Evaluation of Non-Functional Requirements for IoT Applications

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Abstract: Internet of Things (IoT) is a paradigm that enables physical objects to interact and to work together. IoT applications have particular characteristics, such as context-awareness, interconnectivity, and heterogeneity, and particular types of interaction, user interaction with devices (called human-thing interaction), and the interaction between devices (called thing-thing interaction). These characteristics represent the expectation around the system and are also known as Non-Functional Requirements (NFRs). So, during the requirements elicitation of such systems, they can appear as NFRs, and their combination often increases the complexity of the IoT application development and evaluation. Thus, this work aims to identify which approaches and NFRs have been considered in the literature to evaluate IoT applications and the main challenges faced by the evaluators. We use the systematic mapping methodology to provide a comprehensive view of approaches, methods, tools, and processes. As a result, we identified two tools, six approaches, one method, and one process that can be used to evaluate NFRs, a set of 42 NFRs that can be considered for IoT applications, and the main challenges related to the NFRs evaluation for the IoT applications.

1 INTRODUCTION

Internet of Things (IoT) can be defined as a paradigm where intelligent objects interact in an environment through a wireless connection, being able to cooperate to provide services and to achieve common goals (Atzori et al., 2010).

IoT applications are increasingly present in our daily lives, on the streets, in the malls, at work, or in our homes (Rowland et al., 2015). Users have been adapted themselves to the presence of devices that, through sensors, capture data about their environment, their health, their behavior, and learned to use the facilities provided by these solutions.

The growing presence around us of intelligent objects or things like smartphones, smartwatches, intelligent lamps, among others, shows that IoT has become a reality in our lives, being it in the industrial or personal context.

On the other hand, the way users interact with these solutions may differ from how s/he interacts with traditional applications.

IoT applications deal with countless other forms of interactions such as gestures, vocal commands, or the total absence of user actions (Rowland et al., 2015).

Besides the user interaction with devices (i.e., Human-Thing Interaction), IoT applications present a new type of interaction, the Thing-Thing Interaction, which is the interaction between intelligent objects. The connected devices relate without human intervention to perform a task (Andrade et al., 2017).

Moreover, IoT applications have particular characteristics, such as context-awareness, interconnectivity, and heterogeneity, that should be considered in the requirements elicitation and evaluation.

In this scenario, due to the inherent complexity of IoT applications, the traditional evaluation methods available in the literature may not cover all the quality properties that need to be considered. These quality properties or attributes are also known as non-functional requirements (NFRs) (Uckelmann et al., 2011).

NFRs can be defined as a description of a property or characteristic that a system must exhibit or a constraint that it must respect (Wiegers and Beatty, 2013).

Meeting the chosen NFRs is vital to the success of the software (Chung and Prado Leite, 2009). However, ensuring that the system meets NFRs is not a trivial task and there is a need to find out how NFRs...
of IoT applications have been evaluated.

Quality evaluation for IoT applications is a topic that has received attention from the scientific community. Kim (2016), for example, proposed a quality model for IoT applications and specific measures for this type of application.

Andrade et al. (2017) discuss how we can benefit from the ubiquitous field of systems interaction evaluation to evaluate interaction with IoT applications, focusing on both systems’ main differences and similarities and, Bures et al. (2020) present a set of quality characteristics for IoT applications which specifically emphasizes the aspects of security, privacy, reliability and usability.

However, we did not find out a work that summarizes how the evaluation of NFRs for IoT applications has been conducted. Thus, in order to contribute with the NFR evaluation field, this work aims to provide a comprehensive view on approaches, methods, tools, and processes used for the evaluation of NFRs for IoT applications as well as the main challenges faced by the evaluators.

For this, we apply the systematic mapping methodology, which is designed to give an overview of a research topic by classifying and counting contributions in relation to the categories of that classification (Petersen et al., 2015).

The remainder of this paper is organized as follows: Section 2 provides a theoretical background, discussing IoT challenges, and the non-functional requirements. Section 3 describes our methodology; Section 4 presents the results; in Section 5, we discuss the results; and in Section 6 we expose our final considerations and future work.

