Designing for Quality in IoT: A User-Inclusive Approach to Non-Functional Requirements

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***Abstract*—The complexity of Internet of Things (IoT) systems highlights the critical need to address Non-Functional Requirements (NFRs) early in the development lifecycle. NFRs are essential to ensuring quality, yet they are often overlooked in favor of achieving core functionality. This paper presents an approach to elicit NFRs in an IoT context, using a pilot implementation in a vocational education setting focused on the food industry. The pilot of our approach demonstrated the importance of addressing the NFRs separately from functional requirements, raising new insights among participants. Role identification of stakeholders, interview structure and preciseness of documentation needed clarification after the pilot. Feedback from participants showed that the process not only captured key quality attributes but also fostered deeper understanding among stakeholders.**

Keywords-requirements engineering; Internet of Things; IoT systems; quality.

I. INTRODUCTION

The rapid expansion of Internet of Things (IoT) technologies has underscored the critical importance of non-functional requirements (NFRs) in system design and implementation. Unlike functional requirements, which describe what a system should do, NFRs – such as scalability, reliability, security, interoperability, and maintainability – define how a system performs under various conditions. They determine the crucial quality characteristic of an IoT system. In the IoT contexts, where heterogeneous devices, real-time data, and resource constraints are prevalent, the identification and specification of NFRs are particularly complex and could be insufficiently addressed during early development phases, because most attention is often focused on getting the system operational in the first place. This oversight can lead to costly redesigns or system failures.

The IoT context introduces challenges associated with eliciting and specifying non-functional requirements. It examines the specific nature of such systems, and involvement of diverse stakeholders in the requirements gathering process. Understanding these challenges is essential for improving engineering practices and ensuring that IoT systems meet not only their intended functionalities but also quality expectations in real-world environments.

This paper reports our experiences in *IoT Learning Environment* project, which aims at increasing students' knowledge of IoT technologies and their application in different domains. We conducted our experiment in the vocational education department specializing in the food industry.

The food industry exemplifies an environment where monitoring dynamic conditions – such as temperature, air quality, hygiene, and equipment status – is critical. Many of these conditions are also subject to strict regulations, such as mandated temperature ranges for food preservation or time limits for cooling prepared food. IoT technologies enable continuous monitoring and visualization of operational conditions. By embedding sensors and connected devices within the learning environment, IoT systems can collect and transmit data that reflect real-time conditions, providing more immersive and data-driven educational experiences for students of the food industry, thus enhancing learners' understanding of quality and safety parameters related to their work.

We first created an approach to gather non-functional requirements through stakeholder interviews, based on experiences reported in literature. Once the process was defined, we conducted a pilot run in a real-world setting to evaluate its practicality and to obtain feedback for improving the process. Following the pilot, we organized a postmortem analysis involving key participants to reflect on outcomes, and to identify challenges and deviations from the intended process.

The remainder of this paper is organized as follows. Section 2 briefly summarizes research carried out in the area. Section 3 summarizes special characteristics of IoT systems that need to be addressed when gathering NFRs. Section 4 depicts our approach for gathering the NFRs in the IoT context. Section 5 summarizes the observations from a pilot run of the process. Section 6 concludes the paper.

II. RELATED WORK

The elicitation of non-functional requirements in the IoT context has not received much attention in research. Most of the studies concentrate on understanding functional requirements, and a typical method for gathering those is through user scenarios use cases. For functional requirements engineering, formal approaches have been introduced, such as the four-phased model-driven development methodology for IoT applications introduced by Sosa-Reyna et al. [1] and UML-based requirements and specification method called IotReq [2], but methods, tools and techniques for eliciting non-functional requirements for IoT systems are limited.

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According to Gupta [3], non-functional requirements, such as performance, reliability, availability, scalability, maintainability, security and privacy, may have crucial impact on success of adopting the edge computing paradigm within the IoT systems. Paiva et al. [4] have recognized the lack of methods for evaluating NFRs in IoT context and the need for developing systematic approaches to target NFRs for IoT applications.

