Towards a Runtime Devices Adaptation in a Multi-Device Environment Based on People's Needs

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***Abstract*—Internet of Things devices are becoming more and more intelligent. Their ultimate purpose is to perform tasks that help people. In order for these devices to perform their function, they must be configured by users, which implies a considerable investment of effort and time. This configuration also has to also consider that the user's contextual information is constantly changing. Each change in contextual information may require devices to be reconfigured so that their behavior and collaborations with other devices can meet the user's needs. Although this adaptability has already been achieved, it is still a too manual process, which involves a great deal of effort by people. This paper presents the Situational-Context as a proposal to achieve a context adaptation of IoT devices at runtime avoiding human intervention. Thanks to our work we achieve a multi-device collaborative environment that facilitates collaboration between people and devices automatically and with less effort from people.**

Index terms— Internet of Things, Context, Runtime adaptation, People's needs

I. Introduction

We live in a multi-devices world connected to the Internet (Internet of Things-IoT). According to Cisco's reports, there are 3.4 devices per person [1]. If we consider recent estimates, in the next few years we will have about 30 billion smart devices connected to the Internet [2], which will mean that the number of devices per person will increase. One of the general purposes of these devices is to make people's lives easier by simplifying tasks or helping them get things done.

IoT devices can be used to perform simple tasks, such as turning on a light, blood pressure monitoring, or periodic reminders, but the real potential comes when they interconnect with each other, to perform more complex tasks. An example based on heathcare could be that because of high blood pressure detected by the blood pressure monitor, the smart fridge may suggest some of the foods it has that can help to control the blood pressure, or the smartphone may suggest purchasing low-salt products.

The interconnection is essential but not easy to achieve, as we find the great heterogeneity of IoT devices in the market. Each manufacturer develops its own protocols to achieve this interconnection, that makes it possible to coordinate and configure their devices to develop complex tasks, such as the previous ones. This configuration can not be predefined at design time, because it must be adapted to the situations and needs of each person. E.g., not everyone needs to take the same dose of a certain medication to control their blood pressure. This depends on the person and the situation they are in. That is why devices have to be able, firstly, to detect people's preferences or needs and, secondly, to adapt to them. Nowadays, this process result a too manual and should be done in a most automatically way to reduce human intervention and to facility people's daily lives.

IoT devices are becoming intelligent thanks to the processing of information gathered about the context, that can be used to enhance their features and to minimize people interaction. This goal can be addressed by developing software capable of adapting its behavior to people's needs [3], [4]. Several research areas can contribute to provide this adaptation, namely Context Oriented Programming (COP), Ambient Intelligent (AmI), Semantic Web, and Machine Learning (ML). Most of these paradigms allow us to define behaviors for different scenarios at design time, so the adaptation of the devices is limited to situations that developers have been able to identify, making it impossible to adapt them to other situations that may arise from the context and therefore also prevents this operation from being carried out at runtime.

Therefore, the behavior of smart devices must be adapted at runtime to be based on people's needs. This is due both context conditions and people's needs are constantly changing.

During the last years, the authors of this work have proposed the Situational-Context paradigm [5]. The use of Situational-Context to achieve a dynamic adaptation of IoT devices at runtime allows devices to interconnect in the most optimal way taking into account their functionalities and how they can modify the context according to people's needs. This is achieved by using Semantic Web techniques, specifically, with semantic reasoners that allow to extract information about the devices for further processing. This work allows to obtain information about people's preferences through their smartphones. People's smartphones know at all the time where people are, with whom or what they do, and, in addition, they can obtain contextual information and detect the presence of other IoT devices present in the environment. This information is modeled using a conceptual model that allows all the data to be interpreted in such a way that interconnection strategies between devices can be detected. Moreover, thanks to the use of reasoners, these strategies emerge from the context in order to adapt the functionalities of IoT devices to people's

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preferences. Therefore, the benefits of our work lie in achieving the runtime adaptation of IoT devices that depending on the constant changes produced in context and people's needs, and that adaptation occurs automatically, avoiding having to configure these devices manually by people.

The rest of the document is structured as follows. Section II describes the motivations of our work. Next, Section III introduces the concept of Situational-Context. In Section IV we show the conceptual model. Then, in Section V we describe some related work. Finally, in Section VI some conclusions are detailed.