2 BACKGROUND

This study aims to provide an overview of how NFRs’ assessments have been conducted for the IoT applications. Therefore, we consider it appropriate to provide a theoretical foundation regarding the IoT and NFRs as follows.

2.1 Internet of Things

The term Internet of Things was introduced by Kevin Ashton in 1999 and was associated with RFID technology (Ashton, 2009).

Since then, the purpose and use of this technology have evolved, and today IoT can be defined as a paradigm where smart objects interact in an environment through a wireless connection, being able to operate in providing services and achieving common goals (Atzori et al., 2010).

IoT can be considered an extension of Ubiquitous Computing (Carvalho et al., 2020), which refers to devices connected everywhere in such a transparent way that we will not realize they are there (Weiser, 1991).

Due to their similarities, such as mobility and context-awareness, the artifacts that come from Ubiquitous Computing are suitable for IoT applications (Andrade et al., 2017). Therefore, in this work, we consider the NRFs focused on Ubiquitous Computing as suitable for IoT applications.

On the other hand, IoT applications have also some singularities, such as interconnectivity, heterogeneity, and services related to objects.

We present then the following list of IoT features and their definitions (Patel et al., 2016):

- **Interconnectivity:** In IoT applications, different objects can be connected, sharing information within a communication infrastructure.
- **Object-related Services:** IoT applications can provide services related to the objects that integrate the solution, such as privacy protection and semantic consistency between objects.
- **Heterogeneity:** An IoT application is composed of heterogeneous devices, both in aspects related to hardware and aspects related to how they were implemented. However, these devices can interact with other devices or service platforms through different networks.
- **Dynamics:** The state of devices and the context changes dynamically. Devices can, for example, be connected or disconnected, vary in location, have their settings changed, among others. The number of devices that makes up an IoT application can also vary dynamically, depending on the environment and other entities’ presence (for example, objects and people).
- **Scalability:** IoT applications provide the recognition of each object that makes up a solution and ensure communication between them. Since the number of objects that makes up an IoT solution can vary, the system must remain operational regardless of the number of connected objects.
- **Security:** IoT applications must be designed with the security of their use in mind; this includes personal data and their user’s well-being.
- **Interconnectivity:** Allows network access and devices’ ability to consume and produce data within an IoT solution.
Limitations related to these features diminish their potential and impact usability (Rowland et al., 2015). Therefore, it is critical to ensure that these properties are performing as expected in IoT applications.

2.2 Non-Functional Requirements

Non-Functional Requirements (NFRs) can be defined as requirements that are not directly related with specific functionalities offered by the software. They can be related to the emerging properties of the system, such as Reliability and Security (Sommerville, 2011).

According to (Wiegers and Beatty, 2013), quality characteristics are also known as a type of NFRs and they describe the product’s characteristics in various dimensions considered important by the stakeholders, such as security and usability.

Thus, the software quality assurance demands that quality characteristics (or NFRs) are specified, measured, and evaluated, whenever possible, using validated or widely accepted measures and measurement methods (ISO/IEC 25000, 2011).

Another important point to stress in this paper concerning the evaluation of NFRs is that they can be correlated, which means that one NFRs can has a impact in another one. This impact could be positive (helps) or negative (hurts) (Wiegers and Beatty, 2013).

3 METHODOLOGY

As we mentioned in the introduction section, this research aims to identify tools, methods, approaches, and processes for evaluating NFRs in IoT applications.

To this end, we conducted a systematic mapping of the literature (SML), following the guidelines proposed by (Kitchenham and Charters, 2007), which divides the research conduction into three stages: Planning (Section 3.1), Conduction (Section 3.2), and Analysis and Reporting (Section 4).

3.1 Planning

In the first stage of the SML methodology, we set up all the research parameters for conducting the research in a document called the research protocol. In this protocol, we defined the research questions, the search strategy, the selection criteria, and the data to be extracted.

3.1.1 Research Questions

According to the aim of this study, the following research question was defined:

**RQ1 - How Are the Non-Functional Requirements Evaluations Conducted in IoT Applications?**

To better answer this question, we had also defined a set of secondary questions as follows:

- **SQ1** - Which are the approaches, tools, methods, and processes used to evaluate non-functional requirements in IoT applications?
- **SQ2** - Which are the non-functional requirements observed when evaluating IoT applications?
- **SQ3** - Which are the challenges faced when evaluating non-functional requirements?

