Design and evaluation of RFID-based interactive devices distributed in socio-technical environments

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Abstract

This thesis intercepts human-computer interaction, software engineering, and the internet of things. It is applied to health engineering. We propose exploring RFID technology in the Internet of Things by providing a context-aware conceptual model and designing a modular hardware RFID component. The components will extend the features of RFID readers by embedding quality features and mitigating RFID limitations reported in the literature. The component might be fixed or mobile, on vertical or horizontal settings, alone, or in groups. It may be available to different stakeholders of an organization. An evaluation procedure will be proposed for systems using this component. It will be applied to a simulation developed for the health centers 4.0 context by applying it to locating medical equipment. The component will facilitate these devices' management, location, supervision, and operation, which may be vital to saving a patient. We intend to promote RFID technology in IoT systems by facilitating its use and providing comprehensive and easy-to-use guides on how to architect and develop.

Keywords[1]

Internet of Things, RFID, Tabletop, Health Center 4.0

1. Introduction

The Internet of Things (IoT) is a paradigm based on the pervasive presence of identifiable objects (things) that can interact and cooperate to reach common goals. Things are uniquely addressable and equipped with sensing and actuation behaviors [1]. Apart from things, other actors, such as humans and animals, can interact with IoT systems [11].

Regarding the identification strategy in IoT, things may be equipped with technologies such as RFID tags, barcodes, QR codes, and GPS. The selection of technology should depend on the characteristics and architecture of the software system. For example, the RFID technology is composed of tags and readers. Actors interacting through RFID usually carry an RFID reader [10] or a tagged object [5]. Tags may store data and can be determined by nearby RFID readers. Readers may find tags within their reading ranges, can hold or acquire the tag's data, or can simply identify if certain tags are near or not.

RFID technology research was motivated by its presence within the architecture of the tabletops studied at LAMIH[2] in UPHF [3] and also by a quick literature review on location technologies. These tabletops comprise a matrix of 40x40 RFID reader antennas, used to identify at most 1600 tagged objects placed on their surface. Moreover, Brazilian medical professionals from FIOCRUZ[3] reported the need for quickly locating medical devices within a hospital. This feature would be especially necessary during the COVID-19 pandemics. However, Brazilian nurses stated that this was an issue even in standard cases. Therefore, we were motivated to develop a solution for monitoring and quickly locating medical equipment from this report. Furthermore, such a solution would also apply to medical areas in war zones. Therefore, we decided to explore RFID as the identification technology, instead of

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other identification technologies, due to LAMIH's prior knowledge of tabletops equipped with this capture technology.

2. Problem and Motivation

A quick literature review was conducted for comparing features of IoT location technologies. The compared technologies were RFID, GPS, RTK, UWB, and Wi-Fi. Other options may exist but were not spotted in our literature review. Among these, RFID was adopted for these studies because it is low cost, works well indoors, the location occurs in a range of 3 meters for ultra-high passive tags, they do not need batteries and also contains a unique identifier for identifying the tagged objects.

Intending to learn about IoT and RFID, we decided to create a smart table prototype inspired by the tabletops used at LAMIH. The prototype followed a tiled architecture, with 4 (2x2) tiles instead of 1600 (40x40). Each tile contained an RC522 RFID reader and an Arduino. A backend was developed in a Raspberry Pi having an MQTT broker, a dashboard for informing the table's contents in real-time, and a MySQL database. The development occurred during the COVID-19 pandemics.

In the same period, researchers from COPPE/UFRJ[4] were developing IoT applications to assist COVID-19 treatment in hospitals. FIOCRUZ medical professionals reported to COPPE/UFRJ the need for a mechanism to quickly locate equipment within hospitals. This equipment must be clean and returned to its correct compartment to be used again. If it is in use, physicians and nurses must have the means to know where and with whom the equipment is. The demand from FIOCRUZ motivated us to delve into RFID technology to evolve the previous prototype and develop a robust solution to monitor equipment within buildings such as hospitals.

During the prototype development, the first author got in touch with available RFID materials: ISO/IEC 18000-6 [8], scattered guidelines [9], and several standards by GS1[5]. These standards contain hardware specifications, indicate how RFID systems should be architectured and present documentation for low-level software development directly with tags and readers. However, none of these guides give directions regarding the implementation of RFID in context-aware software systems, or regarding the interaction between them and users.

From the point of view of software engineers and developers, the existing guides and standards seem to lack the representation of elements of context-aware IoT systems for the adoption of RFID and the nature of the interactions with them. Motivated by the seeming lack, this research aims to explore RFID technology in literature for proposing a conceptual model for representing the structure of such systems for locating objects in health centers using RFID technology. It will be applied to design an RFID hardware component for equipment monitoring, which may embed several pre-implemented features. We intend to validate the feasibility of a system using this component by simulating the implementation of a Health Centers 4.0 system to locate medical equipment within a hospital.

3. Goal

Following the quick review on location technologies, a systematic mapping [2] was conducted to characterize usage issues of RFID technology in the new generation of interactive software systems.

The usage issues we investigated in this preliminary review are: **how** RFID technology is used in projects, **who** uses it, **why** was it used instead of other technologies, which are the known **requirements** associated with it, which are the common **quality characteristics** and measures, and which are the most frequent **application domains** implementing it. This review gave us a better understanding of how RFID is implemented in IoT systems and how interactions occur when RFID is involved.

Another intended objective is to reduce the explicit interactions of the systems implemented in health centers, so that health professionals focus on their functions instead of on the specificities of the software system. RFID automatic readings permits the implementation of such systems.