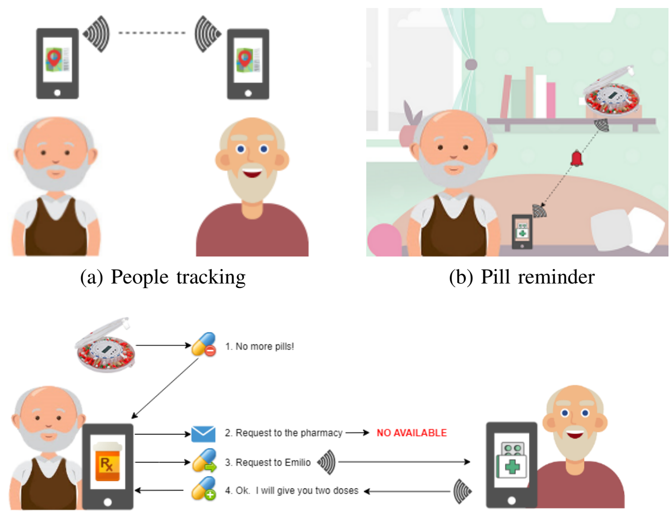
II. Motivation

The solution presented in this paper is general and can be used in several domains, but to show the impact of the devices integration, we are going to use a scenario based on ageing and rurality. This scenario comes from a real use case of a European project where the authors of this paper are involved: International Institute for Research and Innovation on Elderly (4IE) [6]. Its objective is to understand the biomedical, functional and psychological aspects of aging in specific contexts, generate new models and processes for elderly care and technological solutions that contribute to their health and quality of life and the sustainability of services. In the rest of this paper the proposed scenario will be used to show the benefits of our work.

Marty is a 74 years old man who lives in La Calera in the southeast of Cáceres, in the Las Villuercas Mountains. This morning, Marty went for a walk with his friend Rick. They both have their mobile phones with them. Since the village is running out of inhabitants and they are getting older, their sons and daughters always ask them not to go out without their mobile phones in case something happens to them. Marty and Rick are not aware of this, but their mobile phones can do much more than receive calls from their children. In addition, these devices are recording where they walk, where are them, with whom they are and are detecting each other so that their phones now know they are in company (Fig. 1a).

Marty has returned home and it's time to take his medicine. It is notified by the electronic pill dispenser that was given to him last month. This pill dispenser has also detected that there are no pills left for the next day (Fig. 1b). It is very important that Marty does not stop his heart treatment. Although his smartphone made the electronic prescription request, they were unable to bring his medication. There seems to have been a mistake at the pharmacy in Guadalupe, the only pharmacy nearby, and because it is a small town located in the rural area it is not possible for Marty to receive his medicine in time. Fortunately, Rick takes the same medication as Marty and received it last week. Marty and Rick have received a message telling them that tomorrow Rick must give Marty two doses (Fig. 1c).

The scenario presented above is subject to constant change. We observe how the problem arises that a routine operation such as ordering medication can become complex and require additional operations due to problems that arise and were not



(a) People tracking (b) Pill reminder

(c) Doses request flow

Fig. 1: Ageing and rurality scenario

contemplated, such as the error in processing the electronic prescription or the lack of supplies from the pharmacy. Because of this, IoT devices must make decisions in real time to solve the needs of Marty and Rick. In this scenario there are a few changing conditions, but the possibilities that can occur are innumerable and cannot be defined at design time.

One of the main issues is that IoT devices must be configured manually by people, with the consequent investment of time and the need to have a minimal technical knowledge. But perhaps Marty and Rick do not have the necessary knowledge to be able to configure a smart device, or make it behave in a certain way and interact with other devices.

To mitigate this drawback, different works have promoted alternative methods to make IoT devices operate with each other, such as specific *frameworks*, e.g. [7], where a framework is developed to integrate specific domain applications into IoT, or [8], which presents interfaces and interconnection procedures based on oneM2M [9]. The use of ontologies and the Semantic Web are also becoming very important to solve these interconnection problems [10]. The Semantic Web and Internet of Things visions are converging toward the so-called Semantic Web of Things, that aims to enable smart semantic-enabled applications and services in ubiquitous contexts (SWoT) [11].

