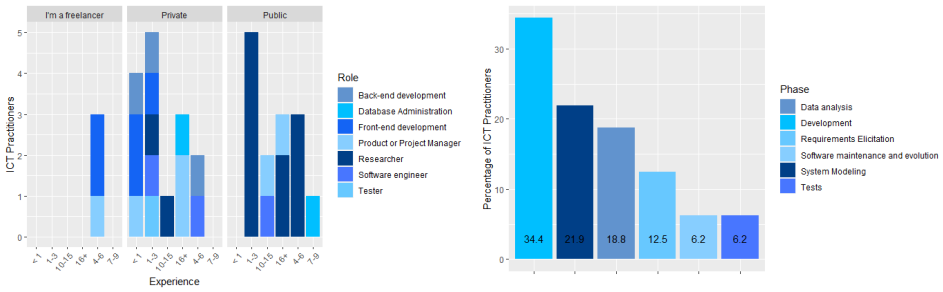
3.3 RQ.3.

To answer this research question, we conducted a survey containing 12 closed and 3 open questions. The survey was sent to researchers, IoT practitioners - especially startups - and IoT enthusiasts. Table 2 presents the questions addressed in the survey. The Survey was available online for 6 weeks. The average time to answer the survey was 12 minutes. In total, 32 practitioners responded to the survey.

37.5% of survey respondents are researchers in the area of software development and requirements engineering, 18.8% said they act as product or project manager, 15.6% act as front-end development, 9.4% of practitioners said they work as back-end development and 9.4% stated that they act as software engineer. 6.2% of practitioners stated that they act as a database administrator and only 3.1% act as a tester, as shown in Figure 1 (a). 31.2% of survey participants have between 1 to 3 years of experience in developing IoT applications, 25% said they have between 4 to 6 years, 18.8% have more than 16 years of experience, 12.5% have less of one year, 9.4% have between 10 to 15 years of experience and 3.1% of practitioners said they have between 7 to 9 years of experience. 46.9% of practitioners work in private organizations and 43.8% work in public organizations. 9.4% of practitioners work as a freelancer, as shown in Figure 1 (a).

Table 2. Survey questions

ID	Question
Q1	What's your e-mail address?
Q2	In which area do you work?
Q3	What is the nature of your organization?
Q4	How long have you been working with software development?
Q5	What phase of software development do you work at?
Q6	Do you or the company you work for use any process or technique to validate the requirements?
Q7	What do you use to elicit requirements?
Q8	What technique do you use to validate requirements?
Q9	Do you know any IoT-specific requirements validation process or technique?
Q10	If yes, which one?
Q11	Do you think that an RE process and an IoT requirements validation technique would be important for the quality of the application?
Q12	What are your challenges to requirements elicitation in the context of IoT?
Q13	Do you think a guide containing RE processes for IoT and requirements validation techniques would help you in developing an IoT system?
Q14	For what reason?
Q15	Do you have any suggestions about this guide?

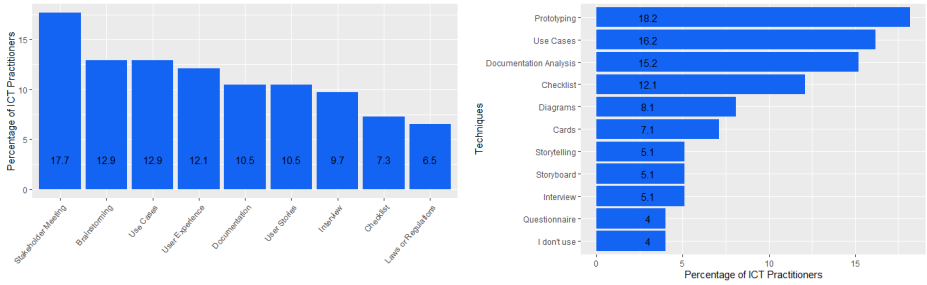


(*a*) (*b*)

Fig. 1. Figure (a) shows the Role, Nature of Organization and Experience, while (b) shows the phase of the software development process the practitioner ICT works on.