3.1.2 Search Strategy

The first step in selecting the papers that answered our search questions was to conduct an automated database search.

For this, we used PICO (Population, Intervention, Comparison, and Outcomes), which is a strategy suggested by Kitchenham and Charters (2007) to identify keywords related to the defined search questions for the search string.

- **Population:** In software engineering, the population can represent a specific software engineering function, an application area, or an industry group. In our context, the population was defined as IoT applications, and we also considered ubiquitous and pervasive systems due to their similarities;

- **Intervention:** Intervention is defined with the methodology, tool, technology, or software procedure used to address a specific issue. In our case, the intervention was defined as the non-functional requirements;

- **Comparison:** Comparison can be defined as the methodology, tool, technology, or procedure with which the intervention is being compared. For this research, we do not define elements of comparison;

- **Outcome:** Outcomes should relate to factors of importance to practitioners in the study area. In our case, we selected terms that represented evaluation approaches as outcomes.

For each PICO element, we also selected synonyms to minimize the risk of restricting the search results. Table 1 shows the terms chosen by each category.
Table 1: Selecting search terms.

<table>
<thead>
<tr>
<th>PICO Strategy</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>AND (method OR tool OR technique OR approach OR process)</td>
</tr>
<tr>
<td>Intervention</td>
<td>(evaluation OR assessment OR verification OR validation)</td>
</tr>
<tr>
<td>Comparison</td>
<td>No terms selected</td>
</tr>
</tbody>
</table>

When connecting the search terms with logical operators, we elaborated the following search string:

("Internet of Things" OR IoT OR "Pervasive*" OR "Ubiquitous") AND ("non-functional requirement*" OR nfr OR "non-functional property" OR "quality characteristic*" OR "quality factor") AND (evaluation OR assessment OR verification OR validation) AND (method* OR tool* OR technique* OR approach* OR process*)

3.1.3 Research Sources Selection

We applied the search string in two databases that were chosen due to their good coverage and stability: Scopus and Web of Science. Therefore, Scopus incorporates other important bases for the Software Engineering field, such as ACM and IEEE. In addition, we also performed a snowballing forward procedure, which means identifying new papers based on a set of papers that cite the paper being examined (Wohlin, 2014).

3.1.4 Study Selection Criteria

We selected for this research, papers that present tools, approaches, methods, or processes for evaluating non-functional requirements for IoT applications. As for time range, once IoT was first cited in 1999 (Ashton, 2009), articles published between 2000 and 2019 were included in the current research. To ensure the correct interpretation of our research results and the replicability of the study, we limited our search to papers written in English.

Regarding the exclusion criteria, we did not consider eligible for this research papers that:

- are secondary or tertiary works;
- are books, technical reports, white papers, short papers (less than 5 pages);
- are not available for download; and
- do not present tools, approaches, methods, or processes of non-functional requirements evaluation for IoT applications.

3.1.5 Data Extraction

After we select the studies, they were submitted to the data extraction step that consists of exploring the work selected to extract information that will help us to answer our research questions.

Table 2 presents the data to be extracted in the selected papers.

3.2 Conducting

This conducting stage was divided into two steps. First, we applied the search string in the Web of Science and Scopus databases. We selected the papers through the study selection criteria. At the end of this process, we obtained a set of approved papers. Then, we used the selected papers to apply the snowballing forward procedure (Wohlin, 2014).

3.2.1 First Step: Search on Databases Sources

We started by applying the string search to the selected databases.

The search string returned 174 papers, 121 by Scopus and 51 by Web of Science. After removing 49 duplicated studies, we obtained 125 papers for the title/abstract screening. At this step, we excluded 88 papers based on our study selection criteria. Thus, we got a set of 37 papers eligible for the entire reading.
Table 2: List of data to be extracted.

