Allowing IoT Devices Collaboration to Help Elderly in Their Daily Lives

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Abstract. Elderly people have the stereotype of being bad to technology, but they are one of the groups that can benefit the most from recent technological advances. The Internet of Things (IoT) is one of the new technologies that aims to facilitate people's lives, automating tasks or allowing them to be carried out more easily. IoT smart devices provide an increasing number of ways for elderly people to stay active, independent and secure. In addition, the collaboration among smart devices increases the possibilities that the IoT offers, achieving that it can be more exploited. Unfortunately, this collaboration is not easy considering the different types of devices that exist in the market and the absence of communication standards. To mitigate this problem, solutions based on semantic web have shown promise, facilitating interoperability among different devices through the representation and the relationship of their information. In this paper, we propose a system that improves the interoperability among smart devices in the application domains of healthcare and smarthome by using semantic web and ontologies. This solution allows a proactive collaboration among smart devices that elderly people have around them regardless of the technology used, in order to increase their quality of life through more effective and efficient monitoring, and promoting actions associated with their needs.

Keywords: Internet of Things · Elderly · Healthcare · Smarthome · Semantic web · Ontology

1 Introduction

The importance of the Internet of Things (IoT) is growing as more and more Internet-connected devices are developed. According to recent estimates [1], we will have around 30 billion smart devices connected to the Internet in the next few years. 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 is being applied in many areas: smarthome, automotive, smart cities, healthcare, etc. [2]. Specifically, in the healthcare application domain, the IoT paradigm allows us for more personalised, preventive and collaborative care, in which patients monitor and manage their own health, and responsibility for healthcare is shared

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between patients and medical staff [3]. These solutions are particularly interesting in homes where elderly can take advantage of these devices for activity monitoring, alarm detection, home security, integrated care, exercise promotion or prevention of social isolation.

The performance of certain tasks requires smart devices to collaborate with each other. These tasks can be detecting the level of air quality taking into account the times a person uses an inhaler or recommending certain foods depending on the glucose level, where devices from different domains are involved. This collaboration is easy when the devices belong to the same application domain and manufacturer, but unfortunately, it becomes more difficult when these are different. In addition, to achieve proactive collaboration between devices, it is necessary that the devices are correctly configured, which requires a minimum of knowledge and time. This is why it is necessary to increase the level of interoperability between smart devices to promote more proactive collaboration with minimal user interaction. Nowadays, there are works that allow a higher level of interoperability to be achieved, but in most cases, they require the intervention of the users, which implies having basic technical knowledge.

This work proposes a solution based on semantic web techniques and ontologies to achieve the collaboration of smart devices in the domains of smarthome and healthcare. Semantic web-based techniques have shown great promise in solving these issues. The main objective of the semantic web is to improve the Internet by extending interoperability between computer systems that use intelligent agents and applications that seek information without human intervention [4]. The semantic web is a widely used resource to achieve semantic interoperability between services and devices. Therefore, the proposed solution includes a system based on the semantic web and ontologies that allows devices belonging to the domains of smarthome and healthcare to interact with each other to facilitate elderly tasks as well as monitoring health conditions or keep caregivers reported. This proposal aims to make elderly people gain in healthcare security through the proactive collaboration of IoT devices.

The rest of this paper is structured as follows. After this introduction, Sect. 2 describes the motivations. Then, Sect. 3 details our proposal to deal with the interoperability among IoT devices. Next, in Sect. 4, some related works are detailed. Finally, in Sect. 5, some final conclusions are drawn.

2 Motivations

Currently, the IoT provides us with many different types of devices that are distributed in application domains. However, the interaction among devices belonging to different domains is not always possible [5]. This makes devices interoperability difficult, which means that everyday tasks can not be solved in the most optimal way. This, in the area of healthcare becomes more critical if we consider that smart devices can monitor a person's state of health, the heart rate, the blood sugar level or keep health staff reported. In addition, if devices in the healthcare area could communicate with those in other domains, such as those in the smart home, more complex tasks could be performed that would provide elderly with more everyday facilities and increase their quality of life.

To show the consequences of the lack of collaboration among IoT devices we propose a scenario where an elderly person has several smart devices that facilitate some tasks, but where collaboration among devices would be required.

George is a 76-years-old man living in Guadalupe, Cáceres. As George is an elderly person, his family has installed in his home some smart devices to monitor his health. Among these devices are a blood pressure monitor, a glucose meter that allows him to have his diabetes under control, and his pantry is controlled through a camera capable of identifying the food he consumes. As a complement to these devices, George wears an activity smartband that controls his daily activity and monitors his heart rate. He also has other smart devices at home that make his day-to-day life easier, such as a smart fridge that controls the food and beverage he has, a multimedia player where he can search and listen to his favourite music, and a virtual assistant that allows him to set up reminders and send alerts.