Mahalank et al. [5] propose a checklist and a template for documenting non-functional requirements for smart traffic management system. Brito et al. [6] describe a procedure for eliciting NFRs in the context of a smart city project providing electric bicycles to the academic community. Tabassum [7] suggests an approach extending use case models, soft goal models and behavioural models for addressing non-functional requirements, especially interoperability and context-awareness for IoT systems, in order to increase the adaptability.

IoT systems are often under pressure to achieve rapid time-to-market. Furthermore, they are commonly developed with agile methods, which utilize user stories for gathering requirements. User stories emphasize functionality, and quality attributes (NFRs) may be even ignored. Sachdeva and Chung [8] state that NFRs should be introduced early in the software lifecycle, including in projects involving cloud and IoT. They also emphasize the importance of quantifying the requirements and setting clear acceptance criteria for them.

Tools to automate requirements elicitation have also been presented. For example, Khurshid et al. [9] introduce a machine learning algorithm to extract the non-functional requirements from documentation, in order to reduce the possibility of missing NFRs during the requirements engineering phase, and to promote security and performance of healthcare systems utilizing IoT.

Security is the most frequently addressed quality characteristic of IoT applications. Alhirabi et al. [10] surveyed the empirical research on security and privacy requirements for IoT, and concluded that using human-centred design might help in integrating these capabilities into systems. They also identify several challenges related to privacy in IoT systems, including the lack of tools, methods and notations for modeling these quality attributes.

III. Non-functional requirements in IoT Context

Non-Functional requirements are the quality attributes that the system must conform to, often referred to as -ilities. They describe how the system should work and consist of qualities that can be observed at run time, such as usability or security, and qualities that are embodied in the system structure, such as testability, scalability or extensibility. Defining non-functional requirements in a measurable way is necessary to determine whether the development work has achieved its goals. [11]

IoT systems tend to be more complex than traditional software or embedded systems, since they consist of a variety of hardware and software components, services and communication solutions. There may be a vast number of combinations involving wireless and wired sensors, actuators, networks, and smart objects – each with varying levels of computing capability. Stakeholders from different groups may access the system in completely different ways, using varying devices and services, which can potentially cause conflicts in requirements specification [12].

IoT systems typically evolve or change during their life cycle, as more advanced technology becomes available and new features are requested by the users. Finally, certain constraints and external factors must be addressed—such as ensuring the privacy of users' personal data, dependencies on specific service providers, and the limitations of existing infrastructure. Figure 1 summarizes the special characteristics of IoT systems. In the figure, the main issues – change, complexity and constraints – are exemplified with a few characteristics that distinguish the development of IoT systems from that of traditional systems.

Figure 2 summarizes the quality attributes that address the challenges set by change, complexity and constraints. Of course, all aspects of quality need consideration, but attributes listed here can be straightforwardly derived from the characteristics of IoT systems. Evolving user needs require flexibility in interaction, and technology upgrades emphasize the need for scalability and maintainability. To improve system understandability, analyzability should be addressed. Integrations to external services require interoperability, and modularity makes the system architecture extendable and manageable. Performance efficiency, security and reliability help in dealing with technological and regulatory constraints.

IV. The NFR Gathering Process for IoT

Figure 3 depicts the process that we have used in our project to gather non-functional requirements. The first phase involves inviting stakeholders from different groups to an interview. The participants should be able to represent views of future users, maintainers and business owners. After the interview, the results are analysed and summarized by the development team. Interpretations and the summary report are validated in a workshop. If all stakeholders have common view of the requirements, they are documented and signed off.

A. The Interview

We created a set of interview questions to elicit non-functional requirements related to the quality attributes identified earlier: interaction capability, maintainability, scalability, analyzability, interoperability, modularity, performance efficiency, security and reliability. Since discussions with stakeholders in IoT projects often focus on the measurements and data, these NFRs often remain implicit unless explicitly addressed during requirements elicitation. We decided to use open-ended questions to encourage detailed responses. Questions were be designed to uncover constraints, expectations, and existing practices, enabling the development team to translate qualitative insights into measurable system attributes. We derived the questions from experiences and documentation