The goal of this thesis is to define a conceptual model to orchestrate hardware and software for interactive IoT software systems engineering in health centers.

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[4] https://www.cos.ufrj.br/

[5] https://www.gs1.org/standards/rfid

The research question is: *How to support the engineering of interactive IoT software systems for locating, using, and managing objects considering health centers constraints and minimum explicit human-computer interaction?*

3.1. Conceptual Model

The conceptual model represents concepts of IoT, interactivity and context-awareness, while applying it to concepts of health centers. The IoT paradigm enables the conception of context-aware systems. The term context-aware appeared for the first time in 1994 [12] to refer to software that adapts according to its location of use based on nearby people and objects, also affected by their changes over time [13]. Context-aware systems are aware of their physical, virtual, and human environment and can adapt, benefiting from the knowledge about a situation [12].

Concerning the interactions, explicit interactions refer to the traditional use of software systems, such as explicitly pressing a button. Implicit interactions refer to the implicit collection of inputs, such as automatically identifying users, collecting data with sensors, and delivering output that was not explicitly requested [12].

The conceptual model will represent these entities: users, technology and environment while also representing the objects, which will be located and managed in the health centers. The model will be generic and will comprise several concepts existing in health centers, so that it can be instantiated in systems for specific places such as hospitals, clinics and labs.

3.2. Design of an RFID Component

We intend to design an RFID component to assist the development of IoT software systems. This component will consist of an RFID reader and pre-implemented features. E.g., requirements such as the reading distance and frequency bands may be configurable; quality measures such as the percentage of successful readings may be stored and presented in a dashboard; certain algorithms may be embedded in the component for decreasing false readings; the presence of a tag near a component may trigger an action by other components through pairing. What to implement will depend on the contents of conceptual model. Several components will be implemented together to cover a whole place, such as the rooms of a hospitals, for locating tagged medical equipment.

4. Current Status

The smart table prototype was developed by the middle of 2020. The systematic mapping, intended to be a preliminary state of art study, was already conducted. It started in July 2021 and was concluded in December 2021. We are currently preparing a publication about the systematic mapping, which will be this research's first publication. For the time being, the protocol and results of the systematic mapping are available in a technical report[6].

We first intend to acquire knowledge about RFID technology through this systematic mapping, and its discussion will be used as a base for achieving the next goals described as part of the methodology.

5. Methodology

A three-phase methodology was developed to reach the research's goals.

5.1. Conception Phase

The systematic mapping delivered plenty of information for most research questions, except for the questions about quality characteristics, RFID requirements, and limitations. It also spotted that ultra-

[6] https://maia.mobi/arq/tech_report_rfid.pdf

high frequency passive RFID may cause interference in some electrical medical equipment [4,6,7,14,15]. Due to this limitation, depending on the requirements of a specific health center, it may be necessary to use other technologies instead, or together with RFID.

The conception phase will comprise further research on systems for locating objects for better understanding the important characteristics to be considered in such software systems. Additionally, we will conduct a systematic literature mapping on another location technology, to verify the feasibility of mixing technologies in such location systems.

5.2. Development Phase

Once the conceptual phase is finished, the design of the conceptual model will begin. It will represent elements of context-aware systems when applied to health centers, while permitting instantiation for specific locations, such as hospitals. It will represent the ubiquity level of technologies, in case of including additional protocols other than RFID. The component will be designed next. It will be used for monitoring equipment in indoor areas. They will be build based on the knowledge acquired during the conception of the model.

We seek to (1) implement support for software quality monitoring by using quality measures; (2) implement algorithms to mitigate RFID technology's limitations; (3) turn the component as much configurable as possible through a manager interface; (4) encapsulating functions for surveying tags given a frequency, pairing with other components, among others. We will build the component as well, just after designing it.

5.3. Feasibility Phase

We wish to evaluate if the components' systems effectively benefit from implementing the component instead of common RFID architecture. We will elaborate a procedure for assessing the use of the system based on quality criteria.

We will check how the built component behaves in distinct applications by verifying its usage and behavior in several settings: for detecting one or more objects on a shelf (horizontal) and for detecting one or more objects hanging on walls (vertical); on moving objects (mobile), such as being carried by a person through a house; when paired to other components (in groups).

As a final step, we wish to validate the research in the context of Health Centers 4.0. It is unclear if we will be able to create a real application within a hospital, so we intend to simulate an application by using a programming tool such as SimPy[7]. We plan on developing a system for managing medical equipment. With the assistance of several RFID components, the system will monitor if tagged equipment such as defibrillators, wheelchairs, and stethoscopes are in their proper place. The system will indicate where and who uses them if they are not. The software system may also remind health professionals to clean the equipment before returning, among other health-related requirements we may find by this validation. Finally, this system will go through the previously defined evaluation procedure. Results will be discussed, the proposal will be refined, and every artifact created so far.

6. Conclusion and Future Works

This research intends to explore RFID technology and providing a conceptual model to facilitae the development of context-aware IoT software systems for health centers. An RFID component will be designed and built to extend the functionalities of common RFID readers and provide extra care with software quality. An evaluation procedure will be developed for systems using the component. These contributions will be validated by simulating and evaluating a system for Health Centers 4.0 context.

As overall contributions, this research intends to promote RFID technology in IoT software systems by facilitating its use and providing comprehensive and easy-to-use guides on how to architect and develop. In addition, this research intends to improve the location of objects in hospitals and other

[7] https://simpy.readthedocs.io/en/latest/contents.html

indoor areas by delivering the design of the RFID component, its documentation, example applications, and an evaluation procedure.

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