These works help to solve the problem of device interconnection, shown in the scenario before presented, but it is not an easy task, because technological diversity of smart devices must be taken into account. In addition, a correct handling of the context, where are involved the own context conditions and people's needs, must be taken into account. Unfortunately, this aspect hardly ever is consider. With Situational-Context we intend to do just that: on the one hand, to provide IoT devices with the capacity to detect in runtime characteristics of the environment such as temperature, humidity, location or detection of nearby devices and even people's needs; and on the other hand, to provide the devices with the ability to evaluate the situation in order to make a decision that is capable of solving people's needs.

III. Situational-Context

Situational-Context is a proposal that provide support for analyzing the conditions that exist at a particular time and place in order to predict, at runtime, the expected IoT systems behavior regarding the people's needs. It is composed of entities. These entities can be both IoT devices and people represented through their smartphones, indistinctly.

This model exploits the capabilities of smart devices to collect, store and then treat calculate locally contextual information to build their virtual profile and the virtual profile of their owner. The virtual profile is a component that contains all entity information. This information is related to all the data that can be captured from the context and make sense to work with them, such as the location in a certain place or at a certain time or with what other people or devices interact. Others devices around an entity can reuse its profile to meet the user's preferences. In addition to the virtual profile, this model has two essential components that will allow to complete the information of the entity and to be able to relate it with others within a context to solve people's needs: *skills* and *goals*. Situational-Context defines that the virtual profile of an entity (IoT device or a person) must contain at least the following information: basic and social profile, goals and skills. These information in contained in different components are explained below though the entity architecture (Fig. 2).

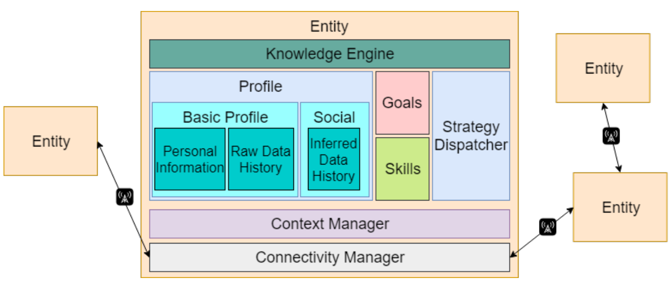


Fig. 2: Entity architecture

- **Connectivity Manager.** Establishes the physical connection between entities. It sends and receives information related to skills, goals, personal information, etc.
- **Context Manager.** Responsible for creating and updating contextual information. It contains the information of the entities belonging to the same situation in a given instant of time.
- **Profile.** Union of the *Basic* and the *Social Profile* of the entity.
  - **Basic Profile.** Basic information that identifies the entity, such as the identifier, manufacturer, model, date of manufacture, etc. (Personal Information). It also contains raw data about the history of interactions with other entities (Raw Data History).
  - **Social Profile.** Stores all inferred data from the basic profile (Inferred Data History). Thanks to this data, Marty's smartphone can know where Marty is moving or who he's accompanied by.
- **Skills.** Entity features. They produce a change in the context. For example, the pill dispenser can order pills from the pharmacy.
- **Goals.** They arise when an entity wants to obtain a state in a property of the environment that with the own capacities is not possible. E.g., due to the situation that Marty's pill dispenser is empty, he must make the electronic prescription and request some doses from Rick.
- **Strategy Dispatcher.** Devices can detect what goals there are in the environment, and which ones can be solved with their skills. A strategy is identified when it is detected how to coordinate the devices in the environment to solve the given goals. The complexity of strategies lies in the collaboration of entities to identify and solve needs. Returning to the example of Marty and Rick, Rick's pill dispenser must establish a strategy to give a few doses to Marty, but only if Rick has plenty of pills.
- **Knowledge Engine.** Analyzes the history of the entity's activities to detect patterns and learn from them, with the goal of automating tasks in the future or detect routines.