These devices make it easy for George to do many of the things he does every day. However, the lack of collaboration among smart devices does not allow that certain actions could be performed, which would be beneficial to George's life. For example, if the glucose meter detects unstable levels of his blood glucose levels, it could notify the refrigerator to recommend a certain type of food or drink water in order to regulate his glucose level, or he could be recommended the right foods from his pantry to maintain a balanced diet and alert if a certain food is running out. In addition, George's family should be informed in these situations. If the virtual assistant were able to recognize these situations, it could report George's health status to his family. The same goes for the media player, which could recommend a more relaxing type of music if his smart band detects a higher-than-normal heart rate.

This scenario (Fig. 1) shows the interoperability problems that can arise when devices from different domains or manufacturers cannot communicate or collaborate with each other in elderly daily lives. Currently, there are works focused on solving problems similar to those detected, and although in some cases can increase the level of interoperability between IoT devices for concrete domains, the user intervention is still required. From our point of view, this interaction should be as minimal as possible when it comes to health care for the elderly. So that, the following section shows the proposed solution that, by using semantic web techniques, achieves that devices from the domains of smarthome and healthcare can collaborate regardless of the manufacturer with minimum human intervention.

3 Proposal

This proposal considers to achieve interoperability between devices and to adapt their services to the needs of elderly. This is achieved through semantic web techniques and ontologies. In this section, the required information that allows elderly to link to the smart devices is specified. Then, a study about the current ontologies is conducted for the smarthome and healthcare domains, with the aim of finding similarities that allow devices belonging to these domains to be related. Following this study, an ontology of its own is proposed which, based on the study carried out, is capable of relating devices from different domains.

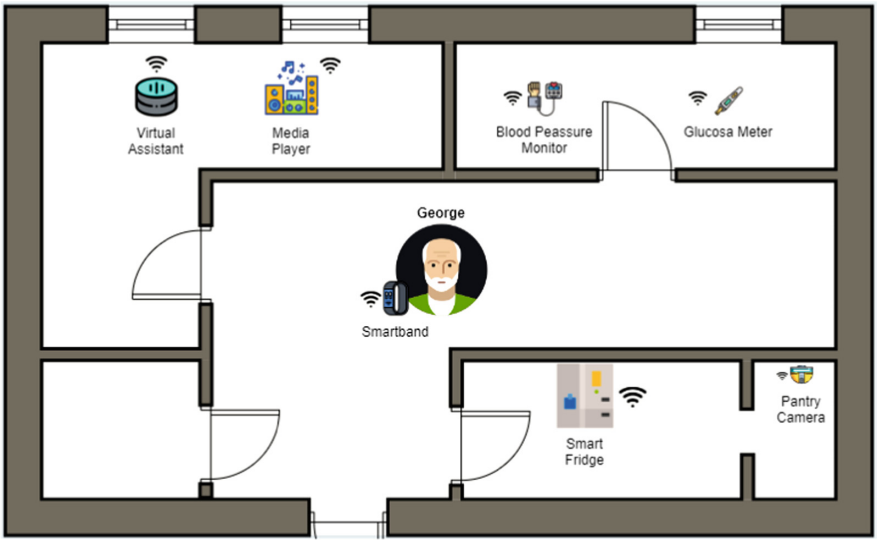

Fig. 1. George's home with different smart devices

3.1 Required Information

To achieve that elder's tasks are easier by the collaboration among smart devices, we must link elder's needs to the services that the devices offer. We define as *needs* the preferences that people have and that need to be covered in order to carry out a certain task, such as, for example, selecting a certain type of food. These needs can be manually specified by the person, or be detected by another device. For example, selecting a specific type of food when a blood sugar level that needs to be stabilized is detected. These needs will be covered by the *services* that the smart devices possess within the scenario. For example, the fridge may recommend specific food available to the person.

Therefore, the minimum information we need to know to perform this process are, on the one hand, the needs of elderly, and, on the other hand, the services of smart devices that are available. Also, additional information is needed to help perform the linking process correctly as specific data of the devices (id, location, service parameters, etc.). This information is represented by ontologies. Below is a study on some of the ontologies considered that could represent the information required in our process.