34.4% of survey respondents work in the Development area, 21.9% say they work with System Modeling, 18.8% work in Data analysis, 12.5% perform functions in the Requirements Elicitation area and, finally, the areas of Software maintenance and evolution and Tests correspond to 6.2% each one, as shown in Figure 1 (b). We also asked practitioners if they know about any RE process proposed for the IoT context or any requirements validation technique. Most IoT practitioners reported not knowing the processes and techniques available in the literature to support the requirements phase of projects in the context of IoT.

Regarding the requirements elicitation techniques used by practitioners, 17.7% of practitioners said they use the Stakeholder Meeting technique, 12.9% use Brainstorming and Use Cases, 12.1% use User Experience, 10.5% use the project documentation and User Stories, 9.7% use Interviews, 7.3% use checklist and 6.5% perform requirements elicitation using Laws or Regulations, as shown in Figure 2 (a). 18.2% of practitioners perform the planning and validation of software requirements in IoT using the Prototyping technique, 16.2% said they use Use Cases, 15.2% said they use Documentation Analysis, 12.1% use Checklist to validate requirements. Diagrams are used by 8.1% of practitioners, Cards by 7.1%, Storytelling, Storyboard and Interview by 5.1% respectively and Questionnaire by 4% of practitioners. 4% of practitioners stated that they did not use any technique to plan and validate the requirements, as shown in Figure 2 (b).



(a) (b)

Fig. 2. Figure (a) shows the technique used by IoT practitioners to requirements elicitation, while (b) shows the technique used to validate requirements by the practitioners.

We also asked if practitioners were aware of any requirements validation process or technique in the context of IoT. Three practitioners responded that they know the SCENARIoTCHECK and SCENARIoT technique, proposed by Souza [37] and Silva [27]. A practitioner claimed to know the checklist and prototyping techniques. Regarding the concerns of practitioners with the development of IoT software, involving aspects related to software requirements elicitation and validation, 20.2% of practitioners said they were concerned about Data Security, 16.3% said they were concerned about issues related to Privacy, 14% concerned about usability, 11.6% are concerned about adaptation for end Users, 10.9% are concerned about the possibility of Failures, 8.5% said they are concerned about Geo-locations issues and Legal issues. Accuracy is a concern of 7% of practitioners and 1.6% of practitioners are concerned with user identification by RFID and possibility of ambiguity, as shown in Figure 3.

According to the results obtained in the survey, we can conclude that the techniques most used by practitioners to perform the specification of require-

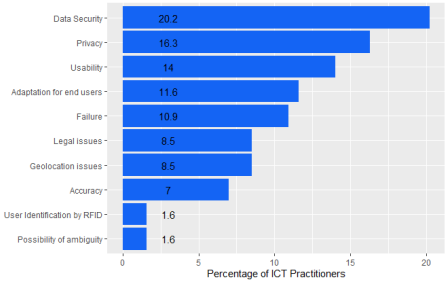


Fig. 3. Concern with the development of IoT software (involving validation, elicitation, etc.)

ments are stakeholders meeting, brainstorming and use cases and the techniques most used by practitioners to validate requirements are prototypes, use cases and documentation analysis.

4 Development of the Proposed Guide

The online guide is available in English and Portuguese and can be accessed via any electronic device. Its purpose is to serve as a basis for planning and developing Internet of Things applications. Considering all the requirements validation processes and techniques identified in this work, the processes and techniques were categorized according to the methodology used by the authors, including the name(s) of the author(s), a brief description and an address to the published work. According to our survey findings, the applications industry in the context of IoT, for the most part, does not use any methodology among those proposed in the literature. This result may be due to the difficulty in identifying in a single place the methodologies and techniques for requirements validating available in the literature and in identifying which of them can be useful for the context of the project developed by the organization. In order to minimize this gap, we propose the IoT-Guide, available and accessible through of the link: https://dsslucas.github.io/iot-guide/about.