<table>
<thead>
<tr>
<th>Data extraction form</th>
<th>Study metadata</th>
<th>Approaches, methods, tools, or process</th>
<th>Type of system</th>
<th>NFRs</th>
<th>Evaluation focus</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Title, authors, and year of publication.</td>
<td>Strategy adopted to evaluate the NFRS.</td>
<td>Ubiquitous System or IoT application.</td>
<td>The NFRs evaluated. System in development, system implemented or both.</td>
<td>The challenges on evaluating NFRs reported within the paper.</td>
<td></td>
</tr>
</tbody>
</table>

After downloading and reading the full text of the 37 papers, we excluded 27 papers that had not answered our research questions. Thus, we got a set of 10 papers for data extraction.

3.2.2 Second Step: Snowballing Forward

To complement the search results through the databases, we decided to perform the Forward Snowballing procedure, which consists of choosing key papers from the study area and analyzing the papers that have cited them (Wohlin, 2014).

For this research, we analyzed the citations referring to the 10 papers selected during the first phase. We performed these search through Google Scholar by searching for each key paper, and then for all the papers that cited them.

Thus, 80 papers were identified and submitted to the same steps and study selection criteria used in the first stage. At the end, we excluded 78 papers that did not answer our research questions and selected 2 papers for data extraction.

4 RESULTS

This section describes the third step of our SML (i.e., Analysis and Reporting), where we analyzed and summarized the research results to answer the research question: RQ1 - How are the non-functional requirements evaluations conducted in IoT applications?

Since we highlight the singularities of IoT applications, it is necessary to understand how these solutions have been evaluated.

Finally, we selected 12 documents for data extraction, following the data extraction form. After that, we analyzed the results and answered our research questions. Table 3 shows the final set of studies and their respective ID.

Table 3: List of final set of studies.

<table>
<thead>
<tr>
<th>ID</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>(Ruiz-López et al., 2012)</td>
</tr>
<tr>
<td>S2</td>
<td>(Ruiz-López et al., 2013)</td>
</tr>
<tr>
<td>S3</td>
<td>(Kim et al., 2017)</td>
</tr>
<tr>
<td>S4</td>
<td>(Rocha et al., 2017)</td>
</tr>
<tr>
<td>S5</td>
<td>(Munnelly and Clarke, 2008)</td>
</tr>
<tr>
<td>S6</td>
<td>(Jazdi et al., 2016)</td>
</tr>
<tr>
<td>S7</td>
<td>(Ruiz-López et al., 2013)</td>
</tr>
<tr>
<td>S8</td>
<td>(Badii et al., 2018)</td>
</tr>
<tr>
<td>S9</td>
<td>(Ghasemi et al., 2019)</td>
</tr>
<tr>
<td>S10</td>
<td>(Chauhan and Babar, 2017)</td>
</tr>
<tr>
<td>S11</td>
<td>(Filho et al., 2020)</td>
</tr>
<tr>
<td>S12</td>
<td>(Alegre-Ibarra et al., 2018)</td>
</tr>
</tbody>
</table>

Figure 1 represents the PRISMA Flow Diagram (Moher et al., 2009) that describes the process adopted to conduct this research and its results.

Figure 2 and Figure 3 show, respectively, the distributions of studies by the type of systems that they were focused on and the type of NFR evaluation, if they were focused on systems in development or systems already implemented.

SQ1 - Which Are the Approaches, Tools, Methods, and Processes Used to Evaluate Non-Functional Requirements in IoT Applications?

We identified 2 tools, 6 approaches, 1 method, and 1 process that can be used for the evaluation of NFRs. Table 4 presents the strategies identified for evaluating NFRs in IoT systems.

SQ2 - Which Are the Non-Functional Requirements Observed When Evaluating IoT Applications?

Once we understood what had been used to conduct the evaluations, it is important to identify if the eval-
ators had considered specific NFRs to evaluate IoT applications.

We found 7 studies that described one or more NFRs as suitable for evaluating ubiquitous systems or IoT applications.

A total of 42 NFRs were identified. Table 5 shows the list of NFRs considered during quality evaluations in IoT applications.

**SQ3 - Which Are the Challenges Faced When Evaluating Non-Functional Requirements?**

By analyzing the final set of studies, we also identified some challenges concerning the evaluation of NFRs in IoT applications.

The most recurrent challenge is the necessity to deal with context-awareness. Other problems are the lack of a systematic approach and appropriate methods for evaluating non-functional requirements in IoT applications.

