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Application development for the Internet of Things: A context-aware mixed criticality systems development platform

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ABSTRACT

The Internet of Things (IoT) is gaining momentum and may positively influence the automation of energy-efficiency management of smart buildings. However, the development of IoT-enabled applications still takes tremendous efforts due to the lack of proper tools. Many software components have to be developed from scratch, thus requiring huge amounts of effort, as developers must have a deep understanding of the technologies, the new application domain, and the interplay with legacy systems. In this paper we introduce the IMPReSS Systems Development Platform (SDP) that aims at reducing the complexity of developing IoT-enabled applications for supporting sensor data collection in buildings, managing automated system changes according to the context, and real-time prioritization of devices for controlling energy usage. The effectiveness of the SDP for the development of IoT-based context-aware and mixed-criticality applications was assessed by using it in four scenarios involving energy efficiency management in public buildings. Qualitative studies were undertaken with application developers in order to evaluate their perception of five key components of the SDP with regard to usability. The study revealed significant and encouraging results. Further, a quantitative performance analysis explored the scalability limits of the IMPReSS communication components.

1. Introduction

Having been around for since the early 2000 s, the Internet of Things (IoT) is rapidly gaining momentum as the availability of “things" significantly increases [1]. IoT has a major impact on smart Energy Efficiency solutions that can be used to analyse building performance data coming from distributed sensors and interact in an autonomous manner with higher-level services in order to build advanced building control applications. However, the development of IoT-enabled applications for the benefit of our society still depends on specific knowledge and tools that prevents it to be widespread. Many software components have to be engineered from scratch to address fragmentation issues, thus requiring huge amounts of effort, as developers must have a deep understanding of the technologies, the new application domain, and the interplay with legacy systems. Also, such systems face many challenges, such as dealing with a huge numbers of sensors and actuators, with mixed-critical applications that require real-time actions and with the need of automated systems based on context-aware management for adapting their behavior to current environment conditions.

There is an evident need for new systems to be developed as IoT–enabled solutions become increasingly more common and Energy Efficiency being imperative in the world agenda today. Energy Efficiency is one of the main targets of the Europe 2020 Strategy for smart, sustainable and inclusive growth adopted by the European Commission [17] and of the National Energy Efficiency Plan of

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the Brazilian Electricity Regulatory Agency [24]. Buildings account for 40% of final energy consumption in the EU [16], so that investing in Energy Efficiency measures in buildings can yield substantial savings. Greater use of Energy Efficiency technologies, combined with renewable energy, offers significant potential energy savings and CO_2 emission reductions in both new and existing buildings. However, a key challenge for the development of Energy Efficiency approaches for public buildings is that management systems must be easy to develop, deploy and use [14]. In the US, the lack of data on the actual energy performance, combined with the physical and operational characteristics of buildings is one of the primary challenges to expanding the building Energy Efficiency refurbishment market [13].

In order to deal with this challenge, we developed an IoT Systems Development Platform (SDP) within the IMPReSS project[1], which enables rapid development of context-aware mixed-criticality IoT–enabled applications. IMPReSS SDP focuses on Energy Efficiency management in public buildings as its first target, but it is also usable for any system intended to embrace a smarter society. The platform comprises a variety of components for making the task of developing IoT–enabled applications easier. These include tools for rapid development of user interface, pre-prepared software and middleware components, mixed-criticality resource management [8], context-aware data storage, analysis, and management [23], and IoT wireless communication management. Additionally, typical middleware components for dealing with energy efficiency management in public buildings are provided that hide the implementation complexity from the application's developers.