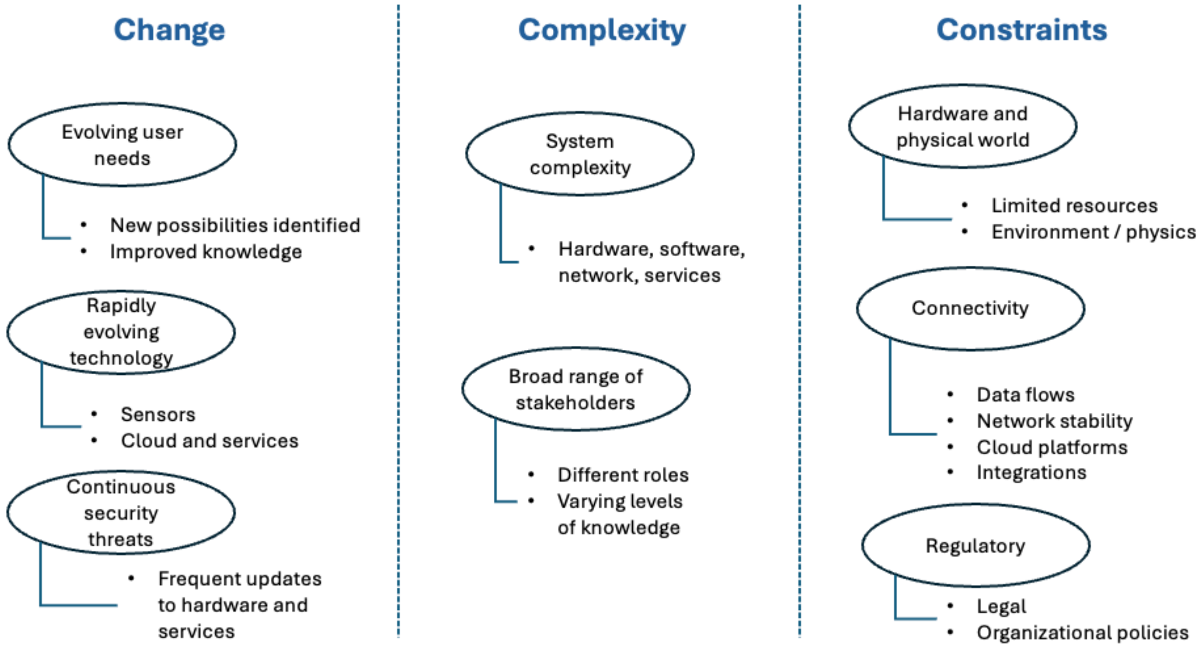

Figure 1. Characteristics of IoT Systems.