## 5 DISCUSSION

We performed a systematic mapping to answer the following primary research question: How are the non-functional requirements evaluations conducted in IoT applications?

Moreover, to better address the aspects involved in this question, we decided to divide this macro question into three secondary questions (SQs). The answers came from a detailed analysis of 12 out of 174 papers returned from the search in databases and the snowballing forward application.

Regarding SQ1, we noticed that most of the approaches, methods, and tools are focused on the requirements elicitation stage and not on evaluating if the IoT systems meet the NFRs previously established.
Also, we only identified one process by this research, MD-UBI (Ruiz-López et al., 2013). This process was defined to support developers and evaluators in elicitation, representation, and evaluation of requirements, focusing on NFRs. This process is model oriented and aims to develop high-quality Ubiquitous Systems, covering the entire software development lifecycle.

Regarding to SQ2, we identified 42 non-functional requirements.

Among the 42 NFRs identified, 14 of these are present as characteristics and sub-characteristics in the quality models proposed by ISO/IEC 25000 (2011).

- System/software product quality: adaptation, availability, ease of use, interoperability, maintainability, modifiability, performance, reliability, reusability, security, testability and usability.

- Quality in use: efficiency and effectiveness.

Two of the selected papers have also cited 27 quality characteristics for ubiquitous systems. This set is proposed by Carvalho et al. (2017) and has some characteristics in common with the two quality models proposed by ISO/IEC 25000 (2011), but it contains specific characteristics for ubiquitous systems:

- Acceptability, attention, calmness, context-awareness, device capability, familiarity, interconnectivity, mobility, network capability, predictability, privacy, robustness, security, scalability, simplicity, transparency, trust, user satisfaction, and utility.
Given the similarities between IoT applications and ubiquitous systems, the use of this set of quality characteristics is also applicable for conducting quality evaluations on IoT systems. The most evaluated NFR was Scalability, which is the ability to provide services to a few or a large number of users (Carvalho et al., 2017). Scalability was considered an important NFR to evaluate by 41.6% of the studies (5 papers). Another NFR identified is related with scalability:

- Elasticity: The ability of the system to provide particular service on demand during a time interval (Chauhan and Babar, 2017).

Availability, reliability, security and usability were also highlighted. They were both cited by 33% of the studies (4 papers).

For SQ3, we identified that the most significant challenge when evaluating IoT systems is the context-awareness, which is the system’s ability to discover and take advantage of contextual information such as user location, time of day, and user activity (Musumba and Nyongesa, 2013). Thus, it is necessary to ensure that the system correctly identifies the contextual information, so the users will be benefited instead of affected by this non-functional requirement.

Another challenge is the lack of specific approaches for the evaluation of NFRs in IoT applications. This result is in line with the discussion held at SQ1, where we identified only 3 studies that focused on the evaluation of NFRs satisfaction and only one process that has a step to evaluate NFRs in the final product.

6 CONCLUSION

IoT applications are gaining more and more space in our daily lives. Therefore, it is necessary to look at how these solutions have been evaluated, mainly concerning non-functional requirements, because they are directly related to the software quality evaluation and the user expectations through the system. In this work, we perform a systematic mapping on the evaluation of non-functional requirements in IoT systems to provide a comprehensive view about this field.

As the main contributions, we identify artifacts (tools, methods, approaches, and processes) to evaluate NFRs and we perceived the lack of artifacts and systematic approaches to evaluate whether IoT applications satisfy the previously established non-functional requirements or not.

We also identified 42 NFRs that can be considered to design and evaluate of IoT applications. Most existing artifacts are focused on the usability and reliability of the solutions, which may represent a concern about how the users interact and how they relate to IoT applications.

As future work, there is a need to develop and validate a process to systematize the NFR evaluation steps for IoT applications with a particular eye to the human-thing and thing-thing interactions.

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REFERENCES


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on Aspects, Components, and Patterns for Infrastructure Software, ACPAIS ’08, New York, NY, USA. Association for Computing Machinery.


nfrs related to user interaction. In 2020 IEEE 28th International Requirements Engineering Conference (RE), pages 102–112. IEEE.