3.2 Ontology Study

An ontology is described as a formal and explicit specification of a shared conceptualization [6] and it is used to represent knowledge within a domain as a set of interrelated concepts [7]. Considering that one of the best practices of the semantic web is to reuse ontologies [8], a study about existing ontologies within the IoT has been performed in order to evaluate whether they can be used to represent the required information to relate IoT devices belonging to smarthome and healthcare domains with elderly. To perform this study we revised one of the largest repositories of ontologies: **Linked Open**

Vocabularies for Internet of Things (LOV4IoT) [9]. This repository contains a wide variety of ontologies in many application domains such as industry, agriculture, robotics, food, climate, energy efficiency, among others, as well as smarthome and healthcare. The considered ontologies belonging to the smarthome and healthcare are appreciated in Table 1. This study considers all the main classes and types of data they possess, with the aim of determining whether, through their use, the information necessary to match devices and people can be represented.

Table 1. Considered ontologies

Ontology	Domain	Description
HealthIoT [10]	Healthcare and wearables	Semantic representation of both medical connected objects and their data
HOTMES [11]	Healthcare and smarthome	To provide personalized care to remote patients with a wide range of chronic conditions
AALUMO [12]	Healthcare and smarthome	This ontology includes specific classes that characterizes users of Ambient Assisting Living (AAL) services, to cover as wide as possible elderly conditions and environments
FIESTA-IoT [13]	Generic IoT	A combination of existing IoT ontologies into a single one with minor updates to overcome the most common issues associated to the mainstream ontologies
SAREF4EE [14]	Smarthome	The Smart Appliances REFerence (SAREF) ontology is a shared model of consensus that facilitates the matching of existing assets (standards/protocols/datamodels/etc.) in the smart appliances domain

Related to the features of these ontologies, the performed study can be summarized as follows:

HealthIoT: it contains several classes and relationships, some of them extended from other ontologies such as SSN (Semantic Sensor Network) or SAN (Semantic Actuator Network), and others dedicated to the measurement of time or specific intervals for patients. This ontology stands out above all for the declaration of the necessary classes as *ssn:Device*, which allows specifying actuators, *san:Actuator*, and even to group them in categories (*HIoT:Categories*).

Although with this ontology we could represent some information required, such as devices (*ssn:Device*) or services (*HIoT:Capability*) there is other information that would not be possible to represent, especially at the level of data types, such as MAC addresses, endpoints or specific values for services.

HOTMES: with this ontology, we can represent numerous information related to patients (*PatientProfile*), which allows us to store a large amount of data about them. In addition, it allows to assign tasks (*PlanningTask)* or to monitor them (*MonitoringTask)*

by means of rules to determine the state of the patient. For clinical monitoring, this ontology is combined with another ontology (HOTMES Clinical) that allows obtaining information from the environment (*EnvironentalInformation*) or representing other control information such as the amount of food the patient eats or if the patient consumes cigarettes. Unfortunately, we cannot apply it to our use case due to the lack of classes to represent information such as services and needs, as well as the relationship between them.

AALUMO: based on the ontology GUMO (General User Model Ontology), this ontology is quite interesting for our work because it allows us to divide people into three dimensions (EmotionalStates, Characteristics and Personality) depending on the information that needs to be used. Within these dimensions, we find specific classes to represent services (*Ability*) and basic human needs (*Personality*), which are very close to what our work needs to represent. Although the information that allows us to represent people's data is quite complete, the part that prevents us from representing our required information is that related to the devices and their associated data.

FIESTA-IoT: this ontology is one of the most complete to improve the interoperability of IoT devices. That is why it takes advantage of important concepts of SSN, IoT-Lite, M3-lite taxonomy, among others, to cover most of the possible needs. Thanks to its great composition, FIESTA-IoT can represent virtual entities (*iot-lite:VirtualEntity*), resources and IoT services (*Service*), which largely solves our needs. However, although the information referring to devices can be represented, the part corresponding to people, as well as their needs would remain unfulfilled, which prevents us from using this ontology.

SAREF4EE: it is based on SAREF, extending 115 classes, 31 object properties and 51 data types. This ontology is quite complete when it comes to representing smart devices and their metadata (*s4ee:Device*). Although this ontology focuses on the representation of multiple types of smart devices with multitude of data types, the part of the representation of people and their relationship with needs is not possible to perform in the way our work requires. Even so, this ontology is interesting to establish basic configurations of devices or to determine when a certain action is carried out, processes that are very close to our needs.

The development of ontologies is usually done to solve a specific problem. It is for this reason that although the ontologies considered have classes and types of data that could solve our problem, they do not achieve it completely, and do not allow us to represent the required information in the way we intend to do it. For this reason, we propose our own ontology to solve the detected problem.