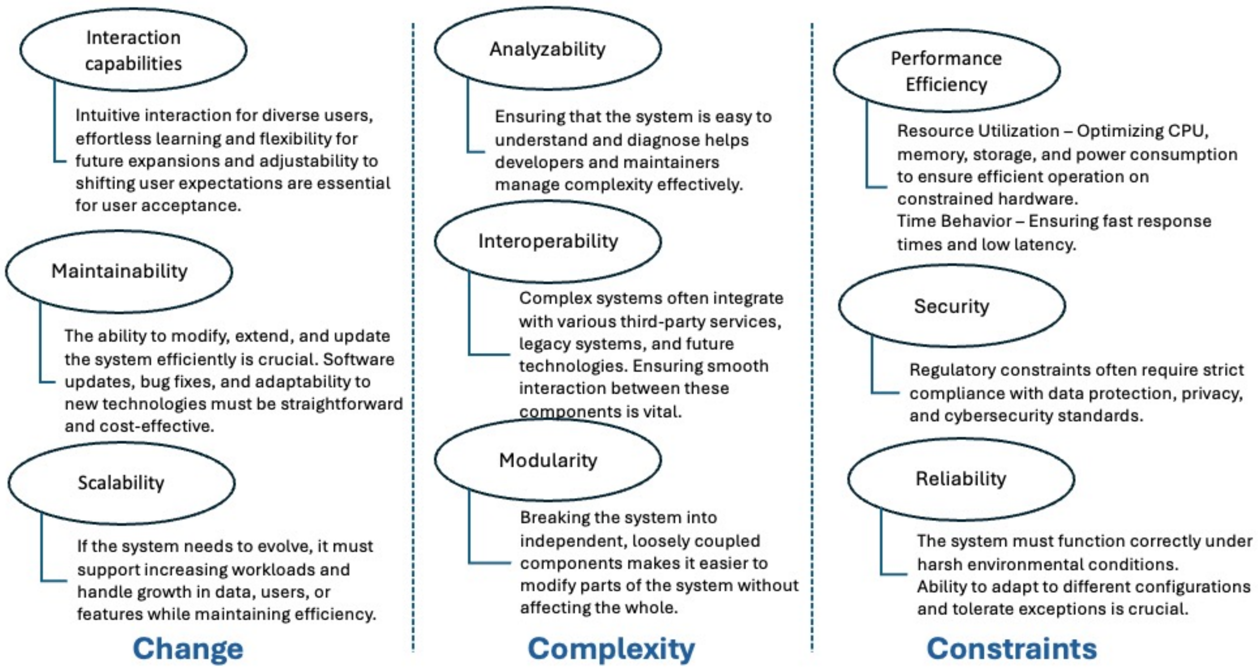

Figure 2. Quality attributes to address in IoT system design.

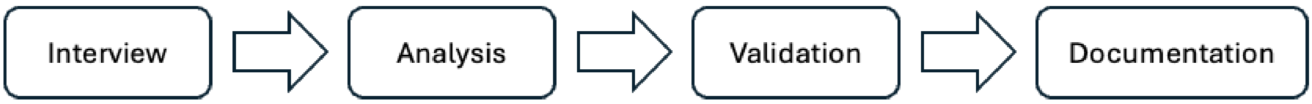

Figure 3. Process of Gathering Non-Functional Requirements.

from dozens of sensor network projects previously implemented in collaboration with the local industrial and educational partner organizations. We focused on operational goals, environmental constraints and stakeholder needs to ensure alignment with technical feasibility and real-world deployment challenges.

To assess interaction capability, questions focus on user interface expectations, system responsiveness, exceptional situations, and means to interact with the system. For maintainability, questions explore how frequently the system is updated and what documentation practices have to be followed. Interoperability questions focus on data exchange standards, third-party system integration, and API usage. Security is addressed by inquiring about necessary authentication mechanisms, data access, and compliance with regulatory standards. For analyzability, questions concern logging practices, monitoring tools, and diagnostic capabilities. Questions about modularity explore how the system is divided into components, the independence of modules, and the ease of updating subcomponents without breaking the whole. Performance efficiency questions address acceptable response times, resource usage under varying loads, and performance thresholds during operational peaks. Finally, reliability questions investigate error recovery mechanisms and system behavior under failure conditions.

A total of 58 questions were introduced in the first version of interview. Table 1 shows examples of the questions. Each question addresses certain aspects of IoT-specific challenges – Change, Complexity and Constraints – and related quality attributes: Maintainability (M), Scalability (S), Analyzability (A), Interoperability (I), Modularity (Mo), Performance Efficiency (PE), Security (Se), Reliability (R), Interaction Capability (IC). The questions were designed so that persons without deep knowledge on technical details of the system would be able to provide their insights. In addition to answering the questions, we wanted to encourage storytelling by the interviewees. Real-life examples, experiences and preferences provide important information about the concerns and expectations that different stakeholders have.

B. Analysis

Analyzing interview responses is a critical step in identifying themes and eliciting the most important qualities to guide the development of the system. Qualitative data gathered through interview often contains implicit insights into stakeholder expectations, concerns and priorities. To extract meaningful information, responses must be evaluated systematically. Answers given by interviewees should be coded and categorized according to the related quality attributes. This process can involve open coding, where recurring ideas are highlighted. The experience and technical expertise of the participants, together with contextual factors must be taken into account when making interpretations of the answers.

TABLE I. EXAMPLE QUESTIONS TARGETING SPECIFIC ASPECTS OF QUALITY.