Due to the detected need about the constantly change in both context and people's preferences, we use the Situational-Context paradigm with which we intend to achieve a better interconnection of IoT devices, and get the maximum benefit by adapting their behavior to people's preferences at runtime. With the exchange of virtual profiles, entities know the goals of others. This information allows to an entity to know if using its abilities can solve the need of another entity. This favors the interaction of entities and allows them to be dependent on the context in which they are, at runtime. This architecture achieves the interconnection of IoT devices at the features level. The interconnection is based on relating the skills of one entity with the goals of another. We know that the goals in an entity arise from the lack of skills when obtaining a desired state in the environment, so we must know how to perform this interconnection and that the goals can be resolved in the best way. Each entity has its own vision of the context, and knows the skills and goals of nearby entities, so that it can interact with them. This is achieved by integrating Situational-Context with Semantic Web and ontologies. In the next section we will go deeper into these techniques.

Using Situational-Context in the previously defined scenario it is possible to detect devices in the environment and their contextual information. In this case, Marty's pill dispenser realizes that there are no doses left, so it notifies Marty that he must place a new order through the electronic prescription. When Marty's smartphone tries to place the order, an error occurs which prevents him from being able to receive of his medication. His smartphone automatically detects this situation, and as it knows that Rick is taking the same medication thanks to the information exchanged when he met previously, it proceeds to request a certain dose. Rick is warned of this, and his pill dispenser checks that he has an extra dose, so he can give some to Marty. In this way, an unforeseen situation produced by a constantly changing context is satisfactorily resolved at runtime. Identifying such situations at design time is almost impossible.

IV. Conceptual-Model

The conceptual model that supports the information contained in the virtual profile is defined through ontologies.

This ontology is able to relate devices that have in common skills and goals, so that the goals of one entity can be covered by the skills of another. Goals are created from the processing of the characteristics of the environment. In other words, when a situation with certain characteristics is detected, these are associated with a specific goal and are stored in the virtual profile of the entity. This whole process is carried out at runtime.

In this way, each entity will have a series of situations that it will have gone through over time. This information is stored in the virtual profile and it can be processed to infer and detect more precise situations. The way of sorting the situations that the entity is going through is called timeline. The situations of the timeline are generated from the featrures extracted from the situations themselves. Deep Learning (DL) techniques are used in this part (Feature Extraction). The information of these situations is valuable to be able to detect patterns of behavior or predict new situations in the future. This information is provided by the different sensors available to the devices such as GPS, lighting, humidity, accelerometer, etc. This model is detailed in Fig. 3.

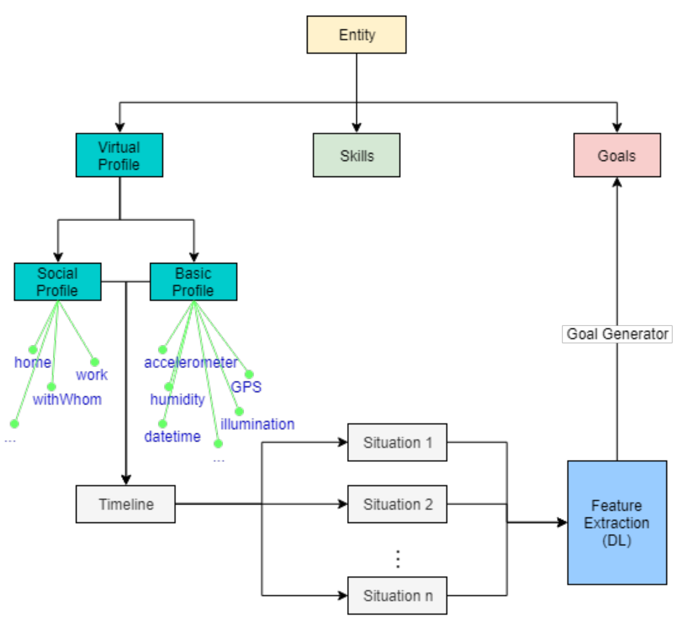


Fig. 3: Conceptual model

When an entity detects another one or more entities, all the information stored in the profiles is exchanged. Each entity contains internally its ontological model (Fig. 4) with the data related to its profile and those around it. This data contains information about the skills, goals derived from situations through feature extraction techniques, situations timeline, personal information, etc. Even more complex skills and goals can be modeled where they can be composed by others. E.g., for the goal of Marty's medication, several skills must be used, such as making the electronic prescription and also requesting the dose from Rick (a goal requires two skills). In this way, all the entities present in one context know the information of the others, so that they can determine whether their skills can meet the goals of another entity and be able to determine a strategy to follow. Therefore, the strategy of interconnection between several entities happens at runtime and emerges from the context.