3.3 Ontology Specification

The proposed ontology is defined as *Ont4E* (Ontology for Elderly) (Fig. 2). The aim of this ontology is to represent the information of smart devices belonging to different application domains and manufacturers as well the information about elderly to achieve a semantic relationship.

Given the fact that both people and devices have services and needs, we use a single class *(Entity)* to represent both concepts, that we treat them equally. In addition, this class allows us to represent the entity's personal information so that it can be correctly

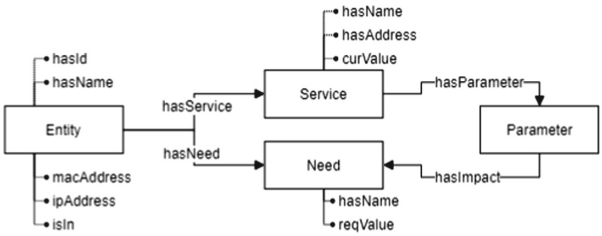

Fig. 2. Proposed ontology to help elderly by using IoT smart devices -*Ont4E*-

identified, and for the moment is not necessary to make a separation. Besides, this ontology is able to represent the services *(Service)* the entities have, as well as the needs *(Need)* that will be solved by the available services. We must bear in mind that the impact of services on needs will not always be the same and will depend on different parameters. For this reason, a class *(Parameter)* has been introduced that receives the necessary parameters to make the invocation and to adapt the service according to the characteristics of the need that it is going to solve. The following section shows the processing that is done through this ontology to communicate devices with each other.

3.4 Ontology Processing

The processing of the ontology goes through several phases (Fig. 3).

1. The smart devices and their services and needs, as well as people with their needs, must be included within the ontology. This is a required step and is currently being developed, but because this phase is outside the scope of the proposed topics and to simplify the process, we assume that this information has already been included in the ontology and is available to be processed.
2. The list of people and devices (entities) is made through the SPARQL query language. SPARQL allows us to search within the ontology and to relate information [15]. In this way, we can identify how devices can collaborate depending on elderly needs.
3. When a search is made to solve a specific need and a device is discovered, its services are invoked. In this way, a device is able to cover an elder's need and allow collaboration with other devices.

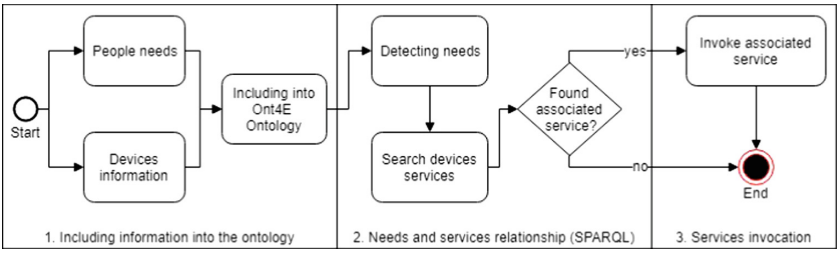

Fig. 3. Ontology processing flow

This process is conducted by a device capable of manipulating the ontology. This device can be from a Raspberry Pi to a dedicated equipment for that purpose. Besides, this process is performed automatically when a person or device is detected on the stage, minimizing the interaction of people with the devices.

3.5 Use-Case Demonstration

Moving on to the previous scenario where George has several devices from the application domains of smarthome and healthcare, the use of the proposed ontology and query languages allows these devices to be able to collaborate. Table 2 shows the devices as well as their services.

Table 2. Use-case smart devices

Device	Application domain	Services
Blood pressure monitor	Healthcare	srv checkBloodPressure
Glucose meter	Healthcare	srv checkGlucoseLevel
Smartband	Healthcare	srv checkHeartRate
Camera pantry	Smarthome	srv checkFoodsAndBeverage
Smart Fridge	Smarthome	srv checkFoodsAndBeverage srv recGlucoseFood srv recBeverage
Media player	Smarthome	srv setMusic srv findArtist
Virtual assistant	Smarthome	srv reminder srv alert srv familyNotification

As stated above, the ontology contains all information about devices and people. Thus, when George's glucose meter detects inadequate levels, it can report this information to the smart fridge or the pantry to suggest George certain types of food to correct these levels. This is done by developing SPARQL queries on the ontology. These queries are performed dynamically according to the needs and services detected in the scenario. An example of a SPARQL query to recommend food when an unstable glucose level is detected can be appreciated in Table 3. In this way, the detected need due to the glucose level (*ne glucose*) is communicated to the devices that are able to cut down it (*srv recommendFood)*, in this case, the smart fridge. In the same way, his blood pressure monitor could perform a similar operation, or the virtual assistant could alert his family to a potentially dangerous situation for George. For example, if the smartband detects a high health rate for a long period of time, a family member can be notified by the virtual assistant to check whether George has a problem. All this is achieved by invoking the services of smart devices to adapt them to George's needs and in a transparent way for him.