Question	Change	Compl.	Constr.
Can you describe any challenges or frustrations you have previously experienced with IoT systems?	IC, M	A	PE, R
How many devices do you currently use, and how do you expect this number to grow?	S	I	PE
Should different user groups have access to different system modules?	S	Mo	Se
What existing systems should the IoT system integrate with?	S	I	-

The mapping of interview questions to specific quality targets helps distinguishing functional and non-functional requirements, as the users of the system tend to concentrate on system features in their storytelling. Performing analysis on the stakeholder needs and expectations early on the project helps to plan the development more effectively and reduces the risk of overlooked constraints and misunderstandings.

C. Validation

The purpose of the validation phase is to ensure that all stakeholders have common understanding of the needed qualities of the system, and that developers have correct interpretation of the users' expectations. In this phase, the development team presents a summary of interview findings, categorized by themes found in the answers. They can also bring out pain points, conflicting goals or insights and experiences they have from previous implementations.

The summary report should be concise and organized into clear thematic sections. Even though the focus is on NFRs, organizing the summary report around the system's operational features may improve stakeholder understanding. For instance, requirements related to latency or performance are closely tied to the user experience and interface, and could be grouped under headings that reflect those aspects. This thematic structuring can make technical content more accessible and relatable to non-technical stakeholders, while still preserving the integrity of the NFRs.

Stakeholders or participants confirm the accuracy of interpretations and if there are misunderstandings or misrepresentations, they are corrected. If project scope or resources are

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limited, prioritization may be necessary. Shared understanding ensures the next steps are grounded in actual user needs.

D. Documentation

The documentation and sign-off phase serves as the formal agreement between stakeholders and the development team. This phase ensures that all identified requirements are approved before design and implementation begin. By systematically documenting and approving non-functional requirements alongside functional ones, development team can better manage risks and ensure that the final system meets both operational goals and user expectations. However, explicit documentation of non-functional requirements may be difficult, as the user needs are often imprecise.

We used a simple template for documenting the NFRs, including the following items: Requirement ID, Requirement Type, Description, Priority, Acceptance Criteria, Dependencies, Assumptions, and Verification Method.

The sign-off process acts as a formal validation checkpoint, ensuring all stakeholders agree on the documented requirements. This alignment not only helps guide the development effort but also supports accountability and traceability throughout the project lifecycle.

V. Observations from the Pilot Run of the Process

The project in which the research is being carried out, aims at developing teaching and learning materials for vocational secondary education. As digitalization affects more and more people's daily lives, their working lives will also change. Various IoT solutions are already in use in many sectors and this development is expected to accelerate dramatically in the future. Understanding the potential of IoT is essential to remain competitive in the future labor market. Today, most students do not have sufficient experience in applying IoT solutions, and at the same time these technologies are increasingly taken advantage of in workplaces.

The project explores how IoT-enabled systems can support learning and visualization in food industry training environments. It focuses on the design and implementation of interactive tools that translate complex sensor data into intuitive visual formats. During the project, we will also examine how such systems can improve situational awareness, decision-making, and compliance with industry standards, ultimately contributing to a more skilled future workforce.

Learning environments in the food industry school participating in our project consist of two distinct areas: food production and bakery (confectionery) training environments. In food production, meat and other food products are prepared in various processing facilities where temperature fluctuations play a critical role during both the production and storage phases. In the bakery environment, temperature and other conditions are essential not only for successful baking, but also for ensuring that ingredients are stored under appropriate conditions.

In both learning environments, materials and ingredients are stored in freezers and cold storage units, with their temperatures monitored in real time using sensors. Real-time temperature monitoring of the production facilities is also essential. Threshold values have been defined for each environment, and alerts are triggered if these limits are exceeded, notifying the staff. Additionally, for legally mandated self-monitoring (HACCP), daily temperature values – most commonly the daily average – are recorded for reporting purposes. In the bakery room, flour dust is monitored, while in the food production area, spice dust is tracked using fine particle sensors to assess air quality.

Currently, the temperatures of various rooms and cooling units are monitored, as the cooling of finished products must be completed within four hours. In future, the goal is to enable real-time monitoring of the entire production process from the initial preparation phase through to the end of the cooling phase. This could even be extended to include tracking up to the end user.