In preparing the guide, we used the following resources: 1) the website was structured using the fifth generation of HTML, with the stylizations of the third generation of CSS [1]; 2) Bootstrap 5 framework [23]; 3) IDE Visual Studio Code [11]; 4) the guide was hosted on Github (`https://pages.github.com/`); 5) The tools Browser-sync (`https://browsersync.io/`) and Node.js (`https://nodejs.org/en/`) were also used. The guide's home page has general information about the Internet of Things, with links to the processes and techniques identified in the literature. In the initial menu, in addition to being able to access the English version of the guide, the end user will also be able to view the contacts of the people responsible for its creation, as shown in page Guide Home Screen at https://dsslucas.github.io/iot-guide/about.html.

On this page, all IoT Requirements Engineering processes identified in the literature review (Table 1) are categorized according to the methodology used by the authors. For each option selected, the end user will be able to view cards containing the title of the published study, its authors, a TAG symbolizing the technique used and a brief description of the study, as illustrated in page Processes: https://dsslucas.github.io/iot-guide/processes.html. In addition to this information, in the references of the studies, there is an appointment to access the publication through DOI, when available. The page Techniques: https://dsslucas.github.io/iot-guide/techniques.html presents the guide screen with the techniques used in the literature to perform requirements validation in the context of IoT. The techniques were also classified according to the type of technique used by the authors. For example, if the user selects the Checklist option, all studies that used checklists to perform requirements validation will be presented in a new screen for the end user. In the survey we asked practitioners what they thought of having a guide containing the processes of RE in the context of IoT and the techniques used by them to validate the requirements. 81% of practitioners said they thought it was important to have a guide to support them in their daily activities. Some reasons mentioned by practitioners were:

> *"A guide would help practitioners quickly to identify a set of techniques and processes available in the literature. One challenge I face with the software development teams I work with is that not all practitioners are well versed in the requirements engineering processes available to support requirements elicitation, analysis and validation phase activities".*

> *"It is important to have a guide with existing processes and techniques. In addition, if you have the report of the problems we may face during the requirements elicitation phase in software development, we can have more clarity in the choice of techniques, according to each project scenario".*

> *"Centralizing a guide of existing processes to carry out the elicitation and validation of requirements can facilitate our work and minimize errors, as most of the time we do not know the processes and techniques that can support us during this very important phase of the development process. software ".*

4.1 Threats to Validity

This research has some threats to validity. The first threat involves the processes identified in the literature, as we cannot guarantee that all studies were identified during the literature review. To minimize this threat, we monitor publications made up to a week before the completion of this survey. Another threat is related to the number of participants who responded to the survey. We know that there are works in the literature with a small number of respondents and that it is difficult to encourage practitioners to participate in this type of research. In order to minimize this threat, we contacted several companies that develop applications in the context of IoT to invite development teams to respond to

the survey. Some companies returned our e-mail, saying that they would not contribute to the survey due to internal political reasons (compliance rules or other contractual clauses). Therefore, the results obtained may not reflect the reality of all companies that develop applications in the context of IoT and thus, we cannot generalize our findings.

5 Conclusion

In this paper we have identified the requirements engineering processes and requirements validation techniques in the context of IoT through a literature review. The review served as the basis for the creation of the IoT-Guide, a guide that can be accessed on any electronic device and which is intended to assist software development teams in the context of IoT in requirements elicitation and validation activities in this context. We conducted a survey with practitioners in the field to identify their perception of the identified processes and techniques. With the result of the survey, we identified the need to propose a guide to support and guide practitioners working in IoT projects, since 50% of respondents said they were unaware of the existing processes and techniques to requirements elicitation and validation. Furthermore, more than 81% of the participants stated that a guide could help them in their daily activities. As future work, we intend to carry out a controlled experiment in two startups using some of the identified processes, as well as the techniques used in the literature to perform requirements validation, in order to verify how these processes can be applied in real scenarios.

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