Meeting IoT Users' Preferences by Emerging Behavior at Run-Time*

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Abstract. Internet of Things systems are increasing their importance in our lives. To provide their maximum benefit, they must be manually configured according to the users' needs and routines. Thus, the increasing number of smart devices and systems being deployed will make this task completely unmanageable in the near future. This could limit the rise and penetration of IoT. Moreover, smartphones are standing out as the interface through which people interact with these systems. Due to their increasing capabilities they can also detect and analyze their users' daily activities. Therefore, this research tries to address this situation by proposing an architecture that allows smartphones to learn from the habits of their users through automatic learning techniques, and a programming model that allows run-time adaptation of the IoT systems behavior to the detected needs through the invocation of the services provided by the smartphones.

Keywords: Internet of Things, context, smartphones, machine learning

1 Introduction

The relevance of the Internet of Things (IoT) increases as more and more connected devices are developed. One of the general purposes of these devices is to make people's life easier, simplifying tasks or executing them automatically.

For these systems to achieve their goals, they must fulfill their users' needs. For that, they have to be manually configured by the users, who often do not have the necessary technical skills, with the consequent investment of time and frustration this can cause. This, which today may be a serious drawback, in the near future in which it is estimated to be 50-100 billion of smart devices [11], may be unmanageable. Likewise, it is not enough to configure the devices once at the beginning, but also users must reconfigure them as their habits and needs change.

These drawbacks may be addressed by developing software capable of adapting its behavior to the people's needs.

Similar problems have already been detected by other researchers [5,13]. Additionally, several research areas can contribute to solve them, specifically

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Context-Oriented Programming (COP), Ambient Intelligent (AmI) and Machine Learning (ML).

Therefore, the problem statement faced in this PhD. work is that the interactions between people and devices requires too much attention and time from people. With the growth predictions of IoT in the near future, this demand may become unmanageable.

The rest of the paper is structured as follows. Section 2 describes related fields and hypothesis about our proposal. Section 3 presents the main objectives of this research. Next, Section 4 shows the the preliminary results. Finally, Section 5 details the evaluation plan of this research work.

2 Related Fields and Hypothesis

This work main hypothesis is the following: By using paradigms such as AmI, COP and ML; and smartphones, that learn about their owners habits and preferences, the interactions between users and IoT systems can be automatized according to the users' preferences.

To address this, the pervasiveness and great computation capabilities of smartphones, in combination with the predictive models created through ML techniques, could be used to learn from people's routines or discover patterns of behavior. This can be done by using one of the most popular ML branches, Deep Learning (DL) [9], taking as input the data gathered by the smartphones about their owners' activities.

According to this hypothesis, the starting point of our approach is the conviction that, a combination of DL techniques with the capabilities of smartphones could provide a significant benefit in this area. Analyzing the information gathered by the smartphones' sensors, we can identify what actions people are doing, at what time, where or when, and which IoT devices they interact with. In this way, we could be able to automate tasks, or predict future behaviors.

Several research works support this hypothesis. First, AmI tries to make everyday environments sensitive and adaptable to people [12]. However, AmI needs to know the users' preferences to establish when a device should act. This is a complex problem when the needs of several people have to be analyzed, specially when their presence was not originally planned within the system.

Second, COP [6] allows software developers to define the behavior of the applications, allowing to activate or deactivate certain behaviors or functionalities depending on the contextual information. However, these programming models require the different behavior to be defined at design time [7]. Behavior depend on users' needs and preferences, as well as changes over time. For this reason, it can be difficult and inefficient, to try to anticipate all possible behaviors at design time. Given this, the possibilities of adaptation of the software would be limited to a certain number of predefined contexts in the source code.

Third, the supervisors of this PhD. work are focusing on solutions to improve the integration between people and IoT systems through the use of smartphones, such as People as a Service (PeasS) [4] and Internet of People (IoP) [10].

Finally, attending aspects of human activity, Lane et al. [8], constructed a prototype of deep learning that runs on a smartphone. The aim was to check if their prototype could improve the ability of a smartphone to detect if someone was performing certain activities, such as eating soup or brushing their teeth.

With this state of the art, we are aware that there are many proposals for software development whose behavior is adapted to the context, but they do not cover in many cases the above mentioned problems. Thus, the research challenges that we address are several. First, the lack of a unified model of person-IoT interaction. IoT devices are produced by various manufacturers, each with their own interaction model. Second, the lack of an automatic negotiation model for the interaction between people and IoT devices according to the people's preferences. Third, the absence of learning models of people's preferences from their interactions with IoT devices. If these problems could be solved, a better integration of people in IoT environments would be obtained.

3 Research Objectives

In addition to the general objective that follows directly from the hypothesis above, this is to achieve a better integration of people with the IoT by making the devices learn about their owners. This doctoral thesis has the following specific objectives:

1. **Design an architecture where people and connected devices are represented.** The architecture must support the identification of the people and devices that are present in a situation, their connections and the automatic configuration of the devices' behavior according to the preferences of the people. The main contribution to be derived from this objective will be an infrastructure that can contribute to the definition of a standard for connecting people with devices independently of the manufacturer.
2. **Propose a learning model about people's preferences.** This model will be hosted on smartphones and must, therefore, meet the resource restrictions of these devices. It will be provided as a service from the smartphones to the architecture in order to make the preferences of all the involved people known. The main scientific contribution associated with this objective will be ML algorithms designed to be executed in smartphones and prepared to manage an important and larger volume of data coming from a single person.
3. **Propose a programming model for the architecture.** Based on the capabilities of each device, it is possible to develop software that will satisfy the people's preferences. The main contribution associated with this objective will be a programming model that, besides allowing programming strategies for specific contexts, will allow strategies to emerge once a context occurs. Neither the context or the strategy will be defined at design time.