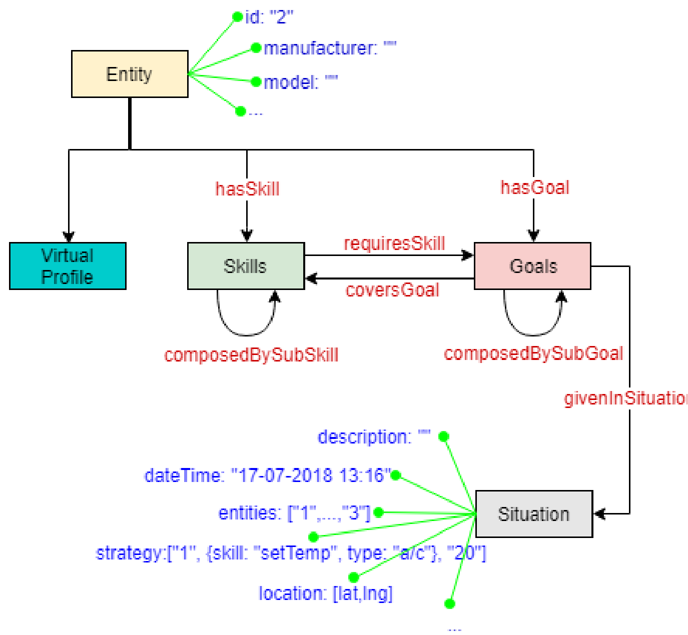


Fig. 4: Ontology

At this point, the Semantic Web will be in charge of strategy detection. The interconnection strategies between different entities are based on semantic reasoners and Sparql queries. Thanks to these technologies we can relate one entity with another, from the information coming from its profiles. The tests carried out for the management of the virtual profile of the entities have been carried out with Apache Jena [12]. Jena is a framework for the Semantic Web based on Java that allows the treatment of ontologies. It was decided to use Jena because it has a version for Android (AndroJena), because the ontology processing would be performed on people's mobile devices and because it is one of the most widespread tools in the world of the Semantic Web, being also easily integrated with reasoners and Sparql queries.

Sparql queries give us the possibility to relate entities based on their skills and goals. At the same time, semantic reasoners provide us with a higher level of knowledge, as they can offer additional information to the one we are requesting.

Both technologies are complementary, and depending on the complexity of the use case or the information we want to extract, we could use one or the other.

Currently, we are doing an exhaustive analysis of different reasoners may be used for this purpose. A semantic reasoner generalizes that of an inference engine by providing a richer set of mechanisms for working. Inference rules are commonly specified by means of a language of ontology and, often, a language of logical description. In this way, thanks to the information modeled in the ontology, the entities can develop their own inferences. There are several reasoner for Semantic Web. For this work, we are interested specifically in Semantic Web reasoner for mobile devices. Thanks to the potential of smartphones, they are able to perform more or less heavy tasks, such as processing data from a user. Mini-ME [13] is a mobile inference engine designed from the ground up for the Semantic Web Of Things (SWoT). It supports standard Semantic Web technologies through the OWL API and implements standard reasoning tasks for knowledge base management and non-standard inference services for semantic-based matching and resource classification. Mini-ME is developed in Java, adopting Android as the current target computing platform, but also runs in Java SE. In [14], Bobed et al. show that the most popular current available Description Logics (DL) reasoners can be used on Android-based devices, and they detail the efforts needed to port them to the Android platform.

Once the strategies to follow have been detected, we know that entities will use their skills to solve goals in the context. Now we are facing a new problem. Given several entities with a common goal, the resolution of this goal has to be developed based on some criteria. Continuing with the previous example, it is detected that Marty needs a series of pills, but Rick will only provide them in the case that he has more than enough, since he also needs them. In other words, a skill must solve the same goal for two different entities. The fact of benefiting one or the other will be given by the taking of a series of decisions. Criteria such as the age of the entities within the context or interaction with the entity providing the skill would be taken into account, in addition to frequency of use or the establishment of a series of weights. In this sense, bio-inspired or multi-objective algorithms can act as arbitrators to decide which entity to benefit or not, given a common goal to be resolved. In [15] a series of algorithms are collected to obtain the most optimal solution in decision-making problems.