In this paper we introduce the IMPReSS approach and discuss the lessons learned from developing and testing IoT–enabled Energy Efficiency applications. An IMPReSS prototype system was developed, deployed and used in different application scenarios for different purposes, such as assessment, demonstrations, troubleshooting, and performance analysis. The main achievement demonstrated with the IMPReSS SDP is a portfolio of applications for decreasing the complexity and cost of collecting massive amount of energy related data in buildings as well as raising user awareness about energy consumption and efficiency. The IMPReSS SDP allows developers to create and experiment with new smart energy management services and use IoT enablers to fuse physical data to appropriate data analysis and control systems. The key functionalities provided by the IMPReSS Middleware are implemented by four main components, dealing with data, context, resource, and communication management.

The effectiveness of the IMPReSS SDP for the development of IoT–based context-aware and mixed–criticality applications was assessed through four scenarios involving energy efficiency management in public buildings. The first scenario is a university classroom with energy efficiency context-aware automated lighting and temperature control. The second scenario is an alarm system, where the application–level mixed-criticality system orchestrates and prioritizes the components that can access resources. The third scenario is the monitoring of energy consumption in a historic public theatre building that uses legacy data storage and analysis features to highlight the energy savings obtained. The fourth scenario shows how a power outage in a university campus is managed using device-level mixed-criticality resource management.

For the evaluation of the platform, a user-perception study was undertaken and five key components of the IMPReSS SDP were evaluated with regard to usability. A group of developers used the SDP to complete programming tasks involving the five features and gave their feedback about their experiences using a standard User Experience Questionnaire (UEQ) [22], which captures the usability and perceived user experience of a product. The IMPReSS SPD received a very positive usability evaluation, which confirms that the IMPReSS SDP offers application developers easy-to-use tools for developing smart city applications.

The key contributions of this paper are threefold. The first contribution is the IMPReSS architecture and implementation, which facilitates the development process of IoT–enabled applications, especially for energy efficiency management in public buildings. When compared to other approaches, the IMPReSS Architecture provides general-purpose built-in features that streamline the work of application developers. The second contribution is a set of four applications developed using the IMPReSS approach for evaluation and demonstration purposes, giving us confidence in the effectiveness of the platform. The third contribution is the positive results obtained from a qualitative analysis of the SDP undertaken by system developers and a quantitative analysis of scalability limits of the communication manager.

In the remainder of the paper, Section 2 presents background and literature review, Section 3 presents the IMPReSS SDP architecture and Section 4 presents its key middleware components. Further, Section 5 shows four applications developed with the IMPReSS SDP and Section 6 presents the results of the evaluation with developers. Section 7 shows results of a performance analysis study that highlights the scalability of the Communication Manager. Finally, Section 8 draws some conclusions and paths for future work.

2. Background and literature review

This section covers key aspects related to the design and implementation of a context-aware mixed-criticality development platform for IoT–enabled applications.

2.1. Software architectures for IoT

Software architecture can be defined as the set of structures needed to reason about the software system, which comprise the software elements, the relations between them, and the properties of both elements and relations [4]. They also play a key role as a bridge between requirements and implementation and therefore it was very relevant to the IMPReSS project. The process of building software architectures for IoT involves the interaction of a variety of components with different roles. The IoT–A project proposed an architectural reference model and a preliminary set of buildings blocks, in order to promote a fully interoperable and scalable vision of IoT [5]. The foundation of the IoT–A reference model is the IoT domain model, which introduces the main concepts of the Internet of Things like devices, IoT services and Virtual Entities (VE), as well the relations between these concepts. The abstraction level of the IoT domain model also has been adopted in this work due to its concepts are independent of specific technologies and use-cases. Particularly, the IoT–A functional model played an important role in the specification of the IMPReSS software architecture, comprised of Functionality Groups (FG) and their interaction.

2.2. Design issues of middleware for IoT

Building interoperable IoT services and applications requires a set of middleware components and system development and deployment tools for rapid software development. In order to avoid developing extremely focused and vertical IoT applications not able to interact with other applications, common and generic middleware services used by different application domains become necessary. Razzaque et al. [26] identified a variety of requirements in different categories for an IoT Middleware, which are also aligned with the functionality groups identified by IoT–A. IMPReSS

[1] http://impressproject.eu