During this project, we carried out a pilot round of our NFR gathering process. The participants' roles in the interview phase included a domain expert (teacher) and a project coordinator. The interviewer and interviewees were physically present in the same location, while the note-taker participated remotely. This setup allowed for direct interaction between the main participants while ensuring accurate documentation of the session. Participants' knowledge of IoT systems and general information technology was significantly higher than that of the system's future "basic users." Consequently, this interview alone does not allow for substantial conclusions regarding the influence of different roles on the formulation of questions. The expertise of the interviewees may have introduced a bias in responses, highlighting the need for further interviews with users possessing varying levels of technical proficiency. A more comprehensive analysis requires diverse perspectives to ensure balanced insights into desired system characteristics.

We found that having two interviewers made the process seamless, and will continue this practice, especially if some participants join remotely. At least one of the interviewers should be familiar with the subject or people in order to enhance engagement, while allowing the other interviewer to concentrate on documentation allows for a more structured and inclusive discussion.

It is advisable to allocate more than an hour for the interview to ensure all perspectives are covered. Beginning with informal conversation helps set the stage for discussion. Afterward, comments are transcribed. A summary report must be provided to the interviewees to ensure clarity and transparency in the process.

A postmortem held after an interview session serves as a structured review to assess the execution of the interview, identify strengths and weaknesses, and enhance future practices. This reflective discussion focused on clarifying how the interview was conducted and evaluating the quality of the questions. During the postmortem analysis, we refined the interview process to improve clarity and consistency.

If an individual can analyze an issue from multiple role perspectives, it is essential to specify the perspective alongside their response. Clearly identifying the viewpoint prevents ambiguity and enhances the reliability of the findings. This practice alwo significantly eases the analysis phase of the process.

The interview questions were perceived by the participants as providing comprehensive coverage of the system. According to the interviewees, the structure and content of the interview allowed for a thorough exploration of key aspects, and relevant areas were adequately addressed. Moreover, the interview questions encouraged participants to consider new perspectives on issues that had not previously been examined. This reflective aspect of the interview highlighted its value not only as a data collection method but also as a tool for enhancing understanding and fostering critical insight among participants.

Before the interview, concerns arose regarding the large number of questions. However, all questions were addressed, albeit some more superficially than others. Based on feedback, the order of questions should be improved and grouped according to the respondents' roles and topics. Grouping the questions according to thematic areas will make the questionnaire more coherent and encourage more accurate responses from the interviewees.

During the documentation phase, we identified the need to more precisely define threshold values for alerts, normal operating ranges for various measurements, and constraints imposed by organizational policies or legislation. To address this, the documentation template was revised to explicitly incorporate these elements.

As a summary, after the first interview:

- Six questions were removed, as they were deemed to add little value compared to others.
- Another six questions specifically related to interfaces and maintenance were merged into two clearer ones.
- The wording of several questions was refined for clarity.
- Each question was reviewed to determine which respondent role would provide the most insightful answers.
- NFR template was refined to target aspects of threshold values and legislation issues more specifically.

VI. Conclusion and Future Work

IoT applications consist of different types of hardware and software components that are required to work together under varying and often demanding conditions. Future users of the system, or other stakeholders, on the other hand, may have very little knowledge on the implementation of the system. This complexity may lead to putting more emphasis on achieving the functionality at the expense of quality aspects.

Clearly, the process of eliciting NFRs in the IoT context requires greater focus. In our ongoing project, we have developed and experimented with a four-phase process to systematically gather NFRs, aiming to create more robust and adaptable IoT architectures. Our work extends prior research on NFRs by offering guidelines that address quality aspects particularly relevant in the IoT context, while also enhancing the involvement of future users in the requirements engineering phase of IoT systems.

Based on our initial experiences, we believe that IoT projects significantly benefit from a well-defined NFR gathering process, which acts as a vital bridge between stakeholder expectations and technical implementation – ensuring that essential non-functional aspects are thoroughly addressed throughout system design and development.

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