The next section shows our architecture, detailing how through the context and the user profiles, it could facilitate the handling of IoT devices.

4 Preliminary Results

This work has already achieved some preliminary results regarding the first objective. In particular, an outline of the architecture supporting the concept of Situational-Context (SC) has been presented. In [1], SC is defined as the composition of the virtual profiles of all entities involved in a given situation. The objective of a *situation* is to achieve the highest level of comfort possible for all participating entities. This is achieved by satisfying the greatest possible number of goals based on the available skills. Understanding by entities in a situation both: smart objects, and users represented through their smartphone.

According to [1], entities have two fundamental properties: *goals* and *skills*. Goals can be understood as an entity need that must be satisfied. For example, a user may need to turn on a lamp when a room is dark. Skills are those capabilities that can solve certain goals. For example, a lamp has the ability to increase the luminosity of a room. Thus, we work in a distributed environment, where the entities collaborate with each other to meet their goals.

Related to the above, the programming model proposed here aims to establish a new way of developing software for IoT systems. To do this, this model must be based on an architecture that allows defining the entities of a context, and what goals and skills they have. Figure 1 represents the components of the architecture. These components are detailed below:

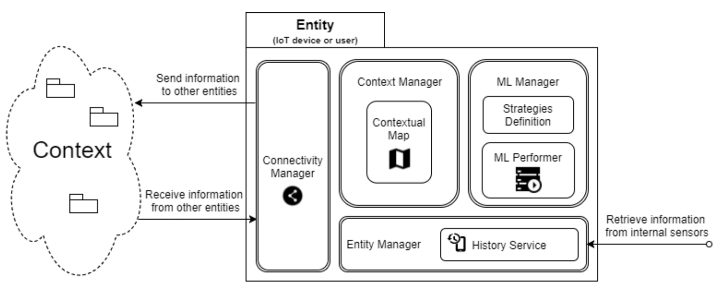

Fig. 1. Components of the proposed architecture

- **Connectivity Manager:** Establishes the links between entities in a context. It sends and receives information from other entities by invoking services. This information is relative to goals, skills, history, etc. Communication between entities can be done using protocols like Bluetooth or WiFi. This is still undefined.
- **Entity Manager:** Here the entity's goals and skills will be defined, as well as its particular information, activity history or privilege level in the context. It will also have services that interpret data from the environment, through internal sensors, to be used in combination with the information provided by other entities when developing strategies.

  - **History Service:** It storages the activity history. These activities are the result of interactions that have occurred in the past with other entities, why they interacted, when, where, what specific situation was being produced, etc. Thanks to this, further activities could be predicted.
- **Context Manager:** It is responsible for creating/updating the contextual map. It will also be in charge of activating or deactivating strategies.
  - **Contextual Map:** It relates the goals and skills of all entities in the context. Therefore, each entity will have its own contextual map based on the entities that surround it. In this way, each entity can know what goals can be solved with their skills. For instance, if a light has the ability to illuminate a room, it must be aware that it can do it.
- **ML Manager:** It is responsible for the entity learning. Two types of learning can be differentiated. The first, individual, where the entity will learn from its own routines to try to predict future behavior. The second, collective, in which the entity will learn from the entities that surround it within the context, with the aim of solving goals that their skills allow.
  - **Strategies Definition:** It analyzes the goals and skills to determine what goals can be addressed by the capabilities available in the contextual map. In addition, it must be consider that a goal could be solved using several different strategies.
  - **ML Performer:** It analyzes the activity history of the entity, allowing the system to learn and detect patterns of behavior, with the aim of automating tasks in the future.

From this architecture, software developers for IoT systems could work on new solutions. These solutions can use the goals and skills of different entities to provide new strategies to solve goals, or use the communication and learning mechanisms of the architecture, to add new skills to existing systems.

5 Evaluation Plan

Although this doctoral work is still in an initial state, we have developed some proofs of concept that validate the viability of the SC in IoT environments. Besides, there are preliminary works to deal with the exchange of information at the network level [3].

The evaluation plan to be followed involves some tasks. First, the architecture development. This task will focus on the development of services for the exchange of information between entities, strategies resolution for one user, and then, for many users. We expect to achieve this in the second quarter of 2018. Second, a learning model, that will pursue executing ML algorithms in smartphones and to predict future actions based on the users' activities. It is planned that this task will provide valid results by the end of 2018. Next, the programming model. This will include a skills and abilities standardization through an ontology and using ML for strategies resolution. This task will be extended throughout 2019.

The case studies associated with these tasks will be developed under the 4IE project. A three years European project focused on gerontology [2].

In conclusion, the architecture and programming model that this thesis proposes will try to take full advantage of the features that IoT devices offer, while facilitating the task of developing software adaptable to them.

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