Table 3. SPARQL query for "glucose" solution

Query: services with "glucose" relation

```
SELECT * WHERE
{
?Need a :Need .
?Need :isImpactOf ?service .
?Need rdfs:comment ?comment .
FILTER (CONTAINS(lcase(str(?Need)),
      lcase("glucose"))) .
?Entity a :Entity .
?Entity :hasService ?service .
}
```

Result

Need	ne_glucose
Service	srv_recFood
comment	Recommend food and beverage
Entity	Smart Fridge

The treatment of the information coming from smart devices through the proposed ontology is capable of solving George's needs, improving his quality of life and keeping his relatives informed of his health status. Therefore, through the information stored in the ontology, when one of the devices detects a specific event or a need of George, it is sent to the Raspberry to perform the search associated with the need and discover which devices can solve it.

4 Related Work

In a society where there is an increasingly ageing population, the collaboration of smart devices from the IoT is a problem that concerns to the scientific community. In this section we highlight some works such as [16], where Azimi et al. study the systems enabled for IoT that address the monitoring of elderly to classify existing approaches from a new perspective and to introduce a hierarchical model for monitoring focused on elderly; or [17], where a research is conducted to develop a theoretical system empirically to determine the central factors that can affect the acceptance of smarthome services by elderly users for medical care.

In addition, the use of semantic web techniques and ontologies is becoming increasing to achieve collaboration among smart devices. Jabbar et al. [18] propose a semantic interoperability model based on IoT (IoT-SIM) to provide semantic interoperability among heterogeneous devices from IoT in the healthcare domain application. In this way, healthcare workers communicate with their patients through heterogeneous devices to control their current health status. In addition, Gomez et al. [19] develop an ontology-based architecture capable of monitoring routine health recommendations and training for patients with chronic diseases, with the aim of providing information on the health status of patients and providing real-time information. Moreover, the smarthome application domain is also quite important within the semantic web, and is quite related to the healthcare domain. Some works in this line demonstrate the importance of this domain, such as [20], where the authors propose an IoT architecture that allows them for personalized medical care, as well as continuous monitoring of physical parameters and

processing of medical data, form the basis of a more intelligent, connected and personalized medical care. In addition, [21] addresses the use of IoT in the healthcare system, the challenges of IoT in the healthcare system and reviews the most interesting solutions in this field.

Additionally, we can also find specific frameworks that try to solve these collaboration issues. Among them are [22], where Maarala et al. process the information coming from the IoT devices through the last generation semantic technologies. To this end, they have developed a semantic reasoning system that works in a realistic IoT environment. In addition, Gyrard et al. address in [23] the issue of the semantic relationship of devices. Besides, in [24] Kiljander et al. develop a framework based on two main aspects: the information and capabilities of the devices are represented with the semantic web; and that the global IoT is divided into numerous intelligent spaces managed by a semantic intermediary.

Thanks to these works we can appreciate that the collaboration between IoT devices is a problem that worries the scientific community. Although these works solve some of the detected aspects, unfortunately, they do not solve all of them. The interoperability between smart devices is increased and it is achieved that these devices are increasingly able to communicate in a more optimal way. However, the interaction with them is still too manual, having to make manual settings to achieve the desired behavior. Therefore, this interoperability depends in many cases still on people making a correct configuration, and as long as it is possible to do it, because it is not always possible.

5 Conclusions

Due to the accelerated ageing of the population, healthcare-focused on monitoring has become of great interest. Thanks to the smart devices of the Internet of Things, these aspects can be solved to a large extent. However, the collaboration among these devices is still difficult in many situations, preventing elderly from getting the maximum benefits from them.

This paper addresses the problem of collaboration among IoT devices from the perspective of elderly care, combining the application domains of smarthome and healthcare. Besides, this collaboration must be achieved in a most transparent way for the user, thus simplify their day-to-day life. The use of the semantic web and ontologies allows us a more efficient treatment of the information coming from the IoT devices to establish semantic relationship between them, and allowing collaboration to solve elderly daily tasks.

This work is a further step towards achieving the IoT devices collaboration but there is still work to be done. In future work we will focus on decision making when using the services of IoT devices, as well as the extension of the ontology to allow the representation of devices from other domains and even more defined information of IoT devices and the people who use them.

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