V. Related Work

As has been detailed above, we can use different paradigms such as AmI, COP, SW and ML, to automate interactions between users and IoT systems according to user preferences. In addition, solutions to improve integration between people and IoT systems through the use of smartphones such as People as a Service (PeaaS) and Internet of People (IoP) were also discussed.

Multi-device collaborative scenarios is a major issue in the research community. In [16], Lagerspetz et al. focus on community formation in IoP, a prerequisite for enabling collaborative scenarios. These scenarios must also take into account the privacy and security of the devices and people involved in them, issues that are addressed in [17].

When we delve into Semantic Web aspects within the scope of Internet of Things, we find several works that follow an objective similar to ours. SocioTal [18] is a project focused mainly on issues of security and data sharing, whose aim is to create a configurable and secure IoT environment that encourages people to contribute with their devices and information, providing appropriate tools and mechanisms that simplify complexity and encourage citizen participation. Gyrard et al. also address issues related to IoT and Semantic Web, and they even have developed their own framework to facilitate interaction between IoT devices from a template generator for different IoT domains [19], based on Semantic Web technologies to explicitly describe the meaning of sensor measurements in a unified way.

As mentioned in Section I, healthcare domain is gaining great importance within the IoT. We can find work focused on the care or treatment of the elderly. In [20], we find We-care, a system for the assistance of elderly people that is able to monitor and record the vital information of these people, as well as provide mechanisms to activate alarms in emergency situations. Along the same lines, Mainetti et al. have designed an Ambient System Living (AAL) system to create better living conditions for older people, capable of constantly monitoring their state of health through data from heterogeneous sources [21].

In addition, if we combine Semantic Web with elderly care, we find an interesting project, SOPRANO [22], an extensible and open AAL platform for elderly people based on semantic concepts and a combination of techniques based on ontologies and a service-oriented device architecture, aims to lead a more independent life in their family environment through a new generation intelligent home with ambient intelligence.

We are aware that there are many proposals for the development of software whose behavior adapts to the context, but that, to the best of our knowledge, do not cover in many cases the problems mentioned above, such as those related to the adaptation of devices to the conditions of the context at runtime. Therefore, the research challenges we address are several. First, the lack of a unified model of human-IoT interaction. IoT devices are produced by several manufacturers, each with its own interaction model. Secondly, the lack of an automatic negotiation model for the interaction between people and IoT devices according to people's preferences. Some of the works mentioned above pursue a similar goal to ours, in terms of achieving an adaptive context in IoT, but we want to make the interconnection of these IoT devices emerge from the situation itself. If these problems could be solved, there would be a better integration of people in IoT environments in terms of interoperability.

VI. Conclusions and Future Work

The adaptation of the systems to the conditions of the context in real time is a very present problem nowadays. This is even more important if we consider the great growth that IoT is experiencing. In addition, we have seen how related works try to solve the same problem, so we consider it to be an issue of great importance.

Although the solution proposed above is valid for any IoT domain, we consider healthcare is one of the most important domains and in which most work is being done to develop devices to help people in their daily lives. As the healthcare domain is becoming increasingly important, we are concerned about the idea of being able to connect as many smart devices as possible to make the lives of older people easier. However, the problem of runtime interconnection in the IoT world is still present today due to the heterogeneity of devices on the market and the context conditions. The interaction between IoT devices is crucial for the resolution of strategies to support people daily tasks, and must allow them to adapt their behaviors to people's needs, which often depends on the collaboration of several intelligent devices.

This work is another step towards achieving the adaptability of IoT devices at runtime, thanks to technologies such as Situational-Context. Considering that both the needs of people and the context that surrounds them are in continuous change, this way we can adapt the behavior of the devices to the needs of people at runtime, without the need to attend previous configurations at design time.

Currently, we are working on how to apply the semantic reasoner for the strategies detection. Once we know which skills and goals are going to be involved in the strategy, we must continue along this path to determine how the devices should act, and refine the interconnection criteria, at the level of privileges or permissions, to be consider. In addition, we will continue to work on the Semantic Web line and ontologies, so that the association of skills and goals is as precise as possible.

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